E-Content

Construction Management and Accounts

Diploma Level Study Notes

Covers: Construction Management, Engineering Economics, Fundamentals of Accounting, Costing & Estimating, Contracts and Tendering

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PART A — CONSTRUCTION MANAGEMENT

1. Introduction to Management & Construction Management

Management is the process of planning, organizing, staffing, directing and controlling resources (men, materials, machines, money, methods) to achieve a defined objective efficiently. **Construction Management (CM)** applies these principles specifically to construction projects — planning, coordinating and controlling a project from inception to completion, aiming to meet the client's requirements of quality, time and cost.

Functions / Elements of Management

- **Planning** — deciding in advance what to do, how, and when to do it.
- **Organizing** — arranging resources and establishing relationships/authority.
- **Staffing** — recruiting and placing the right personnel.
- **Directing** — guiding and supervising the workforce.
- **Coordinating** — harmonizing activities of different departments/agencies.
- **Controlling** — monitoring progress and taking corrective action against deviations.

Objectives of Construction Management

- Complete the project within the stipulated time.
- Complete within the estimated budget/cost.
- Achieve the specified quality and safety standards.
- Optimum utilization of resources (men, machines, materials, money).
- Minimize wastage and avoid disputes.

2. Organization Structures in Construction

An organization is the framework of authority-responsibility relationships that helps a group of people work towards a common goal. Common types used in construction firms:

Typical site hierarchy: Project Manager → Site Engineer/Site Supervisor → Foreman/Mistri → Skilled & Unskilled Labour.

3. Project Planning & Scheduling

Planning determines the sequence of construction operations, while **scheduling** fixes the time frame (start/finish dates) for each activity. Together they form the backbone of project control.

(a) Bar Chart (Gantt Chart)

A Gantt/Bar chart represents each activity as a horizontal bar whose length is proportional to its duration, plotted against a time scale.

Advantages: simple, easy to prepare and understand, good for small projects.
Disadvantages: does not show interdependency between activities; difficult to update for large/complex projects.

(b) Critical Path Method (CPM)

CPM is a network-based, deterministic technique used where activity durations are known fairly accurately (used widely in construction/repetitive work). Activities are shown as arrows/nodes connected in a logical sequence.

Key terms:

- **Event** — a point in time marking start/end of activities (represented by a node/circle).
- **Activity** — a task that consumes time and resources (represented by an arrow).
- **EST** (Earliest Start Time), **EFT** (Earliest Finish Time)
- **LST** (Latest Start Time), **LFT** (Latest Finish Time)
- **Total Float** = LST – EST (or LFT – EFT) — the slack time available for an activity without delaying the project.
- **Critical Path** — the longest path through the network; activities on it have **zero float** and any delay in them delays the whole project.

(c) Programme Evaluation and Review Technique (PERT)

PERT is a probabilistic technique used where activity durations are uncertain (research/new type of projects). Three time estimates are used for each activity:

Symbol	Meaning
to (Optimistic time)	Minimum possible time if everything goes well
tm (Most likely time)	Normal time under usual conditions
tp (Pessimistic time)	Maximum time if unusual problems occur

Expected time, te = (to + 4·tm + tp) / 6

Standard deviation, σ = (tp – to) / 6 and **Variance = σ^2**

CPM vs PERT

Basis	CPM	PERT
Nature	Deterministic (single time estimate)	Probabilistic (three time estimates)
Used for	Repetitive projects (buildings, roads)	Research & non-repetitive/new projects
Orientation	Cost-oriented	Time/event-oriented
Focus	Activity oriented	Event oriented

Steps in Network Analysis

- List all activities and their logical sequence/dependency.
- Draw the network diagram (activity-on-arrow or activity-on-node).
- Estimate durations for each activity.
- Calculate EST, EFT, LST, LFT for every activity/event.
- Identify total float for each activity.
- Identify the critical path (activities with zero float).

4. Construction Materials & Equipment Management

Materials Management

Materials management ensures the right material, in the right quantity, at the right place and time, at the lowest possible cost. It typically involves:

- **Identification** of material requirement from drawings/BOQ.
- **Procurement** — purchasing/ordering from approved vendors.
- **Storage** — proper stacking, protection from weather/theft/damage.
- **Inventory control** — avoiding overstocking (blocks capital) or understocking (delays work); concepts like **Economic Order Quantity (EOQ)**, ABC analysis, and minimum/maximum/re-order stock levels are used.
- **Issue and accounting** — recording consumption against work done.

Construction Equipment Management

Selection of equipment depends on the type of work, quantity, site conditions, and economics of owning vs. hiring. Common construction equipment includes earth-moving equipment (dozers, excavators, loaders), concreting equipment (mixers, batching plants, vibrators), and hoisting equipment (cranes, hoists).

- **Owning** is economical when utilization is high and the equipment is needed long-term.
- **Hiring** is economical for short-duration or occasional requirement, avoiding maintenance/idle-time cost.
- Equipment cost is generally analyzed under **owning cost** (depreciation, interest, insurance, taxes) and **operating cost** (fuel, repairs, operator wages).

5. Site Organization, Safety & Quality Control

Site Organization

Refers to proper layout of the construction site — location of site office, stores, labour huts, access roads, material stacking yards — to ensure smooth material movement and minimum handling cost.

Safety Management

- Use of Personal Protective Equipment (PPE) — helmets, safety shoes, gloves, harnesses.
- Barricading of excavations, proper scaffolding, and signage for hazard zones.
- Regular safety training/toolbox talks and accident reporting/investigation.
- Compliance with statutory safety codes/regulations applicable to the site.

Quality Control

- Checking materials against specifications (cement, steel, aggregates) before use.
- Testing of concrete (slump test, cube compressive strength test) at regular intervals.
- Maintaining quality checklists and inspection at each stage of construction.
- Non-conforming work to be identified and rectified before proceeding further.

6. Labour Management & Productivity

Labour is classified as **skilled** (masons, carpenters, bar-benders), **semi-skilled**, and **unskilled** (helpers). Effective labour management involves proper recruitment, deployment, supervision, incentive schemes and welfare measures.

Labour productivity = Output produced ÷ Labour-hours (or man-days) input. It is affected by factors such as skill level, working conditions, supervision, weather, and availability of materials/tools at the right time.

7. Contracts, Tendering & Specifications

A **contract** is a legally binding agreement between the owner and the contractor defining the scope, cost, time and conditions of work.

Types of Contracts

Type	Description
Item Rate / Unit Price Contract	Payment made per unit quantity of each item of work at agreed rates; most common in I
Lump Sum Contract	A fixed total price for the entire work, regardless of actual quantities.
Cost Plus Percentage Contract	Contractor is paid actual cost of work plus an agreed percentage as profit.
Cost Plus Fixed Fee Contract	Actual cost is reimbursed plus a fixed (not percentage) fee.
Percentage Rate Contract	Contractor quotes a percentage above/below the estimated cost of items.

Tendering Process

Tendering is the process of inviting, receiving and evaluating offers (bids) for carrying out the work, and awarding the contract to the most suitable bidder.

- **Open Tender** — advertised publicly; anyone meeting eligibility can bid; ensures competition & transparency.
- **Limited/Closed Tender** — invited only from a select list of pre-qualified/approved contractors.
- **Single Tender** — invited from only one party, used in emergencies or specialized/proprietary work.
- **e-Tendering** — online submission and processing of tenders through a portal.

Tender documents generally include: notice inviting tender (NIT), drawings, specifications, bill of quantities (BOQ), conditions of contract, and the earnest money deposit (EMD)/security deposit requirements.

Specifications

Specifications describe the nature, quality, grade and proportion of materials, and the method of workmanship required for an item of work. They may be **general specifications** (brief description of materials/workmanship) or **detailed specifications** (item-wise, exact requirements for estimating and execution).

PART B — ACCOUNTS

8. Fundamentals of Accounting

Accounting is the process of recording, classifying, summarizing and interpreting financial transactions of a business in terms of money, so as to ascertain profit/loss and financial position.

Basic Terms

Term	Meaning
Asset	Anything of value owned by the business (land, building, machinery, cash, etc.)
Liability	Amount owed by the business to outsiders (loans, creditors).
Capital	Owner's investment in the business.
Revenue/Income	Amount earned by sale of goods/services.
Expense	Cost incurred to earn revenue.
Debtor	Person who owes money to the business.
Creditor	Person to whom the business owes money.
Drawings	Cash/goods withdrawn by owner for personal use.

Types of Accounts & Golden Rules

Type of Account	Golden Rule
Personal Account (persons, firms, companies)	Debit the receiver, Credit the giver
Real Account (assets/properties)	Debit what comes in, Credit what goes out
Nominal Account (expenses, losses, incomes, gains)	Debit all expenses & losses, Credit all incomes & gains

9. Journal, Ledger, Trial Balance & Final Accounts

Journal

The journal is the **book of original/prime entry** where transactions are first recorded, in chronological order, in the form of a debit and a credit entry (double entry system) along with a narration.

Ledger

The ledger is the **book of final entry** — a set of accounts to which journal entries are posted, so that the net effect of all transactions on each account can be seen (its balance).

Trial Balance

A trial balance is a statement listing the debit and credit balances of all ledger accounts on a particular date. If total debits = total credits, it indicates arithmetical accuracy of the books (though it does not guarantee absence of all errors).

Final Accounts

- **Trading Account** — to find Gross Profit/Loss (Sales – Cost of Goods Sold).
- **Profit & Loss Account** — to find Net Profit/Loss (Gross Profit – Indirect Expenses + Indirect Incomes).

- **Balance Sheet** — a statement of assets and liabilities on a given date, showing the financial position of the business.

10. Depreciation

Depreciation is the gradual, permanent decrease in the value of a fixed asset due to wear and tear, effluxion of time, or obsolescence. It is charged to the Profit & Loss Account as an expense.

Methods of Depreciation

Method	Formula / Basis
Straight Line Method (SLM)	Depreciation per year = (Cost – Scrap Value) / Useful Life (constant amount every year)
Written Down Value / Diminishing Balance Method	Depreciation = fixed % applied on the book value (reducing balance) each year
Sinking Fund Method	A fixed annual amount is set aside and invested so that, with interest, it accumulates to

11. Costing & Estimating in Construction

Estimating is the process of calculating the probable cost of a construction project before it is executed, based on drawings and specifications. **Costing** deals with ascertaining the actual cost incurred and analyzing it.

Types of Estimates

- **Preliminary/Approximate Estimate** — rough cost based on plinth area, cubic content, or unit rate, used for initial administrative approval.
- **Detailed Estimate** — item-wise quantities (from measurements) multiplied by their rates, prepared from BOQ and detailed drawings; most accurate.
- **Revised Estimate** — prepared when the original sanctioned estimate exceeds by a certain percentage (commonly 5% or as per rules) due to changes in design/rates.
- **Supplementary Estimate** — prepared for additional work not included in the original estimate.

Elements of Cost

Cost Element	Includes
Prime Cost / Direct Cost	Direct material + Direct labour + Direct expenses
Overheads / Indirect Cost	Factory/site overheads, administrative overheads, selling & distribution overheads
Total Cost	Prime Cost + Overheads

Rate Analysis is the process of determining the rate per unit of a particular item of work by considering the cost of materials, labour, equipment, overheads and contractor's profit (usually taken as 10–15%).

12. Budgeting & Cash Flow in Construction Projects

A **budget** is a financial plan for a defined period, estimating expected income and expenditure. In construction, budgeting helps plan the funds required at various stages of the project.

- **Cash flow forecasting** tracks the timing of cash inflows (client payments/running bills) and outflows (material purchase, wages, equipment hire) so that funds are available when needed.
- A typical construction project cash-flow curve is **S-shaped** — slow expenditure at the start (mobilization), rapid expenditure during the main construction phase, and tapering off towards completion.
- **Variance analysis** compares budgeted cost/time against actual cost/time to identify deviations and take corrective action.

13. Important Formulas & Quick Revision Table

Topic	Formula
PERT Expected Time	$t_e = (t_o + 4t_m + t_p) / 6$
PERT Standard Deviation	$\sigma = (t_p - t_o) / 6$
Total Float	Total Float = LST – EST (= LFT – EFT)
Straight Line Depreciation	Dep./year = (Cost – Scrap Value) / Useful Life
WDV Depreciation	Dep. = Book Value × Rate %
Gross Profit	Sales – Cost of Goods Sold
Net Profit	Gross Profit + Indirect Income – Indirect Expenses
Total Cost	Prime Cost + Overheads
Labour Productivity	Output / Labour-hours (or man-days)

Transportation engineering

- **Transportation engineering** is the application of technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transportation in order to provide for the safe, efficient, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods from one place to other.

MODES OF TRANSPORTATION

- Basic mode of transportation are
  - ➢Land
    - Roadway
    - railway
  - ➢Water
  - ➢Air

MODES OF TRANSPORTATION

- **Highways**

  Car, Bus, Truck, non- motorized ..etc

- **Railways**

  Passenger and Goods

- **Airways**

  Aircraft and Helicopters

- **Waterways**

  Ships, boats…

- **Continuous Flow systems**

  Pipelines,belts,elevetor,ropeway…etc.

- Merits and Demerits: Based on accessibility, mobility, cost, tonnage..

Airways

- Fastest among all other modes
- More comfortable
- Time saving
- Uneconomical

Waterways

- slowest among all other modes
- It needs minimum energy to haul unit load through unit distance.
- This can be possible between ports on the sea routes or along the river
- economical

Railways

- The transportation along the railways track could be advantageous by railways between the stations both for the passengers and goods, particularly for long distance.
- It depends upon the road transport i.e. road could serve as a feeder system.
- Energy require to haul a unit load through unit distance by the railway is only ¼ to 1/5 of that required by road.
- Safety

Highways

- It gives the maximum service to one and all
- It gives maximum flexibility for travel with reference to route, direction, time and speed of travel
- It provide door to door service
- Other modes are depend on it
- It requires small investment for the government
- Motor vehicles are cheaper than other carriers like rail locomotive and wagons
- It saves the time for short distance
- High degree of accident due to flexibility of movement

Scope of highway engineering

- Development, planning and location
- Highway design, geometric and structure
- Traffic performance and its control
- Materials, construction and maintenance
- Economic, finance and administration

ROLE /IMPACT OF TRANSPORTATION

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

Characteristics of road transport

- Roads are used by various types of road vehicles, like passenger cars, buses, trucks, pedal cycle and animal drawn vehicle.
- It requires a relatively small investment for the government.
- It offers a complete freedom to road users to transfer the vehicle from one lane to another and from one road to another according to need and convenience.
- Speed and movement is directly related with the severity of accident.
- Road transport is the only means of transport that offers itself to the whole community alike.

HISTORICAL DEVELOPMENT OF ROAD CONSTRUCTION

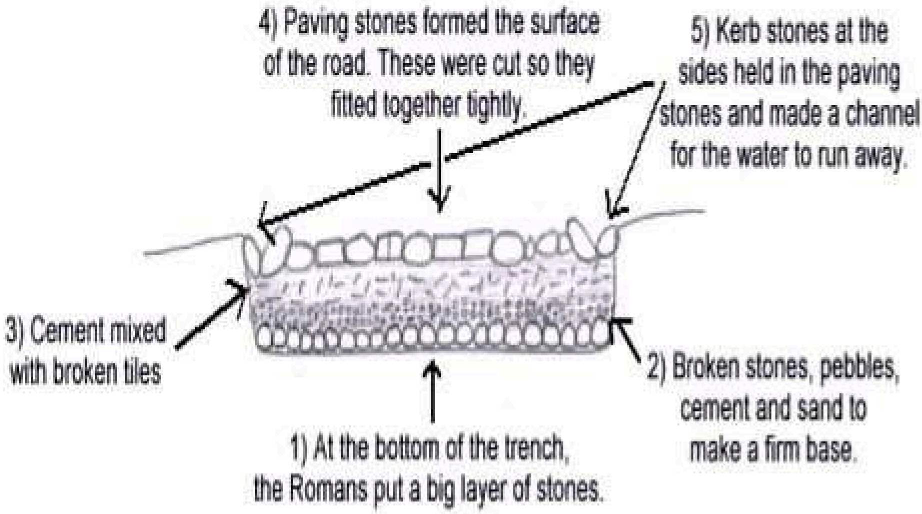
- Oldest mode
  - Foot paths- animal ways, cart path……..
- As civilization evolved the need for transportation increased

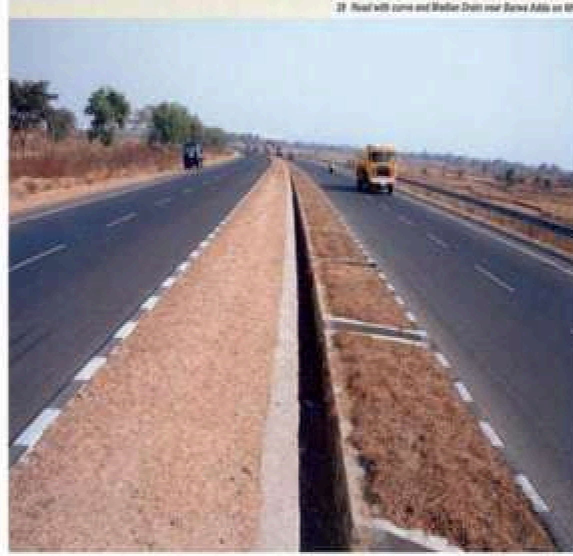
ROMAN ROAD-(500 B.C.)

- They were built straight regardless of gradient
- They were built after the soft soil was removed and a hard stratum was reached.
- Thickness varies from 0.75 m to 1.2m

Roman Road Construction

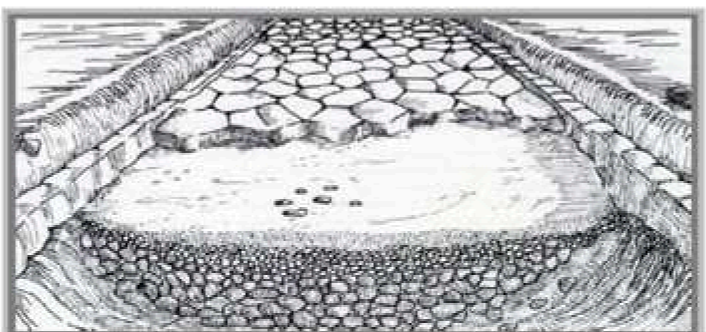
Basic cross section





Modern Highway

Roman Roads



Ref: Roman Roads of Europe, NHH Sitwell, Cassell-London, 1981

Other oldest road transport are

- Tresaguet construction
- Metcalf construction
- Telford construction
- Mecadam construction

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).

Highway Development in India

- Jayakar Committee (1927)
- Central Road Fund (1929)
- Indian Roads Congress (IRC), 1934
- Central Road Research Institute (CRRI), 1950
- Motor vehicle act (1936)
- National Highway Authority of India (NHAI),1995
- First twenty year road plan (1943-61)
- Second twenty year road plan (1961-81)
- Highway Research board (1973)
- National Transport Policy committee (1978)
- Third twenty year road plan (1981-2001)

Jayakar Committee,1927

- After the first World War, motor vehicle using the roads increases, this demanded a better road network.
- In 1927,Indian road development committee was appointed by the government with M.R. Jaykar as chairman.
- Road development in the country should be made as a national interest since local govt. do not have financial and technical capacity for road development.
- An extra tax should be levied 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

- It was formed on 1st march 1929
- The consumers of petrol were charged an extra leavy of 2.64 paisa per litre of petrol to built up this road development fund.
- From this 20% of annual reveneu is to be retain as a central reveneu for research and experimental work expenses..etc
- Balance 80% is allowed by central govt. to various states based on actual petrol consumption or revenue collected.

Central Road Fund , 1929

CRF Act , 2000

Distribution of 100% cess on petrol as follows:

- 57.5% for NH
- 30% for SH

$\left.\begin{array}{l}\text{57.5\% for NH}\\ \text{30\% for SH}\end{array}\right\}$ **MORTH**

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

50% cess on diesel for Rural Road development

Indian Roads Congress, 1934

- Central semi official body known as IRC was formed in 1934.
- To provide national forum for regular pooling of experience and ideas on matters related to construction and maintenance of highways.
- It is a active body controlling the specification, standardization and recommendations on materials, design of roads and bridges.
- It publishes journals, research publications and standard specifications guide lines.
- To provide a platform for expression of professional opinion on matters relating to roads and road transport.

Motor vehicle act

- It was formed in 1939
- To regulate the road traffic in the form of traffic laws, ordinances and regulations.
- Three phases primarily covered are control of driver, vehicle ownership and vehicle operation
- It was revised on 1988

Central road research institute(1950)

- 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.

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.
- It stores the data related to technical knowledge on roads and bridges.

Highway Research Board

- To ascertain the nature and extent of research required
- To correlate research information from various organisation in India and abroad.
- To collect and correlation services.
- To collect result on research
- To channelise consultative services

Classification of Highways

Depending on weather

- All weather roads
- Fair weather roads

Depending the type of Carriage way

- Paved roads(WBM)
- Unpaved roads(earth road or gravel road)

Depending upon the pavement surface

- Surfaced roads(bituminous or cement concrete road)
- 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)

- National highway (NH)
- State highway (SH)
- Major district road (MDR)
- Other district road (ODR)
- Village road (VR)

Based on modified system of Highways classification

- **Primary**
  - Expressways
  - National Highways

- **Secondary**
  - SH
  - MDR

- **Tertiary**
  - ODR
  - VR

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.

The Mumbai-Pune Expressway as seen from Khandala

National Highways

- NH are the main highways running through the length and breadth of India, connecting major parts,foreign highways,capital of large states and large industrial and tourist centres including roads required for strategic movements for the defence of India.
- 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 highway connecting Delhi-Ambala-Amritsar is denoted as NH-1, whereas a bifurcation of this highway beyond Jalandar to Srinagar and Uri is denoted NH-1-A
- The longest highway in India is NH7 which stretches from Varansi in Uttar Pradesh to Kanyakumari in the southern most point of Indian mainland.

National Highways cont…

- The shortest highway is NH47A which stretches from Ernakulam to Kochi and covers total length of 4 Kms.
- **Golden Quadrilateral – (5,846 Kı**
  Kolkata-Chennai-Mumbai
  - NH-2 Delhi- Kol (1453 km)
  - NH 4,7&46 Che-Mum (1290km
  - NH5&6 Kol- Che (1684 m)
  - NH 8 Del- Mum (1419 km)

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.
- Speed 80 kmph

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.
- Speed 60-80kmph

Other district roads

- serving rural areas of production and providing them with outlet to market centers or other important roads like MDR or SH.
- Speed 50-60kmph

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.
- Speed-40-50kmph

Urban Road Classification

- Arterial Roads
- Sub Arterial
- Collector
- Local Street
- Cul-de-sac
- Pathway
- Driveway

ARTERIAL

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

SUB ARTERIAL ROAD

- Bus stops but no standing vehicle.
- Less mobility than arterial.
- Spacing for CBD : 0.5km
- 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
- 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

Driveway

- A driveway is a type of private road for local access to one or a small group of structures, and is owned and maintained by an individual or group.
- Driveways are commonly used as paths to private garages, fuel stations, or houses

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

First 20-years road plan(1943-63)

- The conference of chief engineer held at Nagpur in 1943 finalized the first 20-years road development plan for India called Nagpur road plan
- Road network was classified into five categories.
- The responsibility of construction maintenance of NH was assign to central govt.
- The target road length was 5,32,700 km at the end of 1961.
- Density of about 16km of road length per 100 sq. km area would be available in the country by the year 1963.

First 20-years road plan cont…

- The formulae were based on star and grid pattern of road network.
- An allowance of 15% is provided for agricultural industrial development during the next 20-years
- The length of railway track in the area was also consider in deciding the length of first category road. The length or railway track is directly subtracted from the estimated road length of metalled roads.

Second 20-years road plan(1961-81)

- It was initiated by the IRC and was finalised in 1959 at the meeting of chief engineers.
- It is known as the Bombay road plan.
- The target road length was almost double that of Nagpur road plan i.e. 10,57,330 km.
- Density about 32 km per 100 sq. km. and an outlay of 5200 crores
- Every town with population above 2000 in plans and above 1000 in semi hill area and above 500 in hilly area should be connected by metalled road

Second 20-years road plan cont…

- the maximum distance from any place in a semi develop area would be 12.8 km from metalled road and 4.8 from any road
- Expressways have also been considered in this plan and 1600km of length has been included in the proposed target NH
- Length of railway track is considered independent of road system
- 5% are to be provided for future development and unforeseen factor

Third twenty years road plan (1981-2001)

- The future road development should be based on the revised classification of roads system i.e. primary, secondary and tertiary
- Develop the rural economy and small towns with all all essential features.
- Population over 500 should be connected by all weather roads.
- Density increases to 82 km per 100 sq. km
- The NH network should be expanded to form a square grids of 100 km sides so that no part of the country is more than 50 km away from the NH

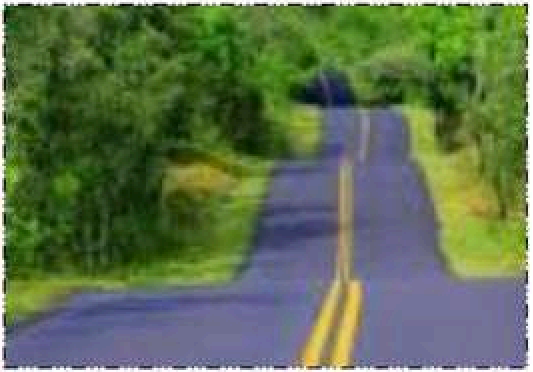
Third twenty years road plan cont…

- Expressway should be constructed along major traffic corridors
- All towns and villages with population over 1500 should be connected by MDR and villages with population 1000-1500 by ODR.
- Road should be built in less industrialized areas to attract the growth of industries
- The existing roads should be improved by rectifying the defects in the road geometry, widening, riding quality and strengthening the existing pavement to save vehicle operation cost and thus to conserve energy

Highway alignment and surveys

Highway alignment

- The position or lay out of centre line of the highway on the ground is called the alignment.
- It includes straight path, horizontal deviation and curves.
- Due to improper alignment , the disadvantages are,
  - Increase in construction
  - Increase in maintenance cost
  - Increase in vehicle operation cost
  - Increase in accident cost
- Once the road is aligned and constructed, it is not easy to change the alignment due to increase in cost of adjoining land and construction of costly structure.

Requrements of highway alignment

- Short
- Easy
- Safe
- Economical

- Short- desirable to have a short alignment between two terminal stations.
- Easy- easy to construct and maintain the road with minimum problem also easy for operation of vehicle.
- Safe- safe enough for construction and maintenance from the view point of stability of natural hill slope, embankment and cut slope also safe for traffic operation.
- Economical- total cost including initial cost, maintenance cost and vehicle operation cost should be minimum.

Factors controlling alignment

- Obligatory points
- Traffic
- Geometric design
- Economics
- Other considerations

Additional care in hill roads

- Stability
- Drainage
- Geometric standards of hill roads
- Resisting length

Factors controlling alignment cont...

Obligatory points

- Obligatory points through which alignment is to pass

  Examples:-bridge site, intermediate town , Mountain pass etc…

- Obligatory points through which alignment should not pass.

  Examples:-religious places, costly structure, unsuitable land etc…

Traffic

- origin and destination survey should be carried out in the area and the desire lines be drawn showing the trend of traffic flow.
- New road to be aligned should keep in view the desired lines, traffic flow patterns and future trends.

Geometric design

- Design factors such as gradient ,radius of curve and sight distance also govern the final alignment of the highway.
- Gradient should be flat and less than the ruling gradient or design gradient.
- Avoid sudden changes in sight distance, especially near crossings
- Avoid sharp horizontal curves
- Avoid road intersections near bend

Economy

- Alignment finalised based on total cost including initial cost, maintenance cost and vehicle operation cost.

Other consideration

- Drainage consideration, political consideration
- Surface water level, high flood level
- Environmental consideration

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

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

stability

- A common problem in hilly roads is land sliding
- The cutting and filling of the earth to construct the roads on hilly sides causes steepening of existing slope and affect its stability.

Drainage

- Avoid the cross drainage structure
- The number of cross drainage structure should be minimum.

Geometric standard of hilly road

- Gradient, curve and speed
- Sight distance, radius of curve

Resisting length

- The total work to be done to move the loads along the route taking horizontal length, the actual difference in level between two stations and the sum of the ineffective rise and fall in excess of floating gradient. Should kept as low as possible.

Engineering Surveys for Highway locations

Before a highway alignment is finalised in highway project, the engineering survey are to be carried out. The various stages of engineering surveys are

- **Map study** (Provisional alignment Identification)
- **Reconnaissance survey**
- **Preliminary survey**
- **Final location and detailed surveys**

MAP STUDY

- From the map alternative routes can be suggested in the office, if the topographic map of that area is available.
- The probable alignment can be located on the map from the fallowing details available on the map.
  - Avoiding valleys, ponds or lake
  - Avoiding bend of river
  - If road has to cross a row of hills, possibility of crossing through mountain pass.
- Map study gives a rough guidance of the routes to be further surveyed in the field

RECONNAISSANCE SURVEY

- To confirm features indicated on map.
- To examine the general character of the area in field for deciding the most feasible routes for detailed studies.
- A survey party may inspect along the proposed alternative routes of the map in the field with very simple instrument like abney level, tangent clinometer, barometer etc…. To collect additional details.
- Details to be collected from alternative routes during this survey are,
  - Valleys, ponds, lakes, marshy land, hill, permanent structure and other obstruction.
  - Value of gradient, length of gradient and radius of curve.

RECONNAISSANCE SURVEY cont..

- ➢ Number and type of cross drainage structures.
- ➢ High Flood Level (HFL)
- ➢ Soil Characteristics.
- ➢ Geological features.
- ➢ source of construction materials- stone quarries, water sources.

- Prepare a report on merits and demerits of different alternative routs.
- As a result a few alternate alignments may be chosen for further study based on practical considerations observed at the site.

Preliminary survey

Objective of preliminary survey are:

- To survey the various alternative alignments proposed after the reconnaissance and to collect all the necessary physical information and detail of topography, drainage and soil.
- To compare the different proposals in view of the requirements of the good alignment.
- To estimate quantity of earthwork materials and other construction aspect and to workout the cost of the alternate proposals.

Methods of preliminary survey:

a) **Conventional approach**-survey party carries out surveys using the required field equipment, taking measurement, collecting topographical and other data and carrying out soil survey.

Preliminary survey cont...

- Longitudinal and cross sectional profile.
  - Plain Terrain` : 100 – 200m
  - Rolling Terrain : 50m
  - Hilly Terrain : 30m
- Other studies
  - Drainage, Hydrological survey, soil survey, Traffic and Material survey.

b) Modern rapid approach-

By Aerial survey taking the required aerial photographs for obtaining the necessary topographic and other maps including details of soil and geology.

- Finalise the best alignment from all considerations by comparative analysis of alternative routes.

Final location and detailed survey

- The alignment finalised at the design office after the preliminary survey is to be first located on the field by establishing the centre line.

Location survey:

- Transferring the alignment on to ground.
- This is done by transit theodolite.
- Major and minor control points are established on the ground and centre pegs are driven, checking the geometric design requirements.
- Centre line stacks are driven at suitable intervals, say 50m interval in plane and rolling terrains and 20m in hilly terrain.

Final location and detailed survey cont..

Detailed survey:

- Temporary bench marks are fixed at intervals of about 250m and at all drainage and under pass structure.
- Earthwork calculations and drainage details are to be workout from the level books.
- Cross sectional levels are taken at intervals of 50-100m in Plane terrain, 50-75m in Rolling terrain, 50m in built-up area, 20m in Hill terrain.
- Detail soil survey is to be carried out.
- CBR value of the soils along the alignment may be determined for design of pavement.
- The data during detailed survey should be elaborate and complete for preparing detailed plans, design and estimates of project.

Drawing and Report

- Key map
- Index map
- Preliminary survey plans
- Detailed plan and longitudinal section
- Detailed cross section
- Land acquisition plans
- Drawings of cross drainage and other retaining structures
- Drawings of road intersections
- Land plans showing quarries etc

New highway project

- Map study
- Reconnaissance survey
- Preliminary survey
- Location of final alignment
- Detailed survey
- Material survey
- Geometric and structural design
- Earth work
- Pavement construction
- Construction controls

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Importance of geometric design

- The geometric design of a highway deals with the dimensions and layout of visible features of the highway such as alignment, sight distance and intersection.
- The main objective of highway design is to provide optimum efficiency in traffic operation with maximum safety at reasonable cost.
- Geometric design of highways deals with following elements :
  - ➢ Cross section elements
  - ➢ Sight distance considerations
  - ➢ Horizontal alignment details
  - ➢ Vertical alignment details
  - ➢ Intersection elements

Design Controls and criteria

- Design speed
- Topography
- Traffic factors
- Design hourly volume and capacity
- Environmental and other factors

Design speed

- In India different speed standards have been assigned for different class of road
- Design speed may be modified depending upon the terrain conditions.

topography

- Classified based on the general slope of the country.
  - Plane terrain- <10%
  - Rolling terrain- 10-25%
  - Mountainous terrain- 25-60%
  - Steep terrain- >60%

Traffic factor

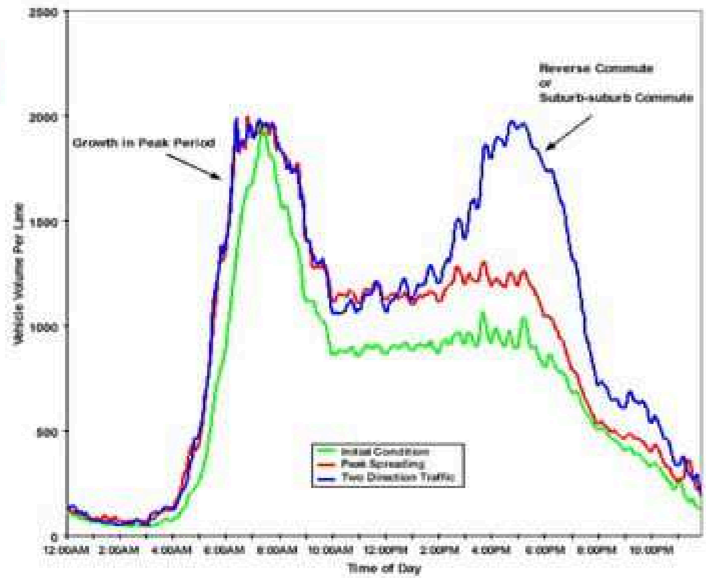
- Vehicular characteristics and human characteristics of road users.
- Different vehicle classes have different speed and acceleration characteristics, different dimensions and weight .
- Human factor includes the physical, mental and psychological characteristics of driver and pedestrian.

Design hourly volume and capacity

- Traffic flow fluctuating with time
- Low value during off-peak hours to the highest value during the peak hour.
- It is uneconomical to design the roadway for peak traffic flow.

Environmental factors

- ➢ Aesthetics
- ➢ Landscaping
- ➢ Air pollution
- ➢ Noise pollution



Pavement surface characteristics

Pavement surface depend on the type of pavement which is decided based on the,

- Availability of material
- Volume and composition of traffic
- Soil subgrade
- Climatic condition
- Construction facility
- Cost consideration

The important surface characteristics are:

- Friction
- Pavement unevenness
- Light reflecting characteristics
- Drainage of surface water

friction

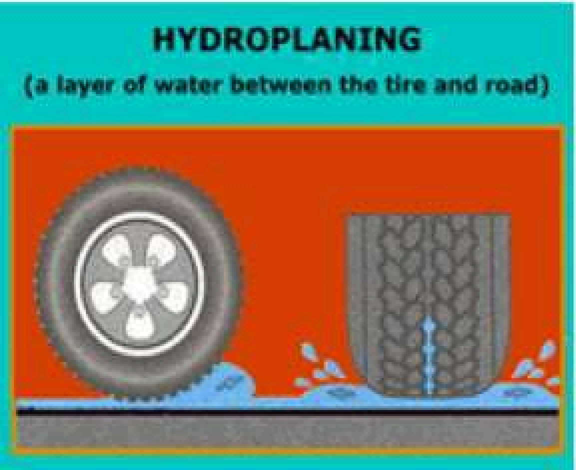
- Skidding: when the path travelled along the road surface is more than the circumferential movement of the wheels due to their rotation.
- Slipping: when a wheel revolves more than the corresponding longitudinal movement along the road.

Factors affecting the friction or skid resistance

- Types of pavement surface
- Roughness of pavement
- Condition of the pavement: wet or dry
- Type and condition of tyre
- Speed of the vehicle
- Brake efficiency
- Load and tyre pressure
- Temperature of tyre and pavement

- Smooth and worn out tyres offer higher friction factor on dry pavement but new tyre with good threds gives higher friction factor on wet pavement

- IRC recommended the longitudinal co-efficient of friction varies 0.35 to 0.4 and lateral co-efficient of friction of 0.15



Pavement unevenness

- Higher operating speed are possible on even surface than uneven surface.
- It affects,
  - Vehicle operation cost
  - Comfort and safety
  - Fuel consumption
  - Wear and tear of tyres and other moving parts
- It is commonly measure by an equipment call "Bump Integrator"
- Bump integrator is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length.
- 250 cm/km for a speed of 100kmph and more than 350 cm/km considered very unsatisfactory even at speed of 50 kmph.

❖ Unevenness of pavement surface may be caused by

- In adequate compaction of the fill, subgrade and pavement layers.
- Un-scientific construction practices including the use of boulder stones and bricks as soiling course over loose subgrade soil.
- Use of inferior pavement material.
- Improper surface and subsurface drainage.
- Improper construction machinery.
- Poor maintenance

Light reflecting characteristics

- Night visibility very much depends upon the light reflecting characteristics of the pavement surface
- The glare caused by the reflection of head light is high on wet pavement surface than on dry pavement particularly in case of black top pavement or flexible pavement.
- Light colored or white pavement or rigid pavement surface give good visibility at night particularly during the rain, and produces glare or eye strain during bright sunlight.

Highway cross section elements

- Carriageway
- Shoulder
- Roadway width
- Right of way
- Building line
- Control line
- Median
- Camber/ cross slope
- Crown
- Side slope
- Kerb
- Guard rail
- Side drain
- Other facilities

Carriageway:

- It is the travel way which is used for movement of vehicle, it takes the vehicular loading .
- It may be cement concrete road or bituminous pavement.
- Width of carriageway is determined on the basis of the width of the vehicle and the minimum side clearance for safety.
- As per IRC specification, the maximum width of vehicle is 2.44m,minimum clearance of 0.68 in case of single lane and 1.02m in case of double lane.

WIDTH OF CARRIAGEWAY

SL. NO.	Class of road	Width of carriageway in 'm'
1	Single lane	3.75
2	Two lane without raised kerbs	7.0
3	Two lane with raised kerbs	7.5
4	Intermediate lane	5.5
5	Multilane pavement	3.5/lane

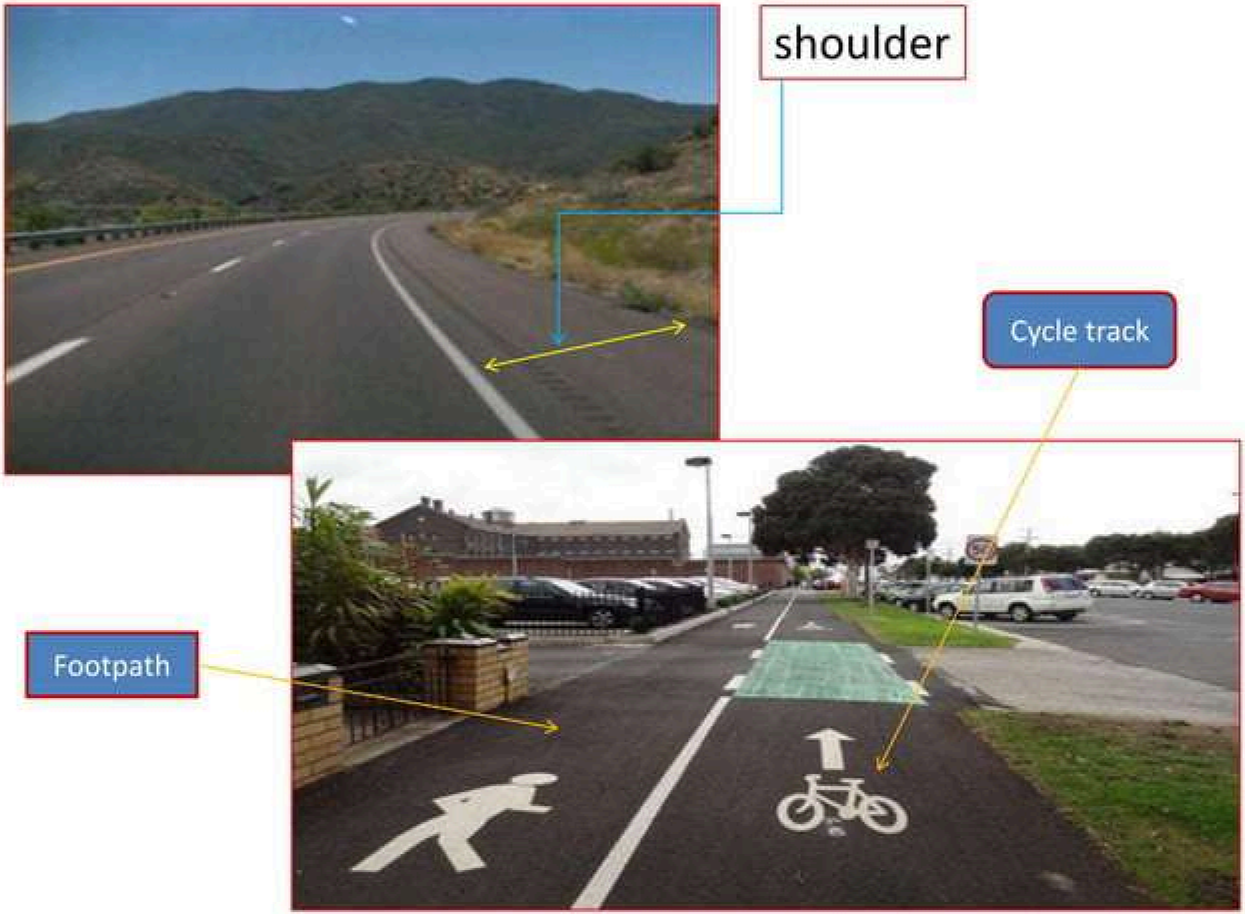
WIDTH OF ROADWAY OF VARIOUS CLASSES OF ROADS

SL. No.	Road classification	Roadway wisth	
		Plane and rolling terrain	Mountainous and steep terrain
1	NH & SH		
	a) Single lane	12	6.25
	b) two lane	12	6.25
2	MDR		
	a) Single lane	9	4.75
	b) two lane	9	4.75
3	ODR		
	a) Single lane	7.5	4.75
	b) two lane	9	4.75
4	Village roads-single lane	7.5	4


Two lane two-way road
carriageway

Shoulder:

- It is provided along the road edge to serve as an emergency lane for vehicle.
- It act as a service lane for vehicles that have broken down.
- The minimum shoulder width of 4.6 m so that a truck stationed at the side of the shoulder would have a clearance of 1.85m from the pavement edge.
- IRC recommended the minimum shoulder width is 2.5 m
- It should have sufficient load bearing capacity even in wet weather.
- The surface of the should be rougher than the traffic lanes so that vehicles are discouraged to use the shoulder as a regular traffic.
- The colour should be different from that of the pavement so as to be distinct.


shoulder
Cycle track
Footpath


unTreated
shoulder
Treated
shoulder

Width of the roadway or formation width:

- It is the sum of the width of the carriageway or pavement including separators if any and the shoulders.

Right of way:

- It is the total area of land acquired for the road along its alignment.
- It depends on the importance of the road and possible future development.
- It is desirable to acquire more width of land as the cost of adjoining land invariably increases very much , soon after the new highway is constructed.

Building lane:

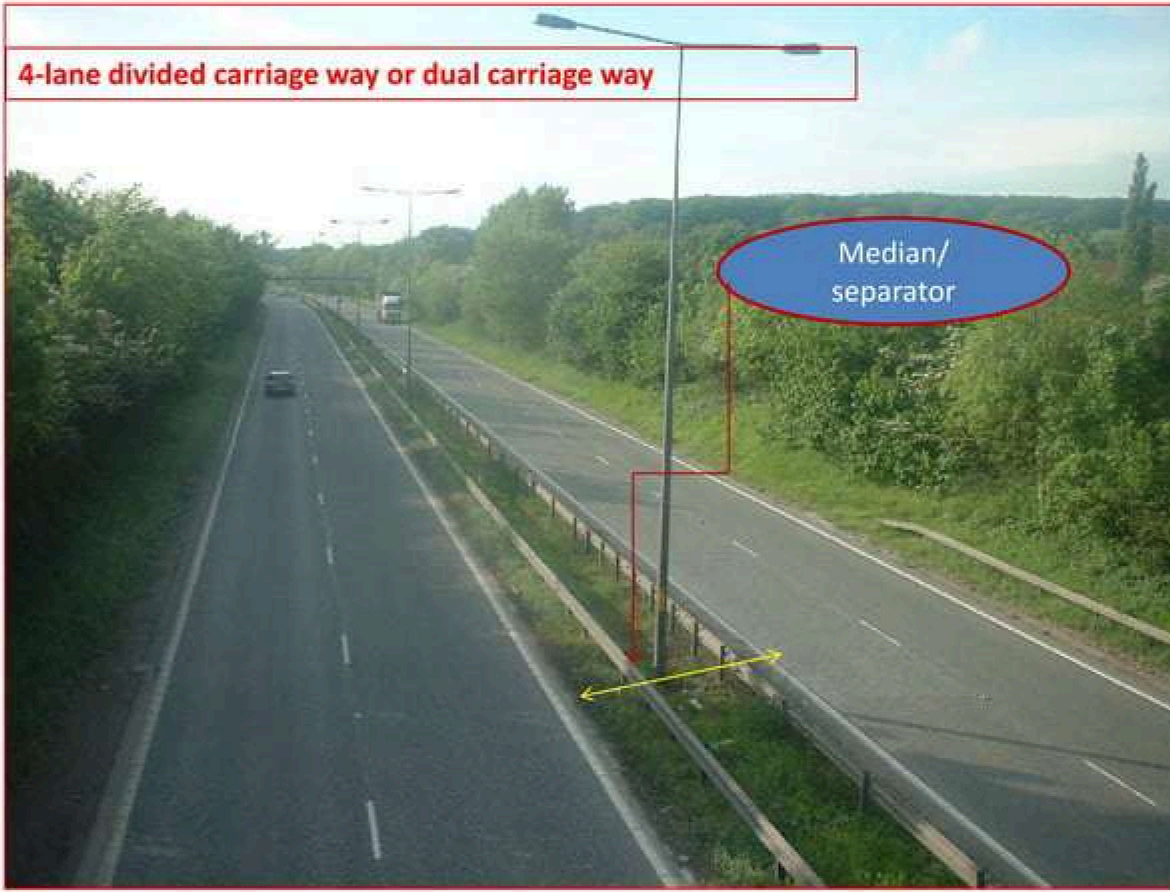
- In order to reserve sufficient space for future development of roads, It is desirable to control the building activities on either side of the road boundary, beyond the land width acquired for the land.

Control lines:

- In addition to “building line”, it is desirable to control the nature of building upto further “set back distance” .

Traffic separators or median:

- The main function is to prevent head on collision between the vehicle moving in opposite direction.
- Channelize traffic into streams at intersection.
- Segregate slow traffic and to protect pedestrians.
- IRC recommends a minimum desirable width of 5 m and may be reduce to 3 m where land is restricted.
- The minimum width of median in urban area is 1.2m.


4-lane divided carriage way or dual carriage way
Median/
separator

Cross slope or camber:

- It is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface.
- To prevent the entry of surface water into the subgrade soil through pavement.
- To prevent the entry of water into the bituminous pavement layer.
- To remove the rain water from the pavement surface as quick as possible and to allow the pavement to get dry soon after the rain.
- It is expressed as a percentage or 1V:Nh.
- It depends on the pavement surface and amount of rainfall.

Shape of the cross slope:

- Parabolic shape(fast moving vehicle)
- Straight line
- Combination of parabolic and straight line

Recommended values of camber for different types of road surface

Sl no.	Type of road surface	Range of camber in areas of rain fall range	
		heavy	light
1	Cement concrete and high type bituminous pavement	1 in 50(2%)	1 in 60(1.7%)
2	Thin bituminous surface	1 in 40(2.5%)	1 in 50(2%)
3	Water bound macadam(WBM) and gravel pavement	I in 33(3%)	1 in 40(2.5%)
4	Earth	1 in 25(4%)	1 in 33(3%)

EXAMPLE-1

In a district where the rainfall is heavy, major district road of WBM pavement, 3.8 m wide, and a state highway of bituminous concrete pavement, 7.0 m wide are to be constructed. What should be the height of the crown with respect to the edges in these two cases ?

Too steep slope is not desirable because of the fallowing reasons

- Uncomfortable side thrust and unequal wear of the tyres as well as road surface.
- Problem of toppling over highly laden bullock cart and truck.
- Tendency of most of vehicle travel along the centre line.

Kerb:

- It indicates the boundary between the pavement and shoulder.
- It is desirable to provide kerbs in urban areas.
- It is of three types

1-Low or mountable kerb:

- It allow the driver to enter the shoulder area with little difficulty.
- The height of the this type of shoulder kerb is about 10 cm above the pavement edge with slope to help the vehicle climb the kerb easily.

2-Semi-barrier kerb:

- It is provided on the periphery of a roadway where the pedestrian traffic is high.
- Height of about 15 cm above the pavement edge with a batter of 1:1 on the top 7.5 cm.
- It prevents parking the vehicle but during emergency it is possible to drive over this kerb with some difficulty.

3-Barrier type kerb:

- It is provided in built-up area adjacent to the foot paths with considerable pedestrian traffic.
- The height of the kerb is about 20 cm above the pavement edge with a steep batter of 1V:0.25H.


kerb

Guard rail

- It is provided at the edge of the shoulder when the road is constructed on a fill exceeds 3 m.
- It is also provided on horizontal curve so as to provide a better night visibility of the curves under the head light of the vehicle.


Guard rail

Road margins

Parking lane:

- These are provided on urban roads to allow kerb parking
- As far as possible only parallel parking should be allowed as it is safer for moving vehicle.
- It should have sufficient width say 3m

Lay bay:

- These are provided near the public conveniences with guide map to enable driver to stop clear off the carriageway.
- It has 3m width,30m length with 15m end tapers on both sides.

Bus bays:

- These may be provided by recessing the kerb to avoid conflict with moving traffic.
- It is located atleast 75m away from the intersection.

Frontage road:

- These are provided to give access to properties along an important highway with control access to express way or free way
- It may run parallel to the highway and are isolated by separator.

Driveway:

- It connect the highway with commercial establishment like fuel stations, service stations etc...
- It should be located away from the intersection.

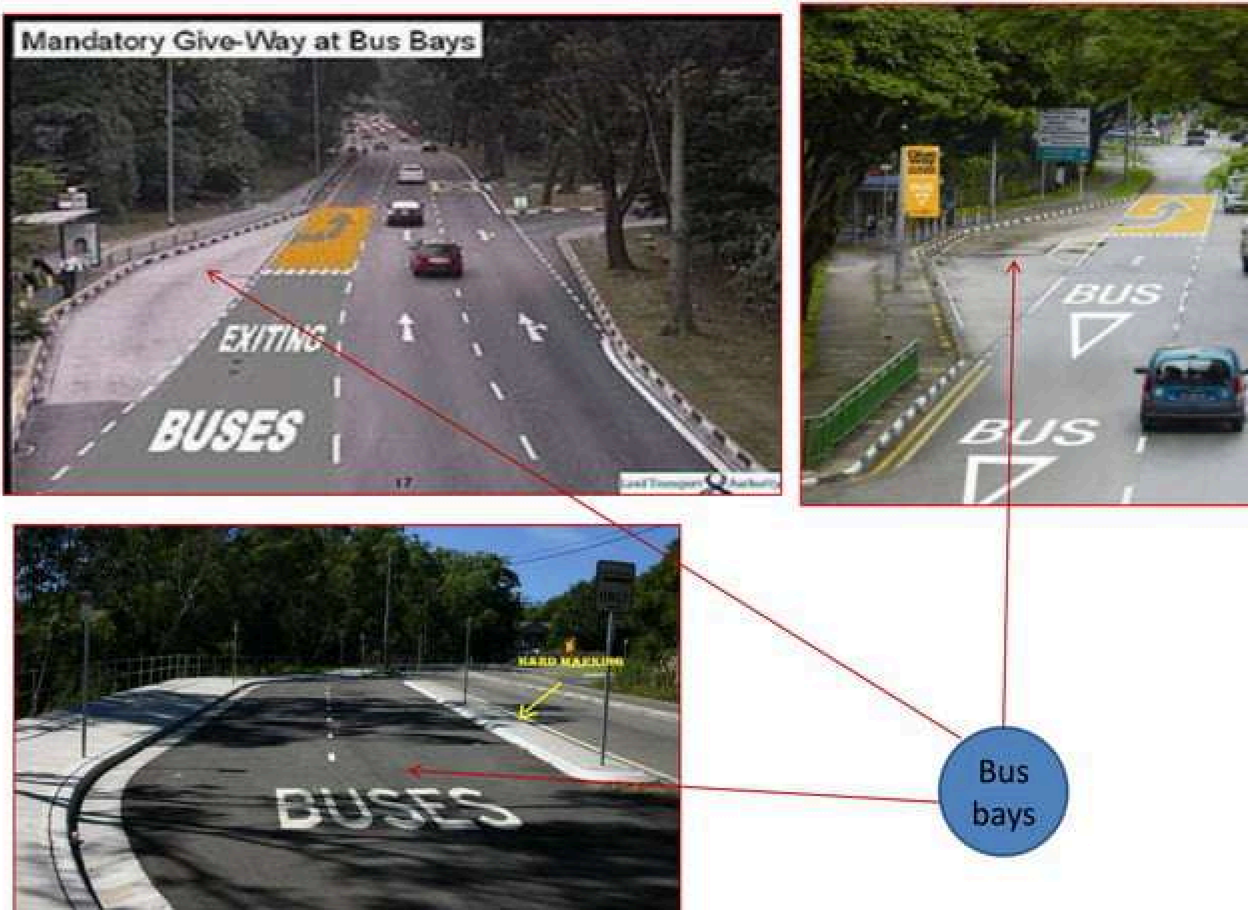
Cycle track:

- It provided in urban areas when the volume of cycle traffic on the road is very high.
- A minimum width of 2m is provided for cycle track.

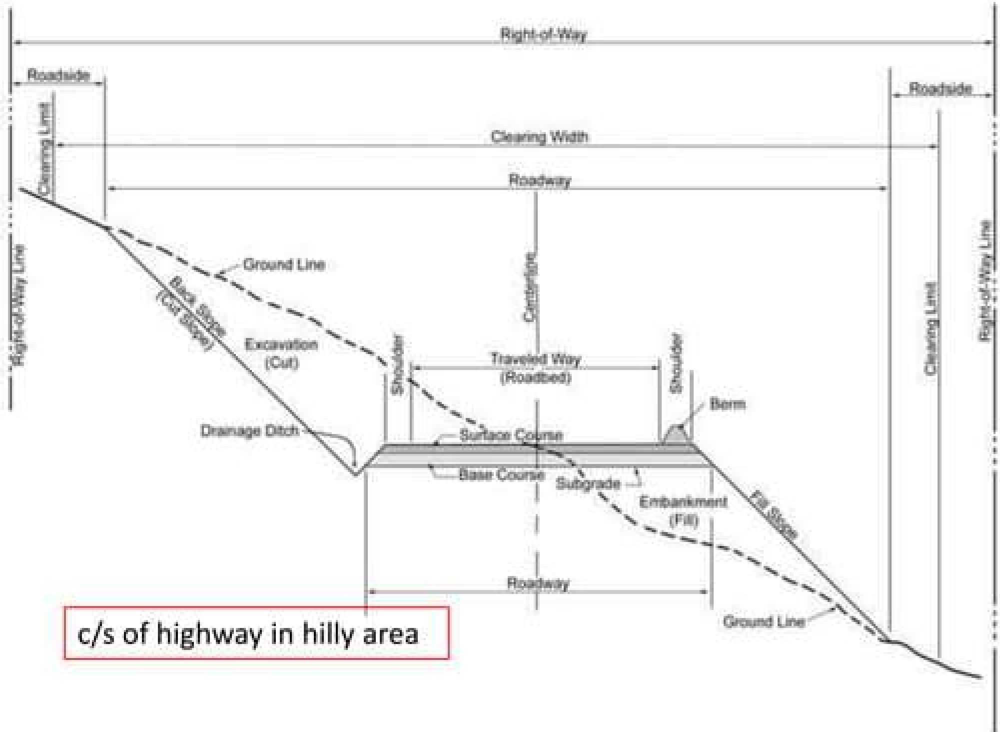
Footpath:

- These are provided in urban areas when the vehicular as well as pedestrian traffic are heavy.
- To protect the pedestrian and decrease accident.
- Minimum width of 1.5m is provided.

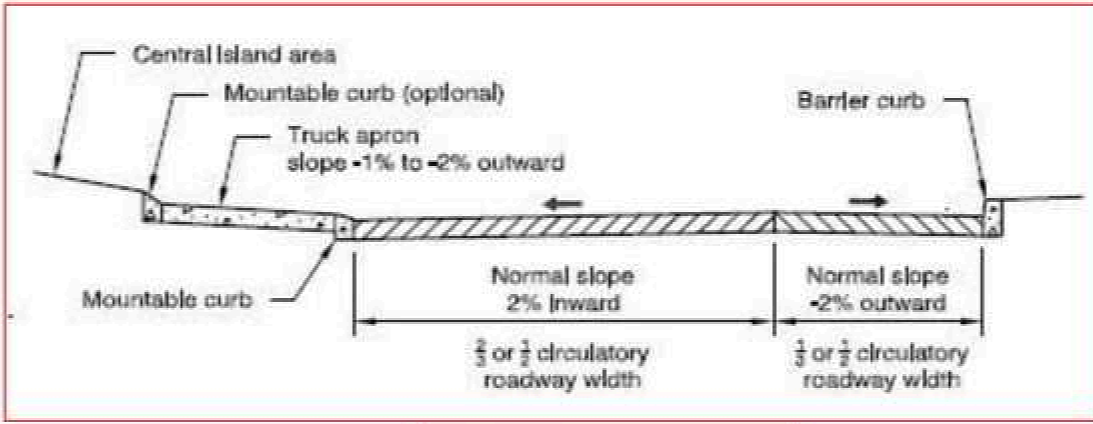

Lay-byes
@Arieh
P WC
Engelberg


Mandatory Give-Way at Bus Bays
EXITING
BUSES
BUS
BUS
BUSES
Bus bays

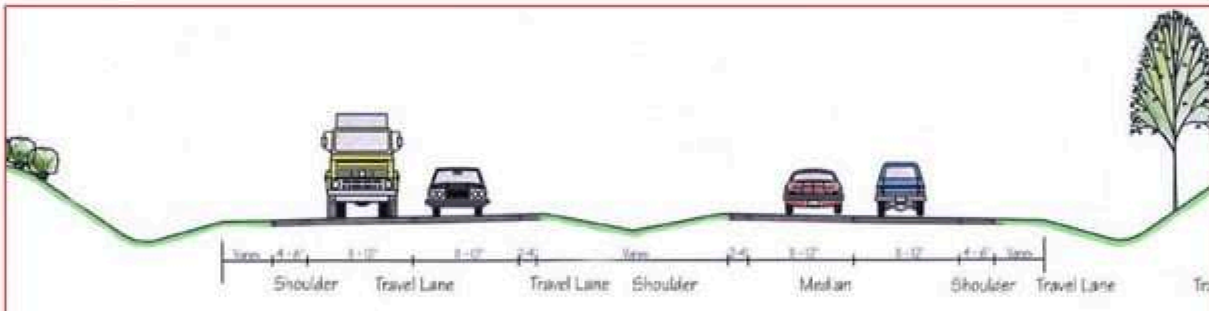

Frontage
road



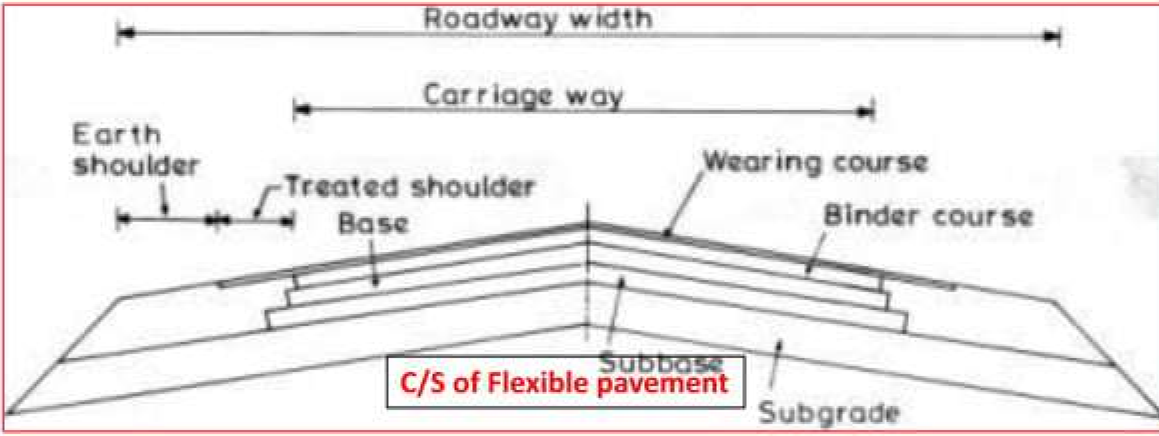
Typical Road Section



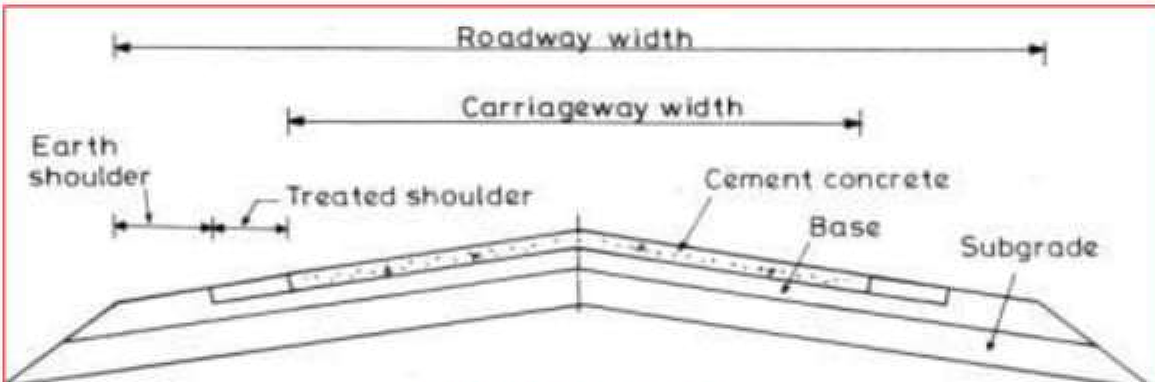
c/s of road in built-up area



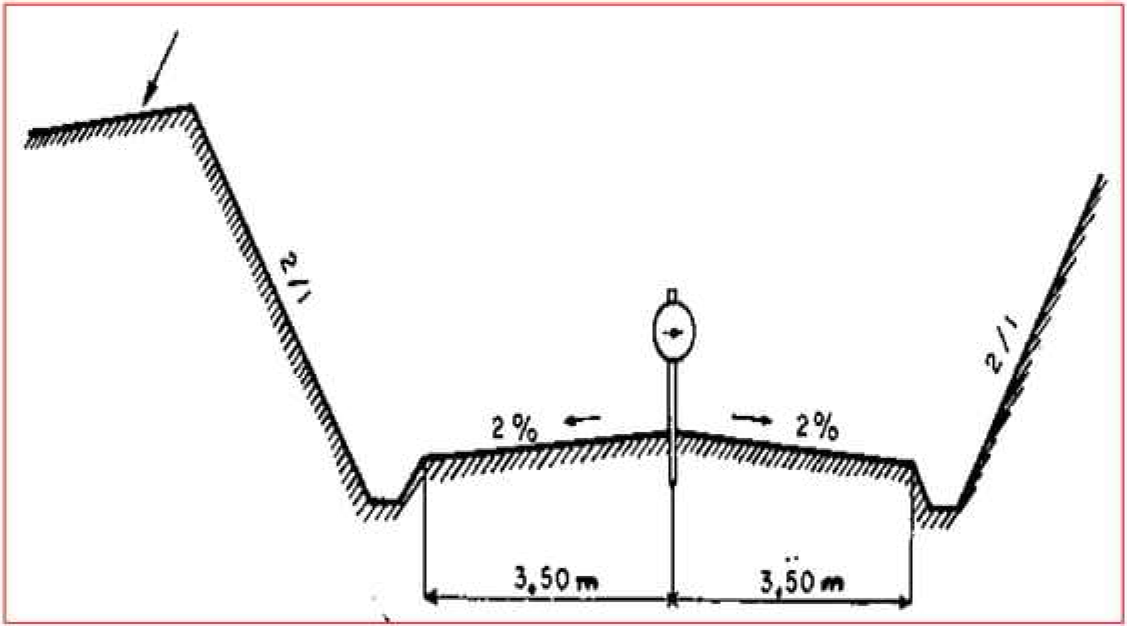
Four Lane Divided Roadway



C/S of Flexible pavement



C/S of Rigid pavement



c/s of road in cutting


Guard rails
RAMP
25
MPH
EXIT

Bibliography

- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros*.
- *IRC Codes*.

SIGHT DISTNCE

- Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway has visibility of stationary or moving objects. OR
- It is the length of road visible ahead to the driver at any instance.

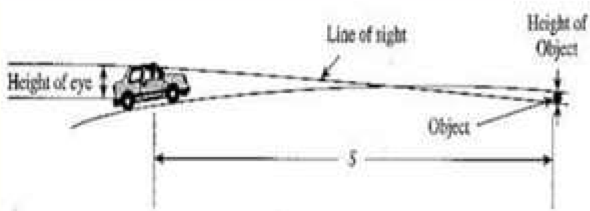
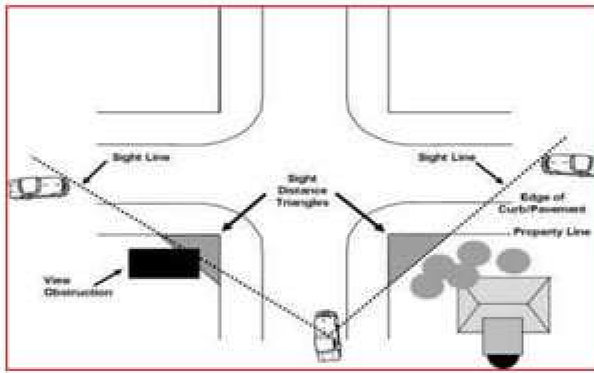


FIGURE 4.8
Stopping sight distance diagram for crest vertical curve.



Types of sight distance

- Stopping or absolute minimum sight distance(SSD)
- Safe overtaking or passing sight distance (OSD)
- Safe sight distance for entering into uncontrolled intersection.
- Intermediate sight distance
- Head light sight distance

Stopping sight distance:

- The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

Over taking sight distance:

- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the minimum overtaking sight distance (OSD) or the safe passing sight distance.

Sight distance at intersection:

- Driver entering an uncontrolled intersection (particularly unsignalised Intersection) has sufficient visibility to enable him to take control of his vehicle and to avoid collision with another vehicle.

Intermediate sight distance:

- This is defined as twice the stopping sight distance. When overtaking sight distance can not be provided, intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

Head light sight distance:

- This is the distance visible to a driver during night driving under the illumination of the vehicle head lights. This sight distance is critical at up-gradients and at the ascending stretch of the valley curves.

Stopping Sight Distance

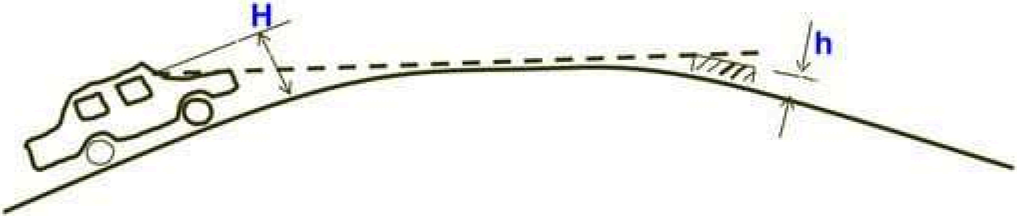
- SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

It depends on:

- Feature of road ahead
- Height of driver's eye above the road surface(1.2m)
- Height of the object above the road surface(0.15m)

Criteria for measurement

- Height of driver's eye above road surface (H)
- Height of object above road surface(h)



IRC

- H = 1.2m
- h = 0.15m

Factors affecting the SSD

- Total reaction time of driver
- Speed of vehicle
- Efficiency of brakes
- Frictional resistance between road and tyre
- Gradient of road

Total reaction time of driver:

- It is the time taken from the instant the object is visible to the driver to the instant the brake is effectively applied, it divide into types
  1. Perception time
  2. Brake reaction time

Perception time:

- it is the time from the instant the object comes on the line of sight of the driver to the instant he realizes that the vehicle needs to be stopped.

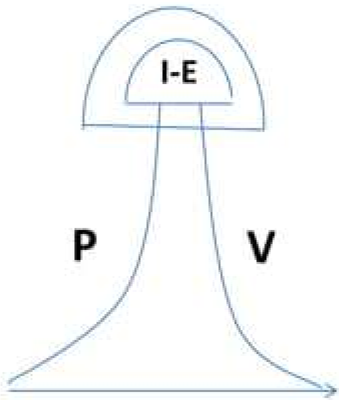
Brake reaction time:

- The brake reaction also depends on several factor including the skill of the driver, the type of the problems and various other environment factor.
- Total reaction time of driver can be calculated by "PIEV" theory

"PIEV" Theory

Total reaction time of driver is split into four parts:

- P-perception
- I-intellection
- E-Emotion
- V-Volition



perception

- It is the time required for the sensation received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord.

Intellection:

- It is the time required for understanding the situation.

Emotion:

- It is the time elapsed during emotional sensation and disturbance such as fear, anger or any other emotional feeling such as superstition etc, with reference to the situation.

Volition:

- It is the time taken for the final action

Total reaction time of driver may be vary from 0.5 sec to 4 sec

Analysis of SSD

- The stopping sight distance is the sum of lag distance and the braking distance.

Lag distance:

- It is the distance, the vehicle traveled during the reaction time
- If 'V' is the design speed in m/sec and 't' is the total reaction time of the driver in seconds,

lag distance = v.t metres.
Where "v" in m/sec
t=2.5 sec

Lag distance=0.278 V.t meters
Where "v" in Kmph,
T= time in sec=2.5 sec

Braking distance :

- It is the distance traveled by the vehicle after the application of brake. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.
- work done against friction force in stopping the vehicle is F x l = f W l, where W is the total weight of the vehicle.
- The kinetic energy at the design speed of v m/sec will be ½ m. v^2

Braking distance= $v^2/2gf$

SSD=lag distance + braking distance

$$\boxed{SSD=0.278V.t + v^2/254f}$$

Table 2.6: Coefficient of longitudinal friction					
Speed, kmph	30	40	50	60	>80
Longitudinal coefficient of friction	0.40	0.38	0.37	0.36	0.35

- Two-way traffic single lane road: SSD=2*SSD
- In one-way traffic with single or more lane or two-way traffic with more than single lane: Minimum SSD= SSD

Example-1

- Calculate the safe stopping sight distance for design speed of 50kmph for(a) two-way traffic on two lane road (b)two-way traffic on single lane road

Example-2

- Calculate the minimum sight distance required to avoid a head on collision of two cars approaching from opposite direction at 90 and 60kmph.coefficient friction of 0.7 and a brake efficiency of 50%, in either case

Example-3

- Calculate the stopping sight distance on a highway at a descending gradient of 2% for design speed of 80 kmph, assume other data as per IRC specification.

OVERTAKING SIGHT DISTANCE

- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the minimum overtaking sight distance (OSD) or the safe passing sight distance.
- The overtaking sight distance or OSD is the distance measured along the centre of the road which a driver with his eye level 1.2 m above the road surface can see the top of an object 1.2 m above the road surface.

Factors affecting the OSD

- speeds of
  - overtaking vehicle
  - overtaken vehicle
  - the vehicle coming from opposite direction, if any.
- Distance between the overtaking and overtaken vehicles.
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

Analysis of OSD

- Fallow the Fig. 4.14, p-96 of highway engineering by S.K. Khanna and C.E.G. Justo
- d1 is the distance traveled by overtaking vehicle "A" during the reaction time t sec of the driver from position A1 to A2.
- D2 is the distance traveled by the vehicle A from A2 to A3 during the actual overtaking operation, in time T sec.
- D3 is the distance traveled by on-coming vehicle C from C1 to C2 during the over taking operation of A, i.e. T sec.
- B is the overtaken or slow moving vehicle.

Cont…

- B is the overtaken or slow moving vehicle moving with uniform speed V_b m/sec or V_b Kmph;
- C is a vehicle coming from opposite direction at the design speed V m/sec or V kmph
- The distance traveled by the vehicle A during this reaction time is d1 and is between
  the positions A1 and A2. this distance will be equal to $V_b.t$ meter
- where t is the reaction time of the driver in second= 2 sec.

$$OSD = d1 + d2 + d3$$

$$OSD = 0.28\, V_b . t + 0.28 V_b . T + 2s + 0.28\, V.T$$

S = SPACING OF VEHICLES = $(0.2\, V_b + 6)$

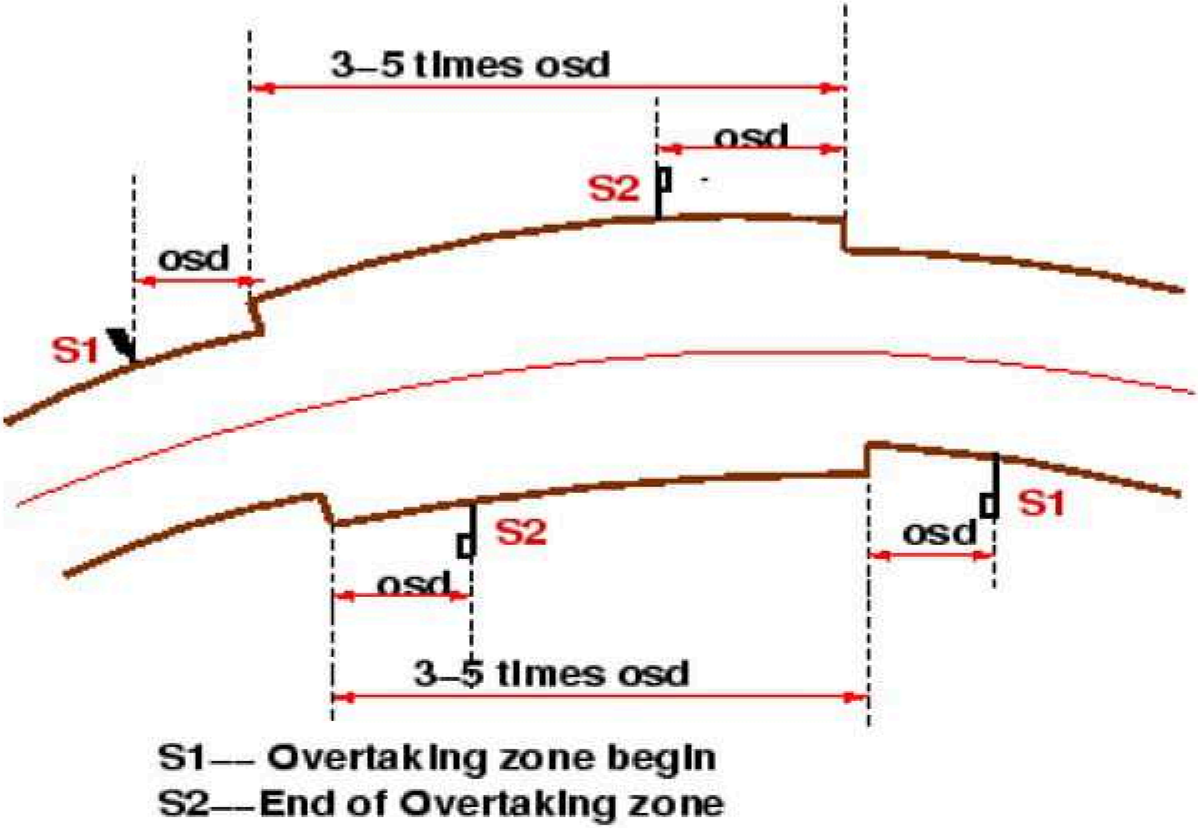
$T = \sqrt{4 \times 3.6 s / A} = \sqrt{14.4 s / A}$

If the speed of the overtaken vehicle is not given
$V_b = (V-16)$ kmph, where V= speed of overtaking vehicle in kmph

- The minimum overtaking sight distance = d1+d2+d3 for two-way traffic.
- On divide highways and on roads with one way traffic regulation, the overtaking distance = d1+d2 as no vehicle is expected from the opposite direction.

Overtaking Zones

- It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance can not be provided. But the overtaking opportunity for vehicles moving at design speed should be given at frequent intervals. These zones which are meant for overtaking are called overtaking zones.
- The minimum length of overtaking zone should be three time the safe overtaking distance i.e., 3 (d1+d2) for one-way roads and 3(d1+d2+d3) for two-way roads.
- Desirable length of overtaking zones is kept five times the overtaking sight distance. i.e., 5(d1+d2) for one-way roads and 5(d1+d2+d3) for two-way roads.


3–5 times osd
osd
S2
osd
S1
S2
S1
osd
osd
3–5 times osd
S1— Overtaking zone begin
S2—End of Overtaking zone

Example-1

The speed of the overtaking and overtaken vehicle are 70 and 40 kmph, respectively on a two way traffic road. If the accleration of overtaking vehicle is 0.99 m/sec^2,

a) Calculate safe overtaking sight distance
b) Calculate the minimum and desirable length of overtaking zone
c) Draw the neat-sketch of the overtaking zone and show the position of the sign post.

Example-2

Calculate the safe overtaking sight distance for a design speed of 96 kmph, assume all other data suitable

DESIGN OF HORIZONTAL ALIGNMENT

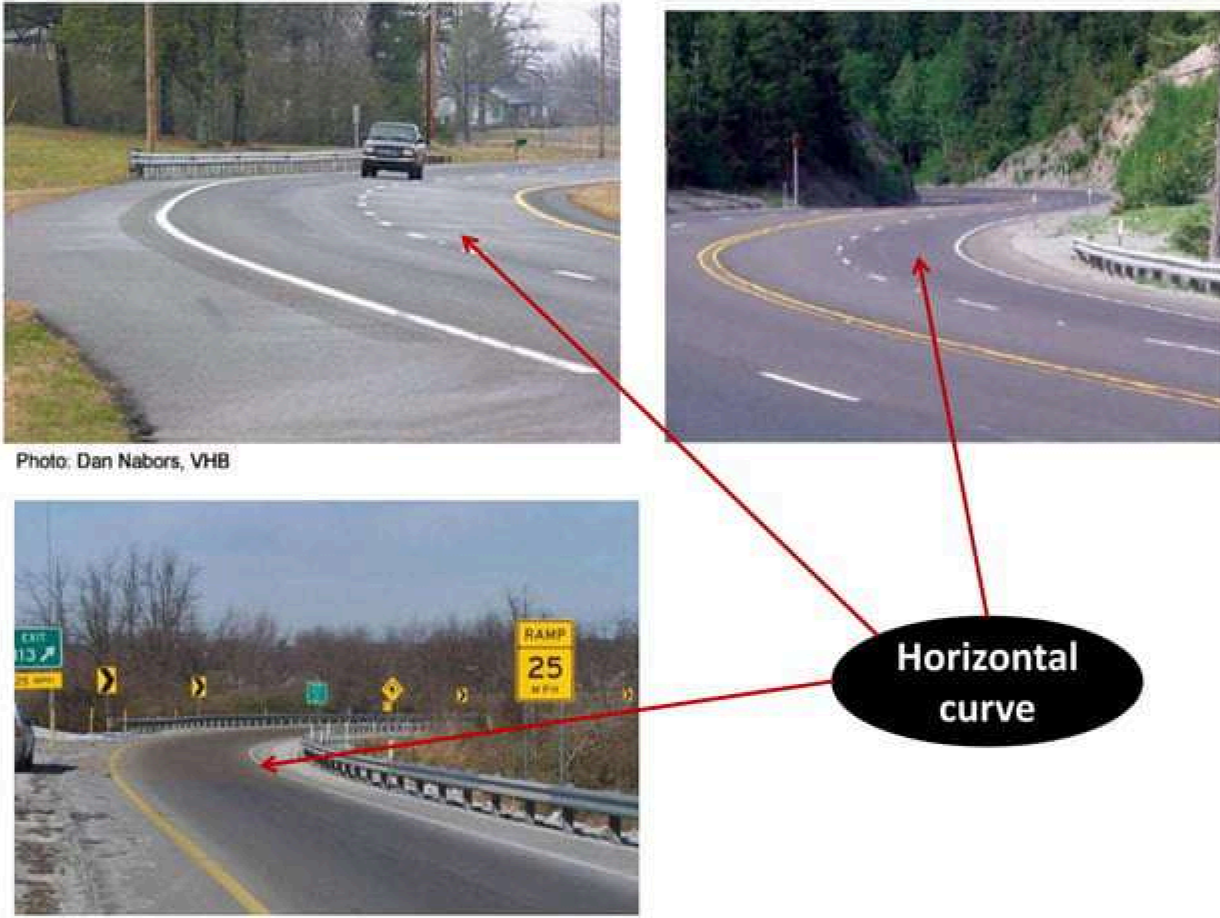
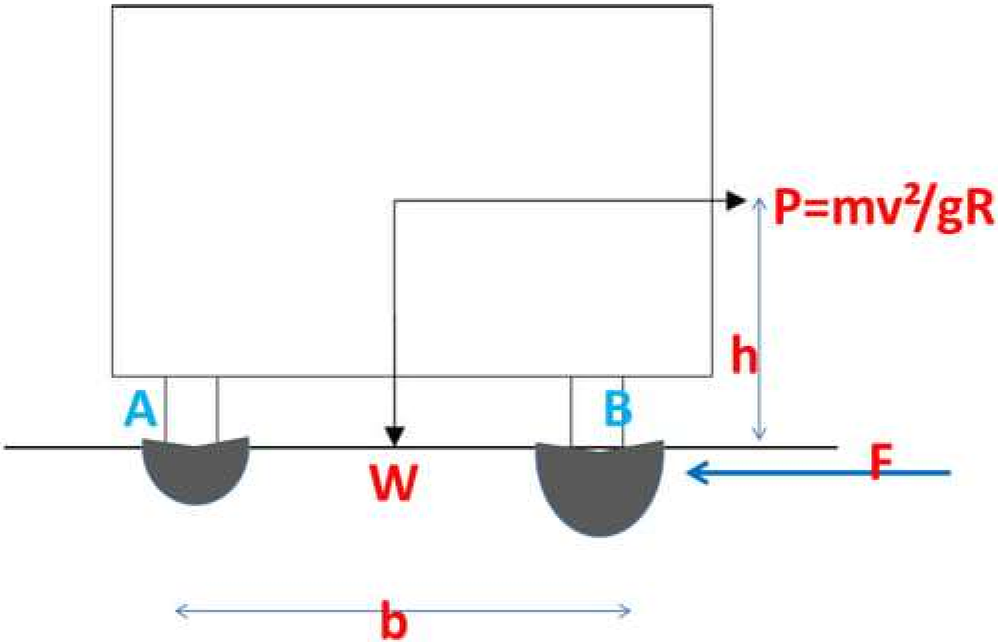


Photo: Dan Nabors, VHB

Horizontal Curves

- A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road. When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle.
- $P = W\,v^2/gR$
- Where,
  - P = centrifuge force, kg
  - W = weight of the vehicle, kg
  - R = radius of the circular curve, m
  - v = speed of vehicle, m/sec
  - g = acceleration due to gravity = 9.8 m/sec



P=mv²/gR
h
A
B
W
F
b

Cont.....

- P/W is known as the centrifugal ratio or the impact factor. The centrifuge ratio is thus equal to v^2/gR
- The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects
  - Tendency to overturn the vehicle outwards about the outer wheels
  - Tendency to skid the vehicle laterally, outwards

Overturning effect

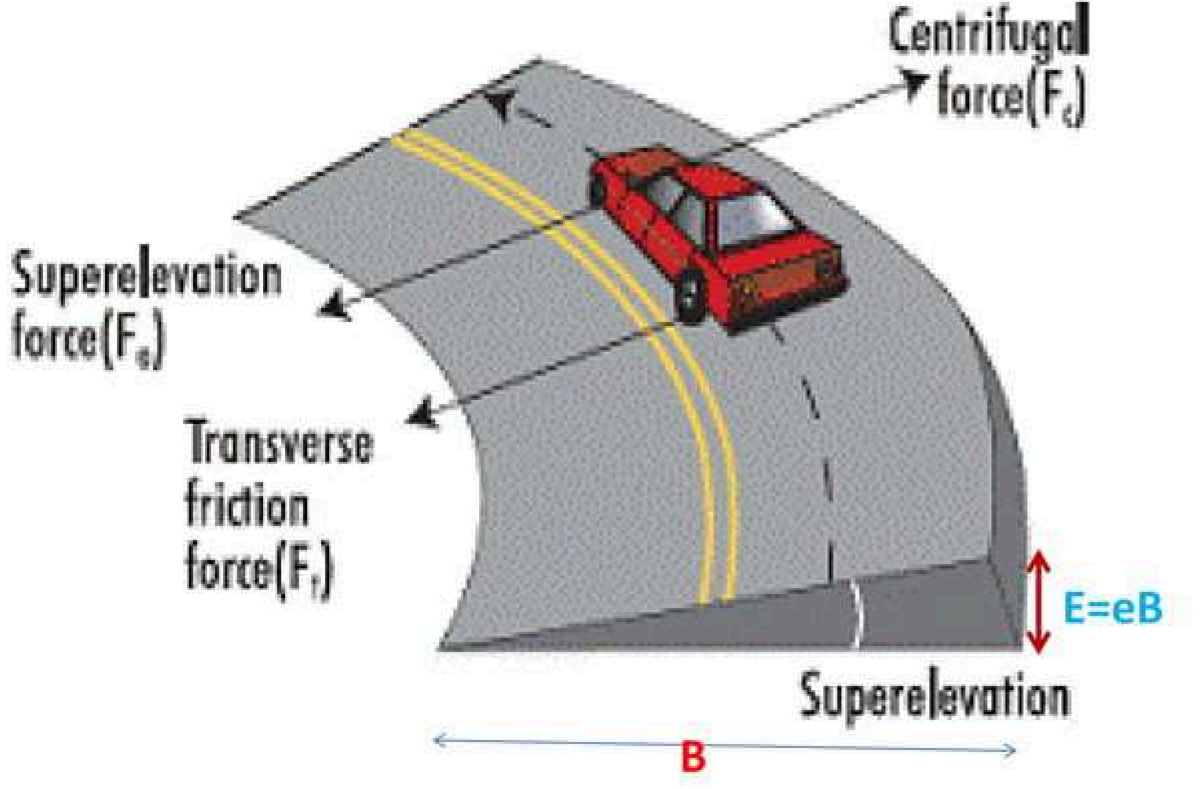
- The equilibrium condition for overturning will occur when $Ph = Wb/2$, or when $P/W = b/2h$. This means that there is danger of overturning when the centrifugal when the centrifugal ratio P/W or v^2/gR attains a values of $b/2h$.

Transverse skidding effect

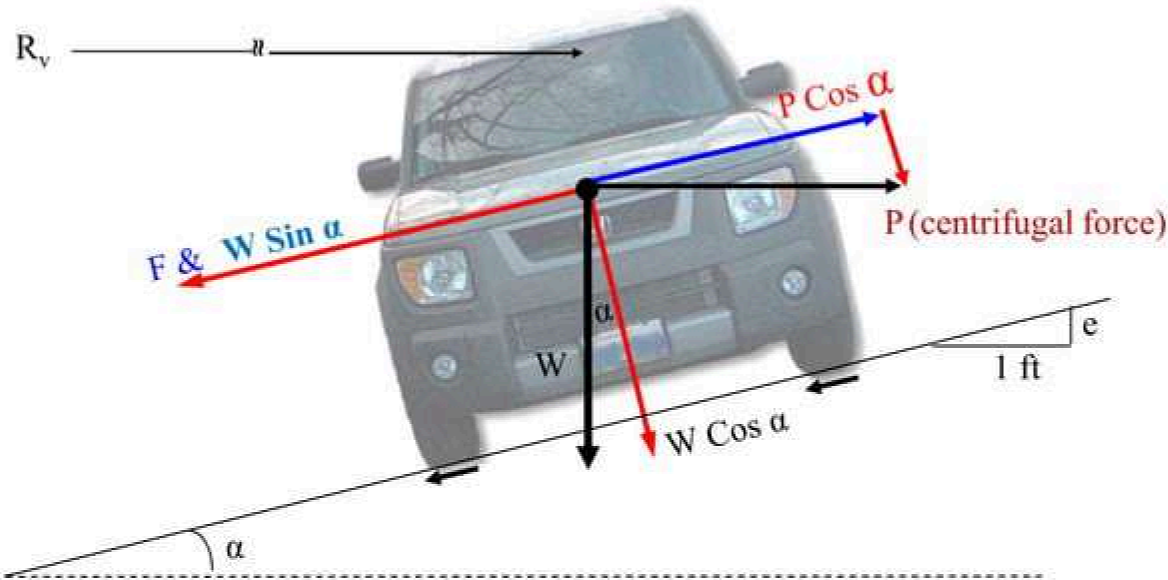
- $P = F_A + F_B = f(R_A + R_B) = fW$
- Since $P = f\,W$, the centrifugal ratio P/W is equal to 'f '. In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction there is a danger of lateral skidding.
- Thus to avoid overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than $b/2h$ and also 'f'
- 'f' is less than $b/2h$.-The vehicle would skid and not overturn
- $b/2h$ is lower than 'f'-The vehicle would overturn on the outer side before skidding

Superelevation

- In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve, this transverse inclination to the pavement surface is known as Superelevation or cant or banking.
- The Superelevation 'e' is expressed as the ratio of the height of outer edge with respect to the horizontal width.


Centrifugal force(F_c)
Superelevation force(F_e)
Transverse friction force(F_f)
E=eB
Superelevation
B

Superelevation



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

Analysis of Superelevation

- The force acting on the vehicle while moving on a circular curve of radius R meters, at speed of v m/sec are
- The centrifugal force $P = Wv^2/gR$ acting horizontal outwards through the centre of gravity, CG
- The weight W of the vehicle acting vertically downloads through the CG
- The frictional force developed between the wheels and the pavement counteractions transversely along the pavement surface towards the centre of the curve

Superelevation cont…

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

OR $$\tan\alpha + f = \frac{V^2}{gR}(1 - f\tan\alpha)$$ Dividing Cos α on both sides

OR $$e + f = \frac{V^2}{gR}(1 - fe)$$ (1-fe)=1-0.15x.o7=0.99= 1

OR $$R = \frac{V^2}{g(f+e)}$$

OR $$\boxed{e + f = \frac{V^2}{gR}}$$ **OR** $$\boxed{e + f = \frac{V^2}{127R}}$$

V in m/Sec
R in 'm'

V in kmph
R in 'm'

Cont…

- e = rate of Superelevation = $\tan \Theta$
- f = design value of lateral friction coefficient = 0.15
- v = speed of the vehicle, m/sec
- R = radius of the horizontal curve, mg = acceleration due to gravity = 9.8 m/sec^2

Maximum Superelevation

- In the case of heavily loaded bullock carts and trucks carrying less dense materials like straw or cotton, the centre of gravity of the loaded vehicle will be relatively high and it will not be safe for such vehicles to move on a road with a high rate of Superelevation. Because of the slow speed, the centrifugal force will be negligibly small in the case of bullock carts. Hence to avoid the danger of toppling of such loaded slow moving vehicles, it is essential to limit the value of maximum allowable Superelevation.
- Indian Roads Congress had fixed the maximum limit of Superelevation in **plan and rolling terrains** and is snow bound areas as **7.0 %**.
- On **hill roads** not bound by snow a maximum Superelevation upto **10%** .
- On **urban road** stretches with frequent intersections, it may be necessary to limit the maximum Superelevation to **4.0 %.**

Minimum Superelevation

- From drainage consideration it is necessary to have a minimum cross to drain off the surface water. If the calculated Superelevation is equal to or less than the camber of the road surface, then the minimum Superelevation to be provided on horizontal curve may be limited to the camber of the surface.

Design ofSuperelevation

- Step-1: The Superelevation for 75 percent of design speed (v m/sec/kmph) is calculated neglecting the friction.

$$\boxed{e=\frac{(0.75V)^2}{127R}}$$

$$\boxed{e=\frac{V^2}{225R}}$$

- Step-2: If the calculated value of 'e' is less than 7% or 0.07 the value so obtained is provided. If the value of 'e' as step-1 exceeds 0.07 then provides maximum Superelevation equal to 0.07 and proceed with step-3 or 4.
- Step-3: Check the coefficient of friction of friction developed for the maximum value of e =0.07 at the full value of design speed.

$$\boxed{f=\frac{V^2}{127R}-0.07}$$

- If the value of f thus calculated is less than 0.15 the Superelevation of 0.07 is safe for the design speed. If not, calculate the restricted speed as given in step -4.

Cont….

- <u>Step-4</u> The allowable speed (V_a m/sec. or V_a Kmph) at The curve is calculated by considering the design coefficient of lateral friction and the maximum Superelevation.
- $e+f=0.07+0.15=v_a^2/127R$
- If the allowed speed, as calculated above is higher than the design speed, then the design is adequate and provides a Superelevation of 'e' equal to 0.07.
- If the allowable speed is less than the design speed, the speed is limited to the allowed speed V_a kmph calculated above and Appropriate warning sign and speed limit regulation sign are installed to restrict and regulate the speed.

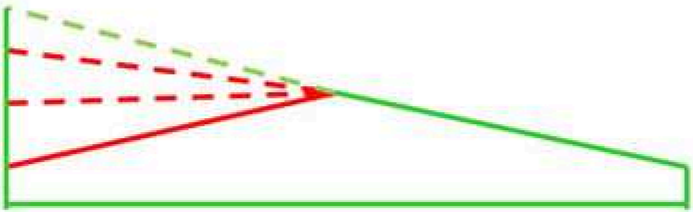
Attainment of superelevation

Split-up into **two parts::**

- Elimination of crown of the cambered section
- Rotation of pavement to attain full superelevation

Elimination of crown of the cambered section

1st Method: Outer edge rotated about the crown



Attainment of superelevation

Disadvantages

- Small length of road – cross slope less than camber
- Drainage problem in outer half

2nd Method: Crown shifted outwards

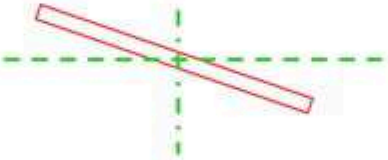
Disadvantages

- Large negative superelevation on outer half
- Drivers have the tendency to run the vehicle along shifted crown

Attainment of superelevation

Rotation of pavement to attain full superelevation

1st Method: Rotation about the C/L (depressing the inner edge and raising the outer edge each by half the total amount of superelevation)



Advantages

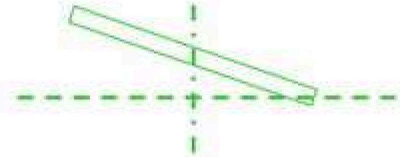
- Earthwork is balanced
- Vertical profile of the C/L remains unchanged

Disadvantages

- Drainage problem: depressing the inner edge below the general level

Attainment of superelevation

<u>**2nd Method:**</u> Rotation about the Inner edge (raising both the centre as well as outer edge – outer edge is raised by the total amount of superelevation)



<u>Advantages</u>

- No drainage problem

<u>Disadvantages</u>

- Additional earth filling
- C/L of the pavement is also raised (vertical alignment of the road is changed)

Example-1

- The radius of horizontal circular curve is 100m. The design speed is 50kmph and the design coefficient of lateral friction is 0.15.
    - Calculate the superelevation required if full lateral friction is assumed to develop
    - Calculate the coefficient of friction needed if no superelevation is provided.
    - Calculate the equilibrium superelevation if the pressure on inner and outer wheels should be equal.

Example-2:

- A two lane road with design speed 80kmph has horizontal curve of radius 480m. Design the rate of superelevation for mixed traffic. By how much should the outer edges of the pavement be raised with respect to the centre line , if the pavement is rotated with respect to the centre line.

Exapmle-3:

- Design the super elevation for a horizontal highway curve of radius 500m and speed 100kmph

Example-4

- The design speed of highway is 80kmph. There is horizontal curve of radius 200m on a certain locality. Calculate the superelevation needed to maintain this speed.

Radius of Horizontal Curve

- The ruling minimum radius of the curve for ruling design speed v m/sec. or V kmph is given by.

$$\boxed{R_{Rulling} = \frac{V^2}{127(e+f)}}$$

- According to the earlier specifications of the IRC, the ruling minimum radius of the horizontal curve was calculated from a speed value, 16 kmph higher than the design speed i,e., (V+16) kmph.

Example-1

- Calculate the values of ruling minimum and absolute minimum radius of horizontal curve of a national highway in plane terrain. Assume ruling design speed and minimum design speed values as 100 and 80 kmph respectively.

Widening of Pavement on Horizontal Curves

- On horizontal corves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width,
- Widening is needed for the following reasons :
  - ✓ The driver experience difficulties in steering around the curve.
  - ✓ The vehicle occupies a greater width as the rear wheel don't track the front wheel. known as 'Off tracking'
  - ✓ For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.
  - ✓ While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

Off tracking

- An automobile has a rigid wheel base and only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.
- The required extra widening of the pavement at the horizontal curves depends on the length of the wheel base of the vehicle 'l', radius of the curve 'R' and the psychological factors.

Analysis of extra widening on curves

- It is divided into two parts;
  - ✓ **Mechanical widening (W_m):** the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening
  - ✓ **Psychological widening (W_{ps}):** extra width of the pavement is also provided for psychological reasons such as , to provide for greater maneuverability of steering at high speed, to allow for the extra space for overhangs of vehicles and to provide greater clearance for crossing and overturning vehicles on curve.
- Total widening $W = W_{ps} + W_m$

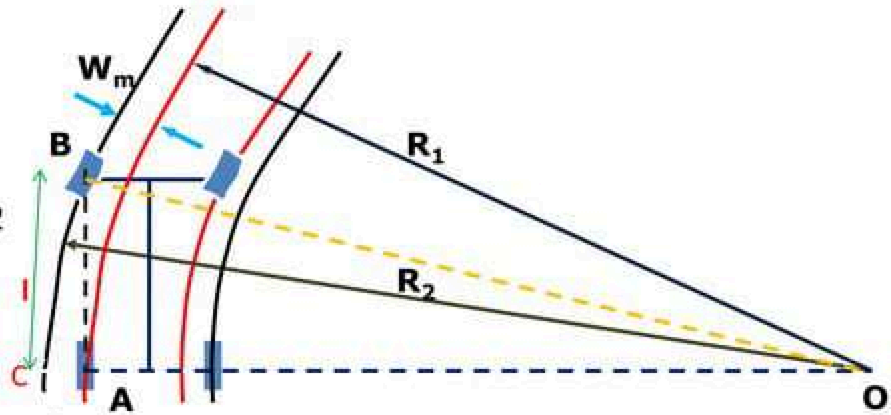
Mechanical Widening

$W_m = R_2 - R_1$

From Δ OAB,

$OA^2 = OB^2 - BA^2$

$R_1^{\,2} = R_2^{\,2} - l^2$



$(R_2 - W_m)^2 = R_2^{\,2} - l^2$

$l^2 = W_m (2 R_2 - W_m)$

$W_m = l^2 / (2 R_2 - W_m)$

$W_m = l^2 / 2R$ (Approx.)

or $W_m = nl^2/2R$

Where, R = Mean radius of the curve in m,

n=no. of traffic lanes

R = Mean radius of the curve, m

l = Length of Wheel base of longest vehicle , m

(l = 6.0 m or 6.1m for commercial vehicles)

V= design speed, kmph

Psychological Widening

$$\boxed{W_{Ps} = \frac{V}{9.5\sqrt{R}}}$$ (Empirical formula)

V = Design speed of the vehicle, km/h

R = Radius of the curve, m

Total extra widening = Mechanical widening +Psychological Widening

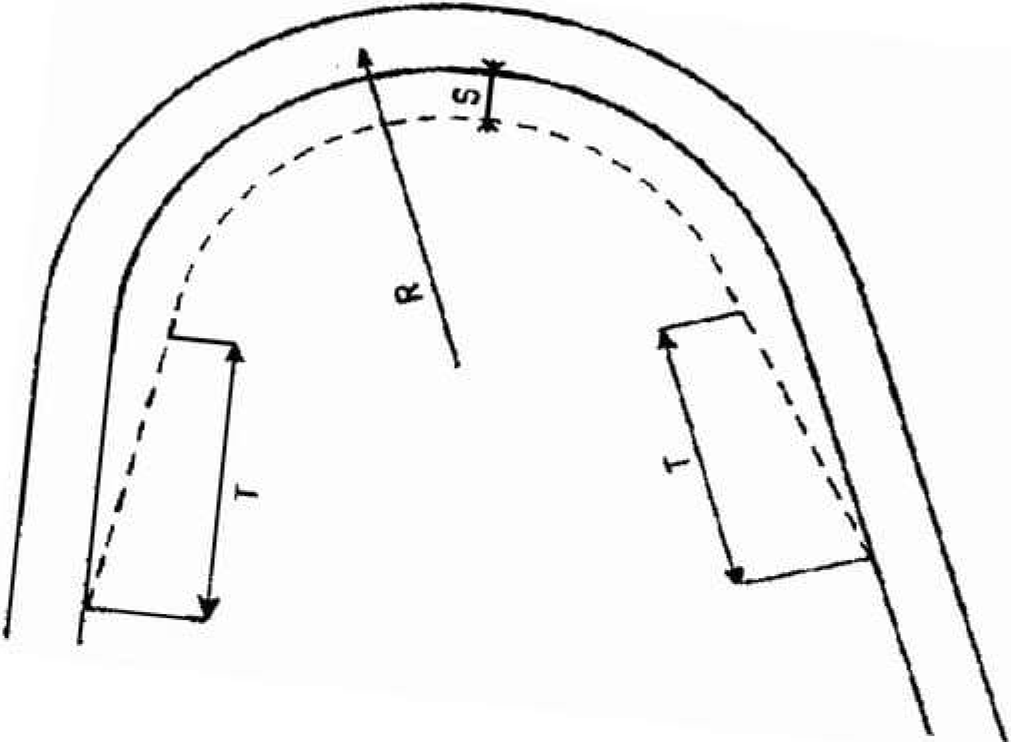
$$\boxed{W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}}$$

Method of introducing extra widening

- With transition curve: increase the width at an approximately uniform rate along the transition curve - the extra width should be continued over the full length of circular curve
- Without transition curves: provide two-third widening on tangent and the remaining one-third on the circular curve beyond the tangent point
- With transition curve: Widening is generally applied equally on both sides of the carriageway
- Without transition curve: the entire widening should be done on inner side
- On sharp curves of hill roads: the entire widening should be done on inner side

Method of introducing extra widening

Follow Fig- 4.27, p-123



Example-1

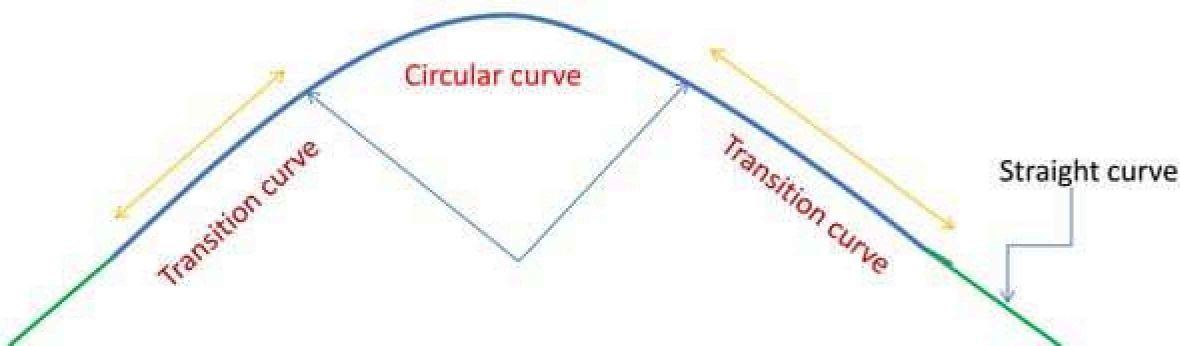
- Calculate the extra widening required for a pavement of width 7m on a horizontal curve of radius 250m if the longest wheel base of vehicle expected on the road is 7.0 m. design speed is 70 kmph.

Example-2

- Find the total width of two lane road on a horizontal curve for a new National highway to be aligned along a rolling terrain with a ruling minimum radius having ruling design speed of 80 kmph. Assume necessary data as per IRC

Horizontal transition curves

- When a non circular curve is introduce between a straight and a circular curve has a varying radius which decreases from infinity at the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point) for the gradual introduction of centrifugal force is known as transition curve.



Objectives for providing transition curve

- ✓ To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
- ✓ To enable the driver turn the steering gradually for his own comfort and security
- ✓ To provide gradual introduction of super elevation
- ✓ To provide gradual introduction of extra widening.
- ✓ To enhance the aesthetic appearance of the road.

Type of transition curve

- spiral or clothoid
- cubic parabola
- Lemniscate

Follow the Fig-4.29, p-126 of highway Engineering by S.K. Khanna and C.E.G. Justo

- IRC recommends spiral as the transition curve because it fulfills the requirement of an ideal transition curve, that is;
  - ✓ rate of change or centrifugal acceleration is consistent
  - ✓ Radius of the transition curve is infinity at the straight edge and changes to R at the curve point (Ls ⍺1/R)and calculation and field implementation is very easy.

Length of transition curve

- Case-1: Rate of change of centrifugal acceleration

$$\boxed{L_S = \frac{0.0215V^3}{CR}}$$

$$\boxed{C = \frac{80}{(75+V)}}$$

0.5 < C < 0.8

- Where,
  - ✓ Ls= length of transition curve in 'm'
  - ✓ C= allowable rate of change of centrifugal accleration, m/sec²
  - ✓ R= Radius of the circular curve in 'm'

case-2: Rate of introduction of super-elevation

- If the pavement is rotated about the center line.

$$\boxed{Ls = EN/2 = eN/2(W+We)}$$

- If the pavement is rotated about the inner edge

$$\boxed{Ls = EN = eN(W+We)}$$

- Where W is the width of pavement
- We is the extra widening
- Rate of change of superelevation of 1 in N

case-3: By empirical formula

- According to IRC standards:
  - ✓ For plane and rolling terrain:

$$\boxed{L_S = \frac{2.7V^2}{R}}$$

  - ✓ For mountainous and steep terrain:

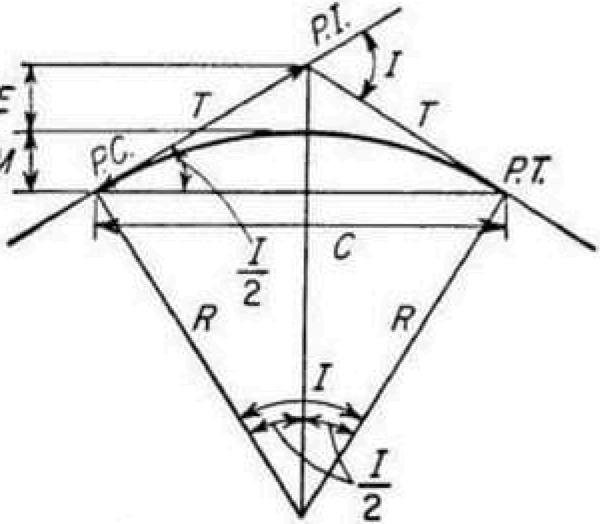
$$\boxed{L_S = \frac{V^2}{R}}$$

The design length of transition curve(Ls) will be the highest value of case-1,2 and 3

Shift of the transition curve

Shift of the transition curve ‘S’

$$\boxed{S = \frac{{L_s}^2}{24R}}$$



Circular curve.

Example-1

- Calculate the length of the transition curve and shift using the following data;
  - ✓ Design speed= 65 kmph
  - ✓ Radius of circular curve= 220 m
  - ✓ Allowable rate of superelevation= 1 in 150
  - ✓ Pavement rotated about the centre line of the pavment
  - ✓ Pavement width including extra widening= 7.5 m

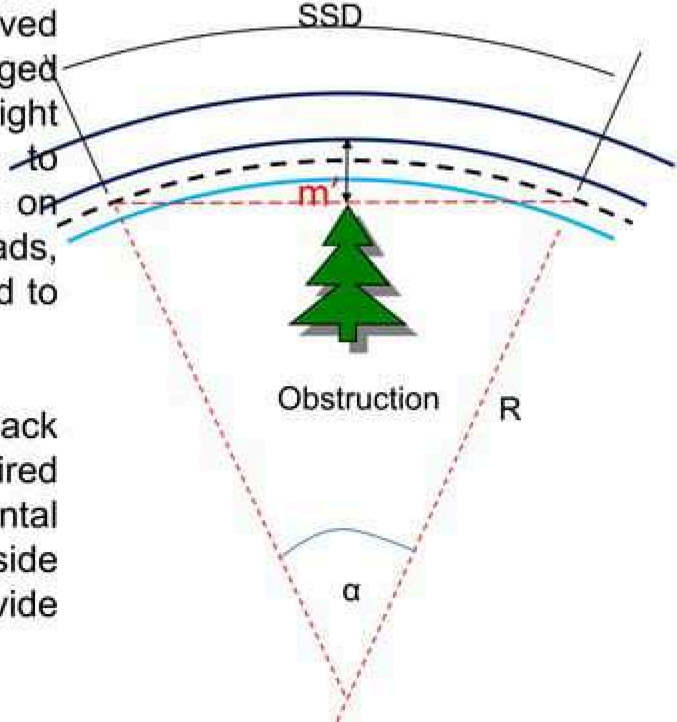
Example-2

- A national highway passing through rolling terrain in heavy rain fall area has a horizontal curve of radius 500 m. Design the length of transition curve using the fallowing data.
  - ✓ Design speed of vehicle= 80 kmph
  - ✓ Allowable rate of superelevation= 1 in 150
  - ✓ Pavement rotated about the inner edge of the pavment.
  - ✓ Pavement width excluding extra widening= 7 m.

Set-back distance on horizontal curve

Where there are sight obstruction like buildings, cut slope or trees on the inner sides of the curves, either the obstruction should be removed or the alignment should be changed in order to provide adequate sight distance. If it is not possible to provide adequate sight distance on the curves on existing roads, regulatory sign should be installed to control the traffic suitably.

clearance distance or set-back distance is the distance required from the centre line of a horizontal curve to an obstruct on the inner side of the of the curve to provide adequate sight distance



Case-I: if length of curve (Lc) > sight distance(S)

$$\boxed{m' = R - (R-d)\cos\frac{\alpha'}{2}}$$

$$\boxed{\frac{\alpha'}{2} = \frac{180S}{2\pi(R-d)}}$$

Where,
M' = set-back distance
d = the distance between the centre line of the road and the centre line of the inside lane in 'm'
R = radius of the curve in 'm'
α = angle subtended by the arc length 'S' at the centre

Case-II: if length of curve (Lc) < sight distance(S)

$$\boxed{m' = R - (R-d)\cos\frac{\alpha'}{2} + \frac{S - L_C}{2}\,Sin\frac{\alpha'}{2}}$$

$$\boxed{\frac{\alpha'}{2} = \frac{180 L_C}{2\pi(R-d)}}$$

Where ‘L_C’ is the length of curve and ‘S’ is the sight distance

Example-1:

- There is a horizontal curve of radius 400 m and length 200 m on this highway. Compute the set-back distance required from the centre line on the inner side of the curve so as to provide for
    - ✓ Stopping sight distance of 90 m
    - ✓ Safe overtaking distance of 300 m
    - ✓ Distance between the centre line of the road and the inner lane is 1.9 m.

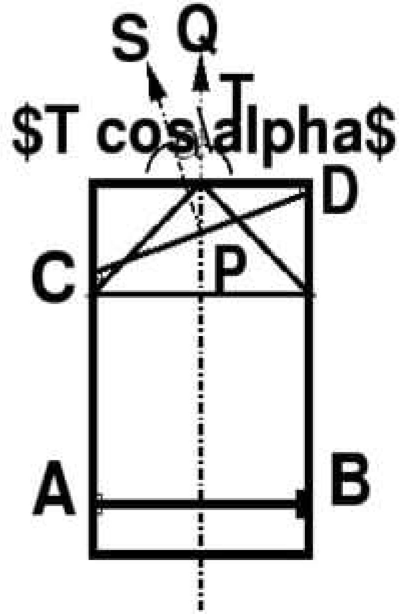
Example-2:

- A state highway passing through a rolling terrain has a horizontal curve of radius equal to the ruling minimum radius for a ruling design speed of 80 kmph. calculate the set-back distance required from the centre line on the inner side of the curve so as to provide for minimum SSD and ISD.

Curve resistance

The automobiles are steered by turning the front wheels, but the rear wheels do not turn. When a vehicle driven by rear wheels move on a horizontal curve, the direction of rotation of rear and front wheels are different and so there is some losses in the tractive froce.

thus the loss of tractive force due to turning of a vehicle on a horizontal curve , which is termed as curve resistance will be equal to (T- T cos α) or T (1-cos α) and will depend on turning angle α



Bibliography

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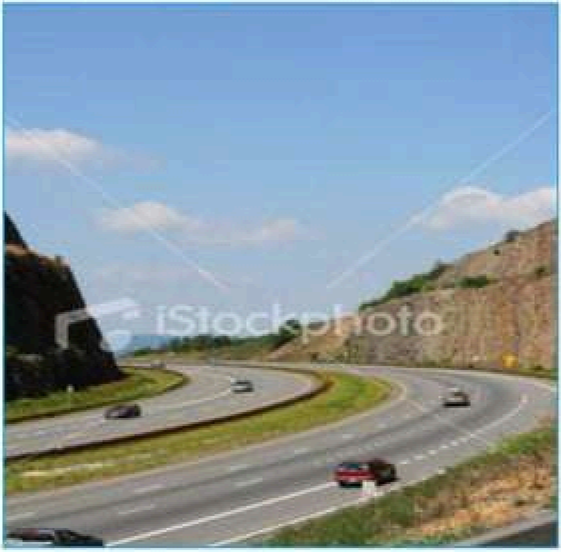
- *IRC Codes*.

Vertical alignment



The vertical alignment is the elevation or profile of the centre line of the road.

The vertical alignment consist of grade and vertical curve and it influence the vehicle speed, acceleration, sight distance and comfort in vehicle movements at high speed.

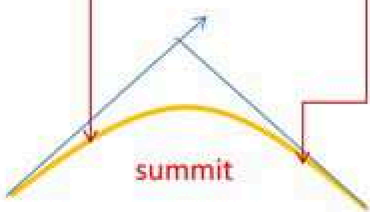
Gradient

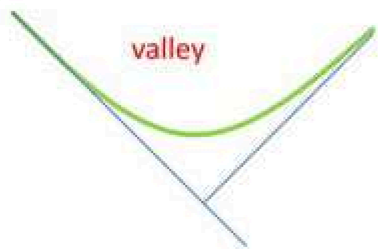
- It is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal unit). Some times the gradient is also expressed as a percentage i.e. n% (n in 100).

- Represented by:

+n % + 1 in X (+ve or Ascending)

or -n% - 1 in X (-ve or descending)





Typical Gradients (IRC)

- Ruling Gradient
- Limiting Gradient
- Exceptional gradient
- Minimum Gradient
- Ruling gradient (design gradient):
- It is the maximum gradient within which the designer attempts to design the vertical profile of road, it depends on
  - Type of terrain
  - Length of grade
  - Speed
  - Pulling power of vehicles
  - Presence of horizontal curves
  - Mixed traffic

Limiting Gradient:

- Steeper than ruling gradient. In hilly roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, it depends on
  - Topography
  - Cost in constructing the road

Exceptional Gradient:

- Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 m at a stretch.

critical length of the grade:

- The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, initial speed.

Minimum gradient

- This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains require some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions.
- A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains.

Value of gradient as per IRC

Terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and Rolling	3.3% (1 in 30)	5%	6.70%
Mountainous terrain	5% (1 in 20)	6%	7%
Steep terrain up to 3000m (MSL)	5% (1 in 20)	6%	7%
Steep terrain (>3000m)	6% (1 in 16.7)	7%	8%

SUMMIT CURVE

Length of summit curve(L) for SSD

- Case-1(L > SSD)

$$\boxed{L = \frac{NS^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2}} \quad \text{or} \quad \boxed{L = \frac{NS^2}{4.4}}$$

- Case-2(L < SSD)

$$\boxed{L = 2S - \frac{\left(\sqrt{2H} + \sqrt{2h}\right)^2}{N}} \quad \text{or} \quad \boxed{L = 2S - \frac{4.4}{N}}$$

length of summit curve for OSD

- Case-1(L > OSD)

$$\boxed{L = \frac{NS^2}{8H}} \quad \text{or} \quad \boxed{L = \frac{NS^2}{9.6}}$$

- Case-2(L < OSD)

$$\boxed{L = 2S - \frac{8H}{N}} \quad \text{or} \quad \boxed{L = 2S - \frac{9.6}{N}}$$

S=sight distance i.e. SSD, OSD or ISD
N= deviation angle
i.e. algebraic difference between two grade
H=height of driver eye above the carriageway i.e. 1.2 m
h=height of driver eye above the carriageway i.e. 0.15 m

VALLEY CURVE

Length of valley curve for comfort condition:

$$L = 2\left[\frac{N\left(\frac{V}{3.6}\right)^{3}}{C}\right]^{\frac{1}{2}}$$

OR

$$L = 0.38\left(NV^{3}\right)^{\frac{1}{2}}$$

N= deviation angle i.e. algebraic difference between two grade
C= rate of change of centrifugal acceleration may be taken as 0.6 m/sec³
V= speed of vehicle in kmph

Length of valley curve for head light sight distance

- Case-1(L > SSD)

$$L = \frac{NS^2}{(2h_1 + 2S\tan\alpha)}$$

OR

$$L = \frac{NS^2}{(1.5 + 0.035S)}$$

- Case-2(L < SSD)

$$L = 2S - \frac{(2h_1 + 2S\tan\alpha)}{N}$$

OR

$$L = 2S - \frac{(1.5 + 0.035S)}{N}$$

h1=height of head light above the carriesway
α= inclination of focused portion of the beam of light w.r.t horizontal or beam angle .
N= deviation angle i.e. algebraic difference between two grade.
S=head light distance is equal to SSD

Example -1

- A vertical summit curve is formed at the intersection of two gradient, +3% and -5%. Design the length of summit curve to provide a SSD for a design speed of 80 kmph. Assume any other data as per IRC.

Example-2

- A vertical summit curve is to be designed when two grades, +1/50 and -1/80 meet on a highway. The SSD and OSD required are 180 and 640 m respectively. But due to the site conditions the length of the vertical curve has to be restricted to a maximum value of 500 m if possible. Calculate the length of the summit curve needed to fulfil the requirements of SSD , OSD or atleast ISD.

Example-3

- A valley is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. design the length of valley curve to fulfill both comfort condition and head light distance requirements for a design speed of 80 kmph. Assume allowable rate of change of centrifugal acceleration is 0.6 m/sec3

Example-4

- An ascending gradient of 1 in 100 meets a descending gradient of 1 in 120. a summit curve is to be designed for a speed of 80 kmph so as to have an OSD of 470 m.

Grade compensation

- At the horizontal curve ,due to the turning angle α of the vehicle, the curve resistance develop is equal to T(1-Cos α). When there is a horizontal curve in addition to the gradient, there will be a increase in resistance to fraction due to both gradient and curve. It is necessary that in such cases the total resistance due to grade and the curve should not exceeded the resistance due to maximum value of the gradient specified.
- Maximum value generally taken as ruling gradient

Cont….

- Thus grade compensation can be defined as the reduction in gradient at the horizontal curve because of the additional tractive force required due to curve resistance (T−Tcosα), which is intended to offset the extra tractive force involved at the curve.
- IRC gave the following specification for the grade compensation.
    1. Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.
    2. Grade compensation is (30+R)/R %, where 'R' is the radius of the horizontal curve in meters.
    3. The maximum grade compensation is limited to 75/R%.

Example-1

- While aligning a hilly road with a ruling gradient of 6%, a horizontal curve of radius 60 m is encountered. Fond the compensated gradient at the curve.

Bibliography

- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros*.
- *IRC Codes*.

PAVEMENT

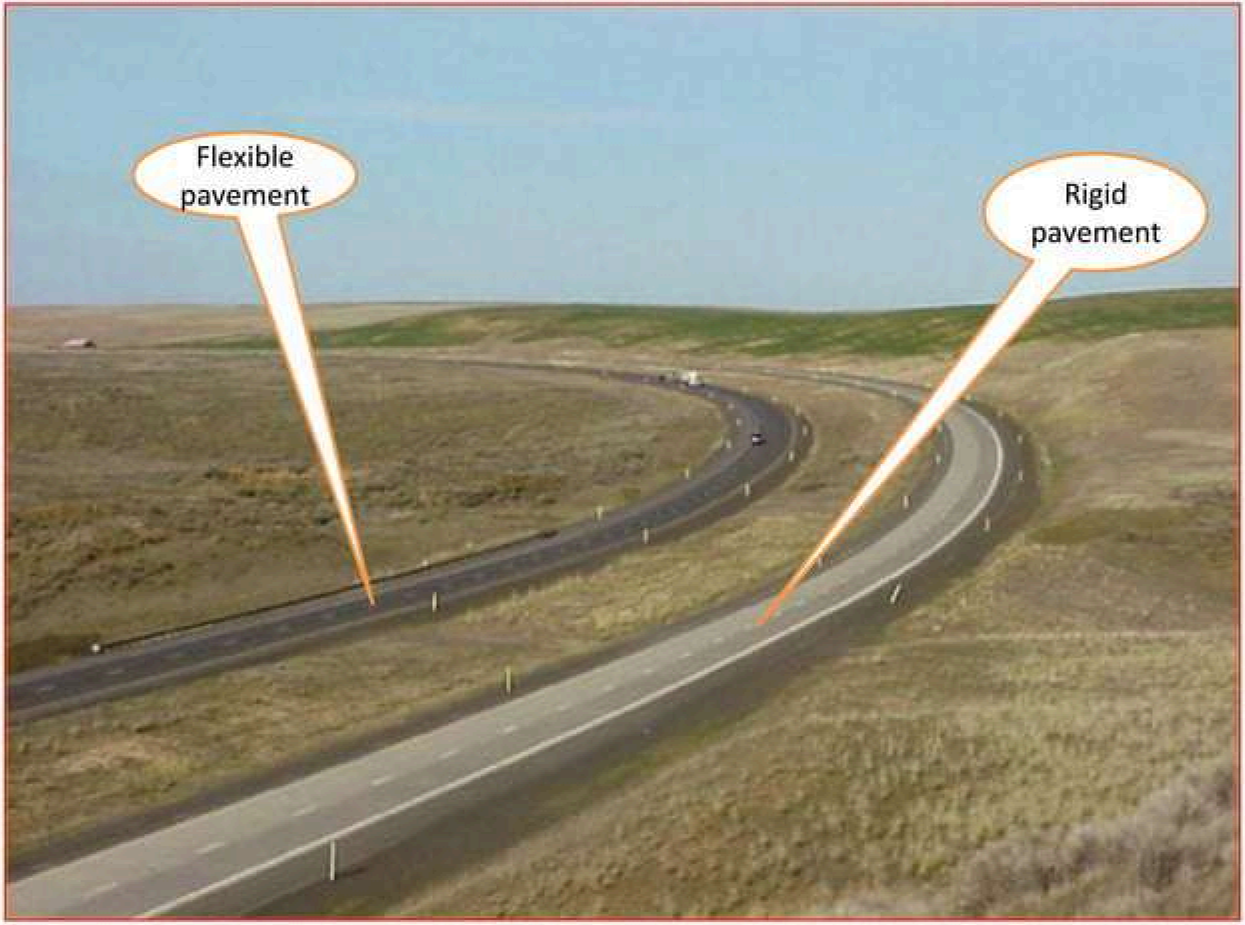
- **pavement** is the durable surface material laid down on an area intended to sustain vehicular load or foot traffic, such as a road or walkway.
- It is of two types
  - Flexible pavement or bituminous pavement or black top pavement
  - Rigid pavement or cement concrete pavement or white surface pavement

COMPARISON OF FLEXIBLE PAVEMENT & RIGID PAVEMENT

FLEXIBLE PAVEMENT	RIGID PAVEMENT
1. Have low flexural strength	1. Have more flexural strength
2. Load is transferred by grain to grain contact	2. No such phenomenon of grain to grain load transfer exists
3. Surfacing cannot be laid directly on the sub grade but a sub base is needed	3. Surfacing can be directly laid on the sub grade
4. No thermal stresses are induced	4. Thermal stresses are induced
5. expansion joints are not needed	5. expansion joints are needed
6. Design life 10-15 years	6. Design life 20-30 years
7. Initial cost of construction is low	7. Initial cost of construction is high
8. Maintenance cost is high	8. Less maintenance cost
9. Road can be used for traffic within 24 hours	9. Road cannot be used until 14 days of curing
10. Damaged by Oils and Certain Chemicals	10. No Damage by Oils and other chemicals


Rigid
Pavement


Flexible
pavement


Flexible pavement
Rigid pavement

Requirements of a pavement

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil.
- Structurally strong to withstand all types of stresses imposed upon it.
- Adequate coefficient of friction to prevent skidding of vehicles.
- Smooth surface to provide comfort to road users even at high speed.
- Produce least noise from moving vehicles.
- Dust proof surface so that traffic safety is not impaired by reducing visibility.
- Impervious surface, so that sub-grade soil is well protected.
- Long design life with low maintenance cost.

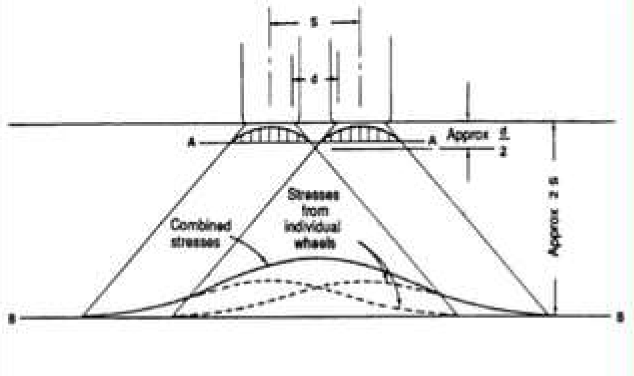


Figure 5-3. Distribution of pressures produced by multiple-wheel assemblies

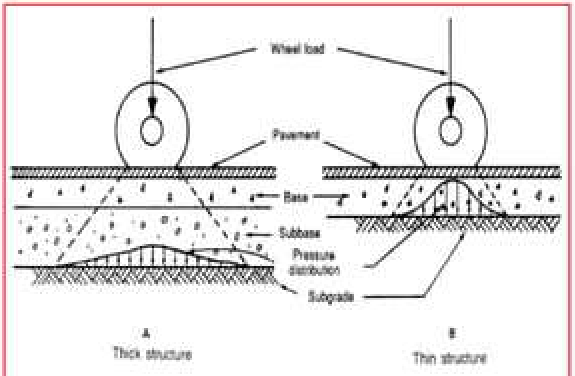
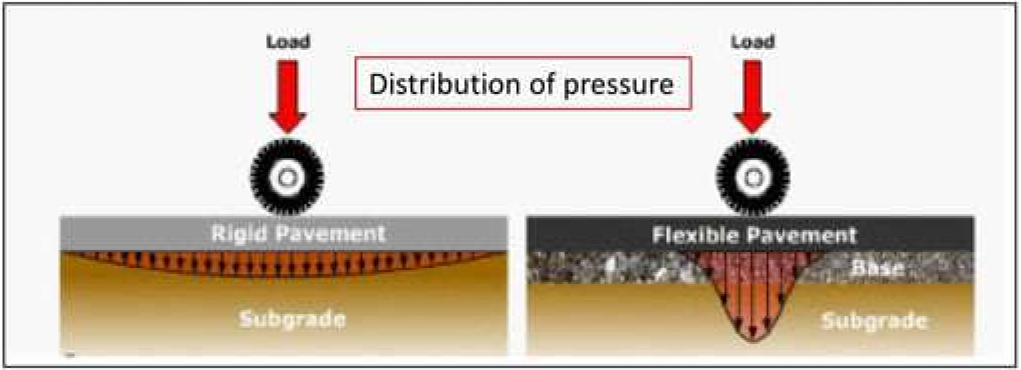


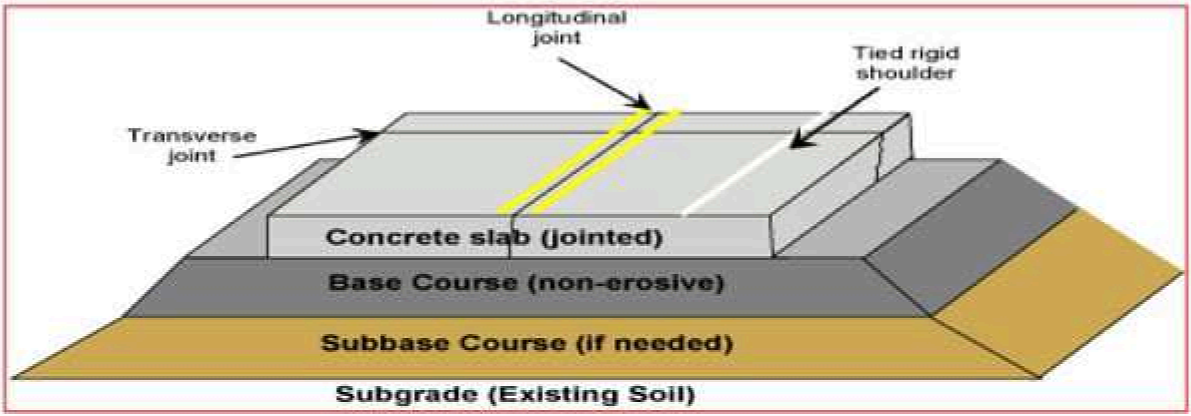
Figure 5-2. Distribution of pressures under single-wheel loads



Types of flexible pavements

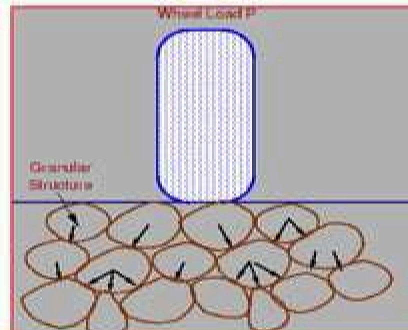
- Conventional layered flexible pavement
- Full - depth asphalt pavement
- Contained rock asphalt mat (CRAM).
- **Conventional flexible pavements** are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.
- **Full - depth asphalt pavements** are constructed by placing bituminous layers directly on the soil sub-grade. This is more suitable when there is high traffic and local materials are not available.
- **Contained rock asphalt mats** are constructed by placing dense/open graded aggregate layers in between two asphalt layers.

c/s of flexible pavement



c/s of rigid pavement

c/s of flexible pavement



Load is transferred by grain to grain contact

Typical layers of a flexible pavement

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance and to seal the surfacing against the ingress of water.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course.it is generally applied on impervious surface.

Prime Coat: Prime coat is an application of low viscous liquide bituminous material over an existing porous or absorbent pavement surface like WBM.

- Prime objective is to plug the capillary voids of the porous surface and to bond the loose materials on the existing surface like granular bases on which binder layer is placed. It provides bonding between two layers.


Prime coat
Seal coat

Typical layers of a flexible pavement

Surface course:

- Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).
- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It provide a smooth and skid- resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Typical layers of a flexible pavement

Binder course:

- This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course.
- The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course:

- The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone and other untreated or stabilized materials.

Typical layers of a flexible pavement

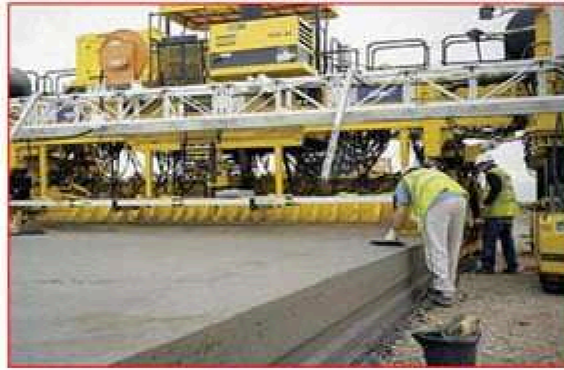
- **Sub-Base course:** The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage.
- It may WBM or WMM
- A sub-base course is not always needed or used. For example, a pavement constructed over a high quality.
- **Sub-grade**: The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed.
- It should be compacted to the desirable density, near the optimum moisture content.

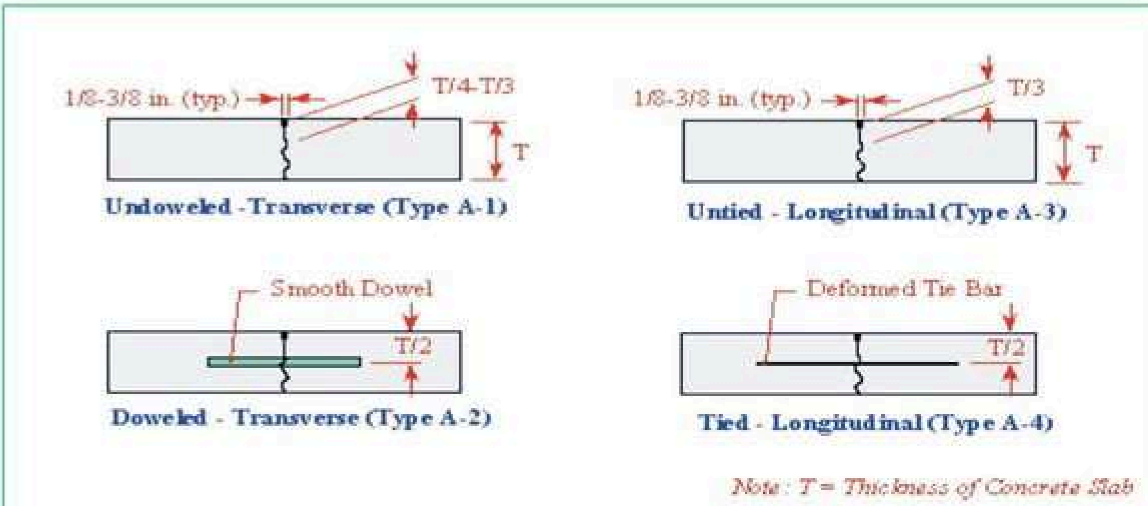
Types of Rigid Pavements

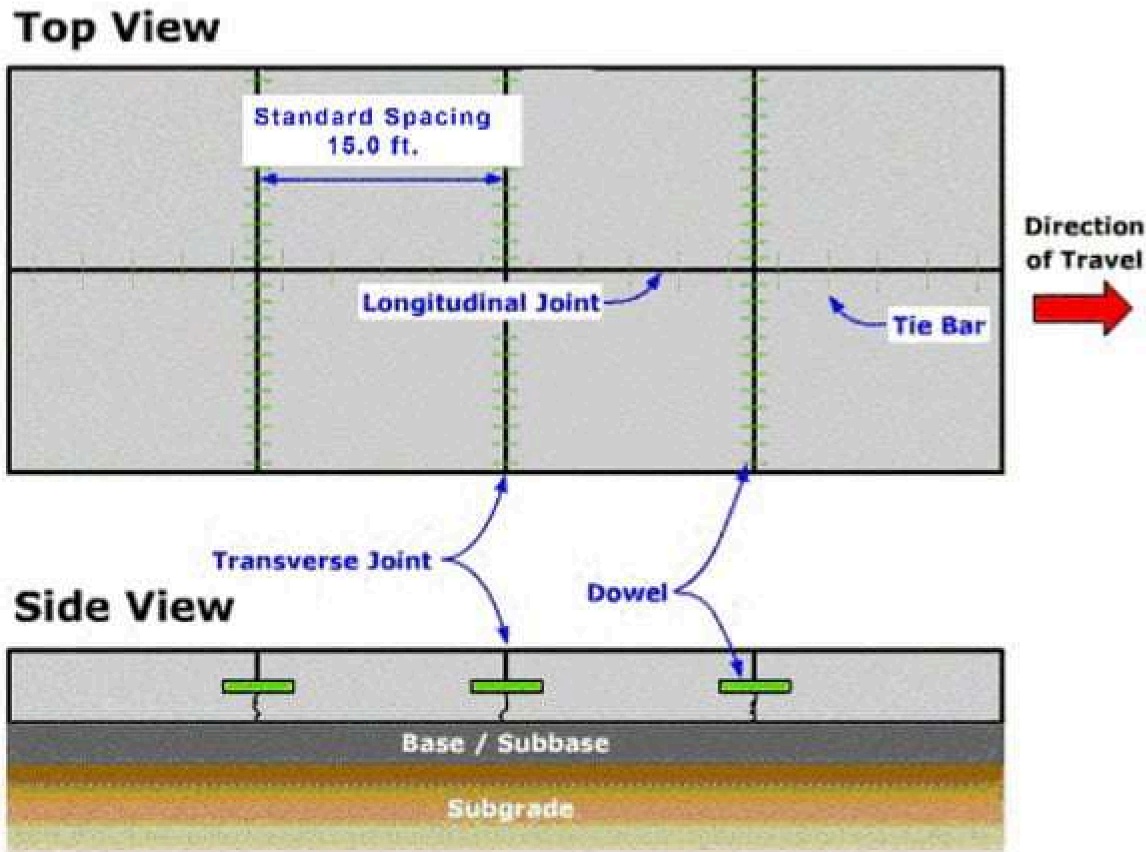
- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP)
- Pre-stressed concrete pavement (PCP).

Types of Rigid Pavements

- **Jointed Plain Concrete Pavement:** constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally has a joint spacing of 5 to 10m.
- **Jointed Reinforced Concrete Pavement**: reinforcements do not improve the structural capacity significantly but they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcements help to keep the slab together even after cracks.
- **Continuous Reinforced Concrete Pavement:** Complete elimination of joints are achieved by reinforcement.




1/8-3/8 in. (typ.)
T/4-T/3
T
Undoweled - Transverse (Type A-1)
1/8-3/8 in. (typ.)
T/3
T
Untied - Longitudinal (Type A-3)
Smooth Dowel
T/2
Doweled - Transverse (Type A-2)
Deformed Tie Bar
T/2
Tied - Longitudinal (Type A-4)
Note : T = Thickness of Concrete Slab



Top View
Standard Spacing
15.0 ft.
Direction
of Travel
Longitudinal Joint
Tie Bar
Transverse Joint
Dowel
Side View
Base / Subbase
Subgrade


Rigid pavement
Longitudinal joint
Transverse joint

Granular materials

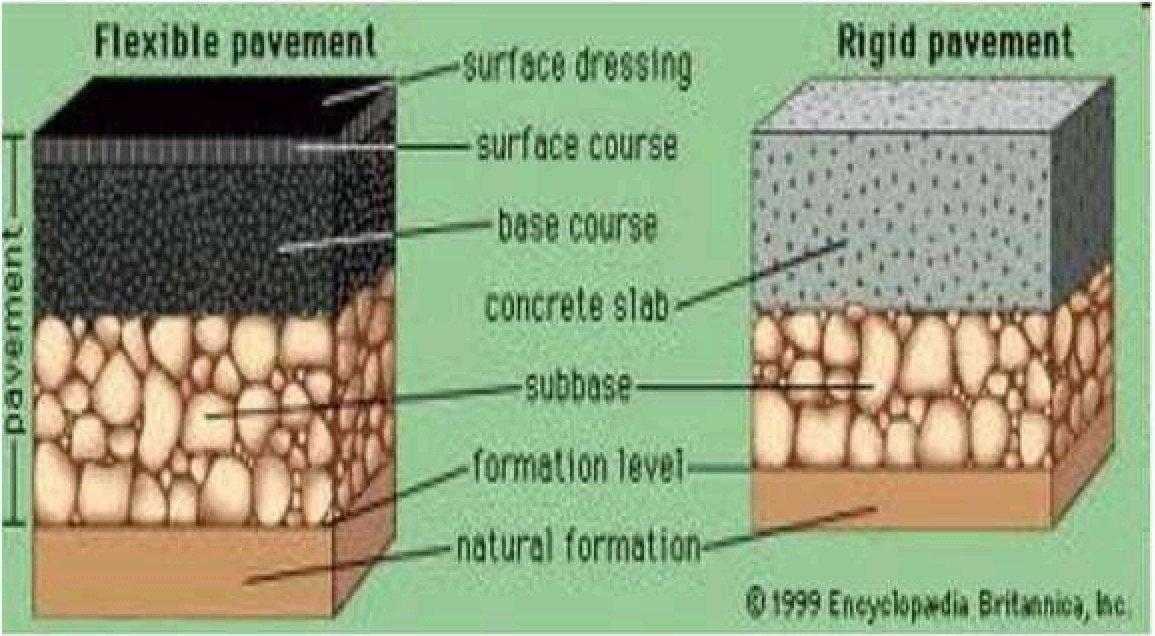
Bibliography

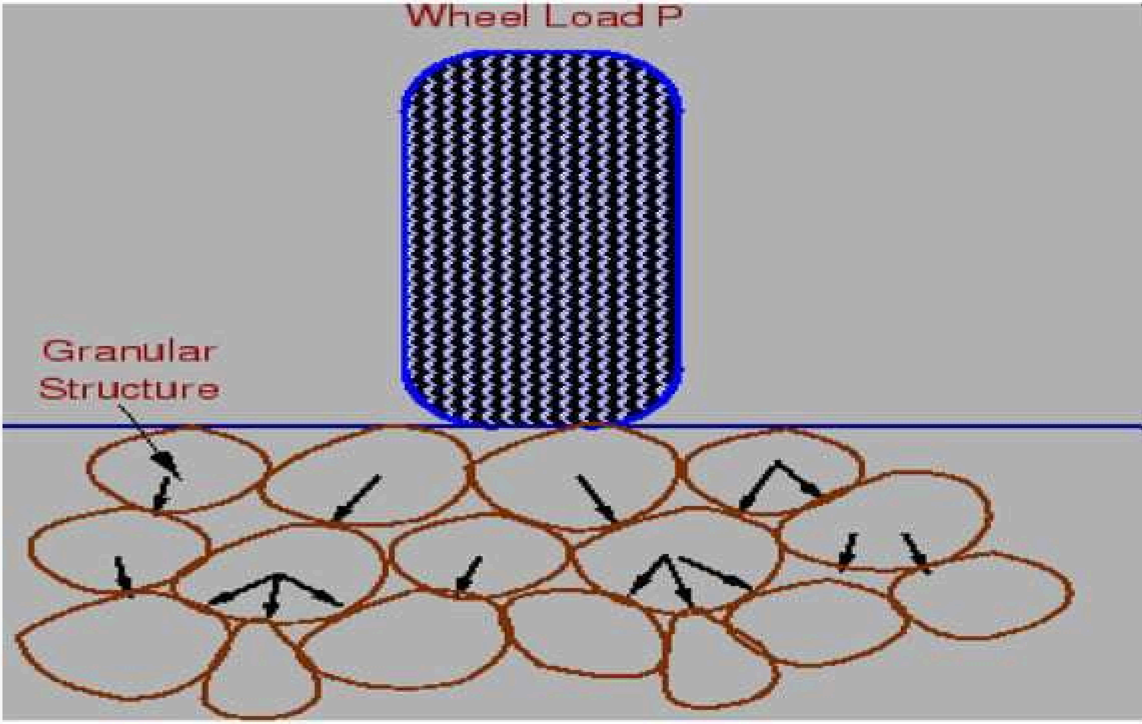
- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros*.
- *IRC Codes*.

FLEXIBLE PAVEMENT

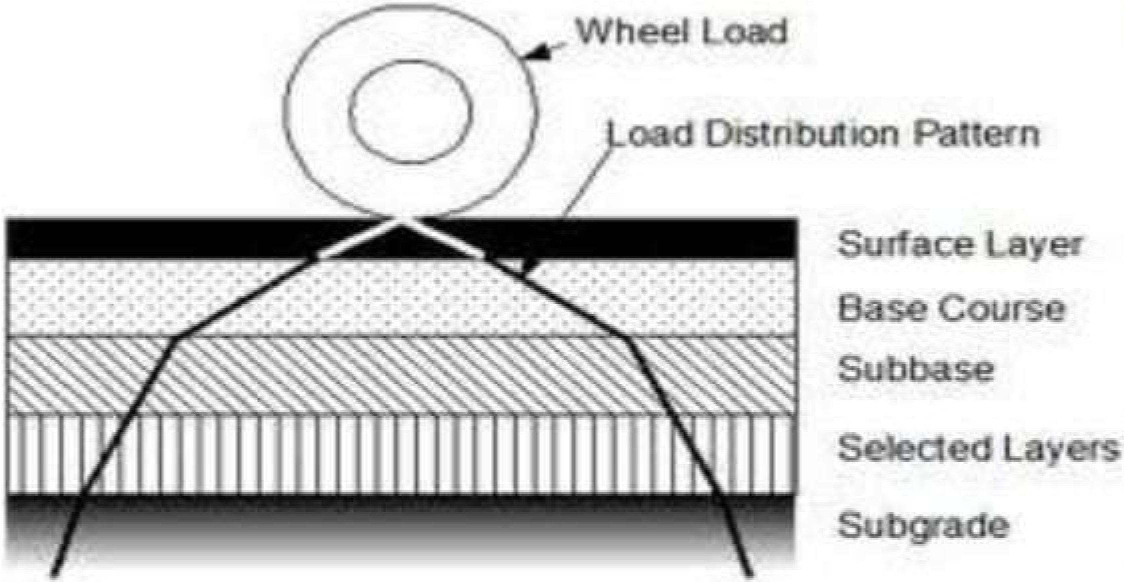
RIGID PAVEMENT

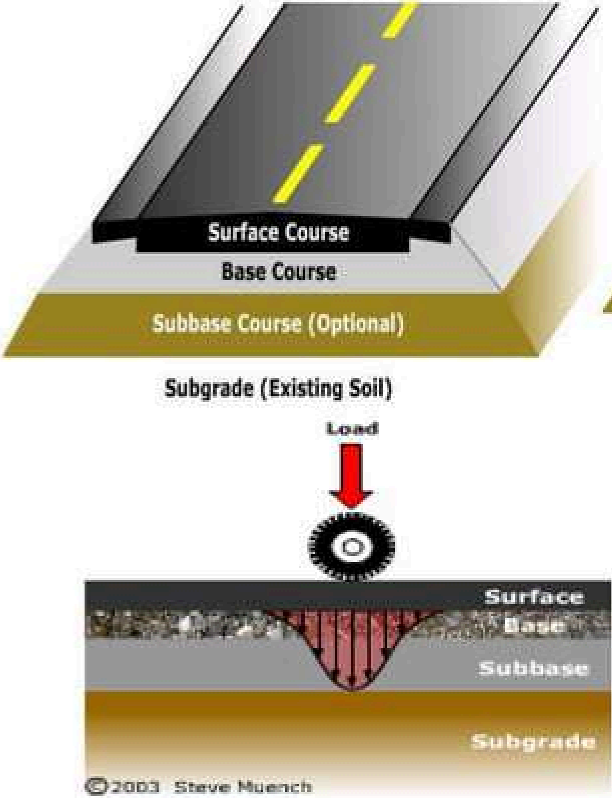
Types of Pavements



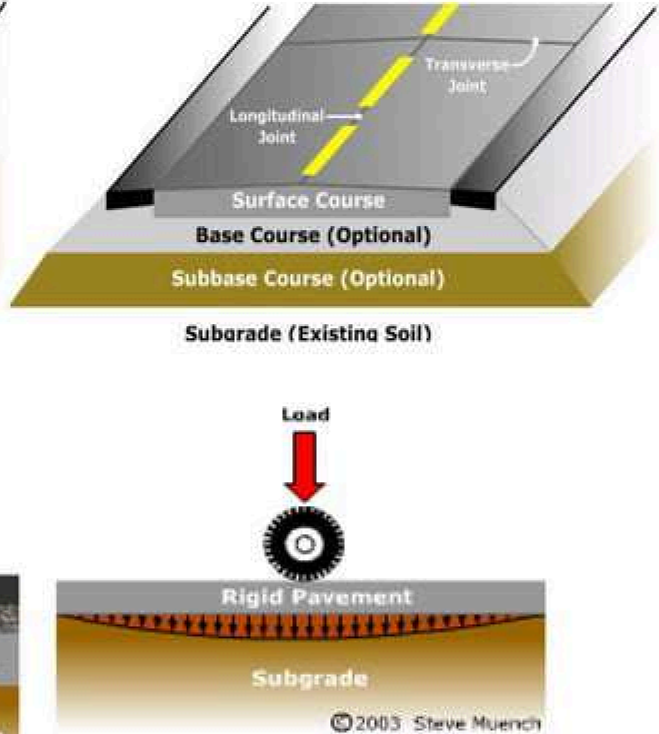

Wheel Load P
Granular
Structure

Wheel Load Distribution



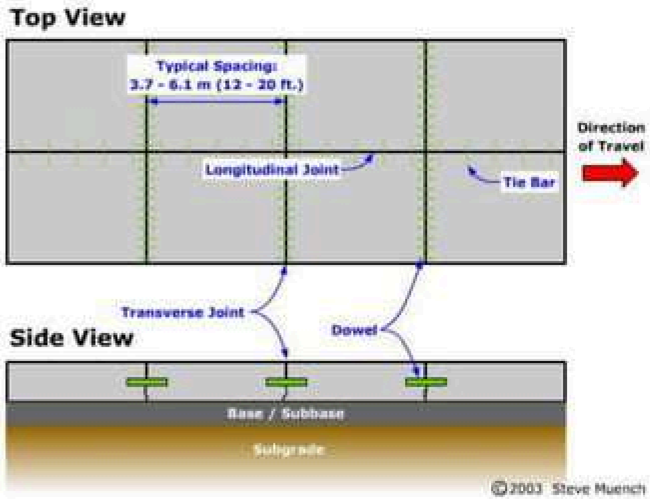


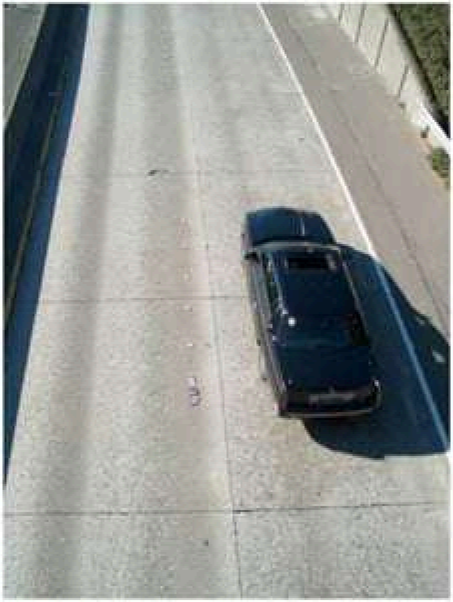
Flexible



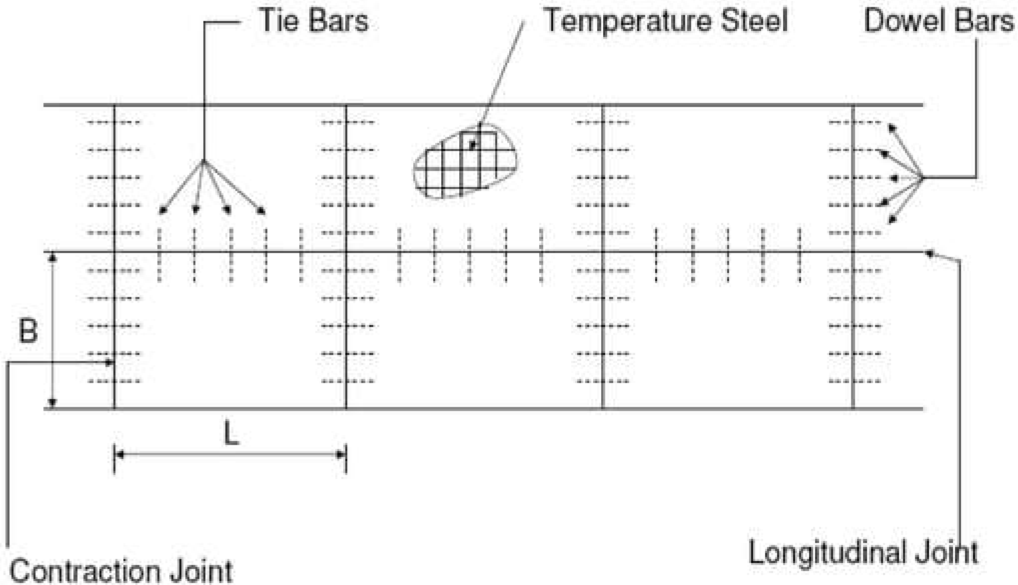
Rigid

- Jointed Plain Concrete Pavement (JPCP)





Jointed CC Pavement



LOAD DISTRIBUTION

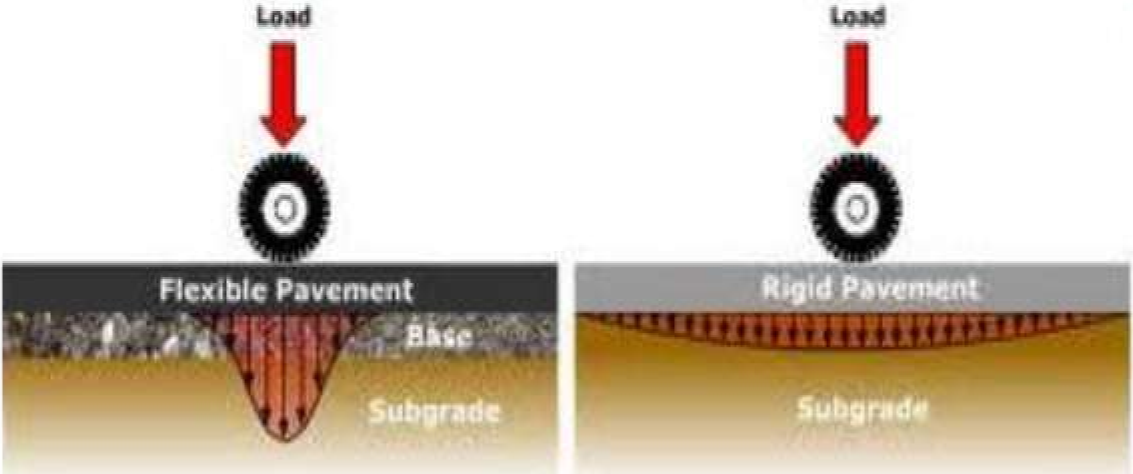
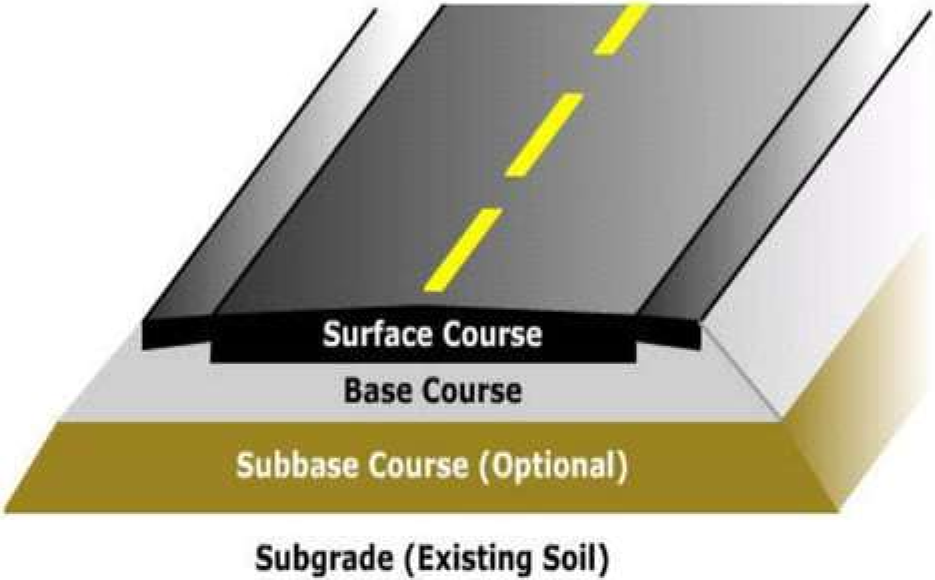


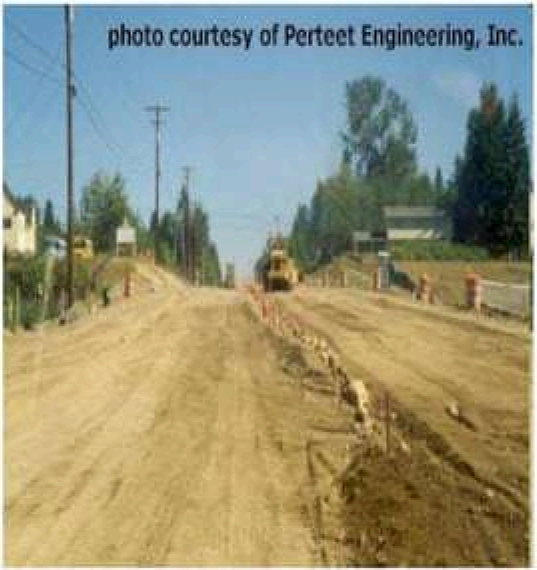
Figure 1: Rigid and Flexible Pavement Load Distribution

Components of Flexible Pavement



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.



Flexible Pavement Design

IRC (37-2001)

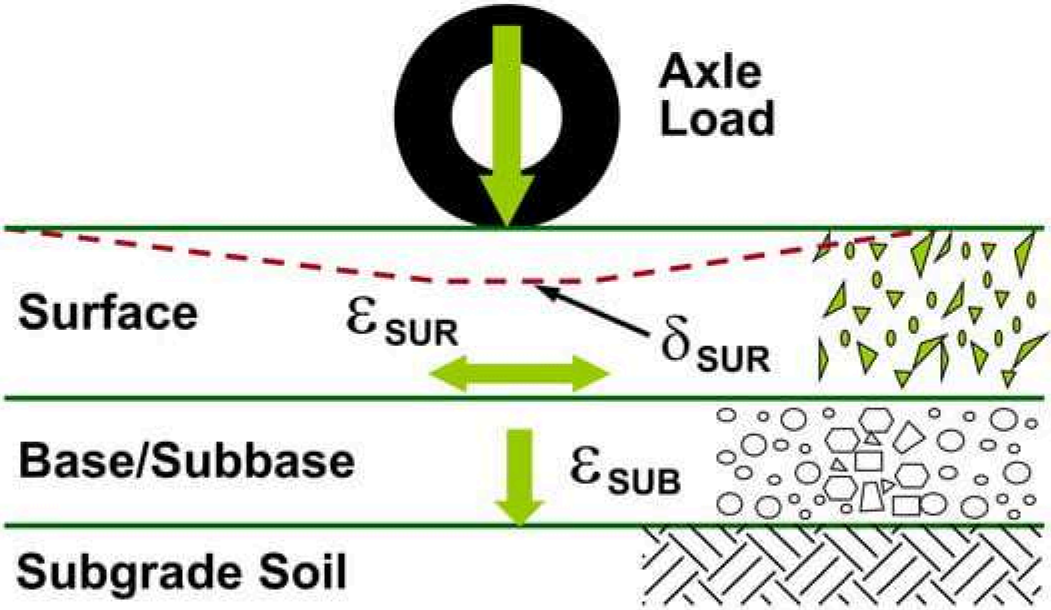
Basic Principles

- Vertical stress or strain on sub-grade
- Tensile stress or strain on surface course

Factors for design of pavements

- Design wheel load
  - Static load on wheels
  - Contact Pressure
  - Load Repetition
- Subgrade soil
  - Thickness of pavement required
  - Stress- strain behavior under load
  - Moisture variation
- Climatic factors:(rain fall)
- Pavement component materials
- Environment factors:(height of embankment and its detailed)
- Traffic Characteristics
- Required Cross sectional elements of the alignment

Pavement Responses Under Load

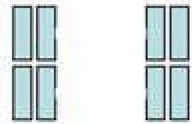


Axle Configurations

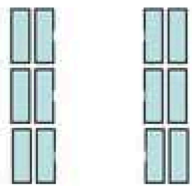
An **axle** is a central shaft for a rotating wheel or gear

Single Axle With Single Wheel
(Legal Axle Load = 6t)

Single Axle With Dual Wheel
(Legal Axle Load = 10t)

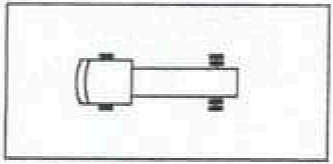


Tandem Axle
(Legal Axle Load = 18t)

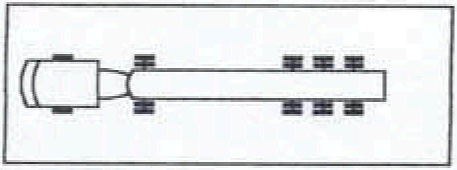


Tridem Axle
(Legal Axle Load = 24t)

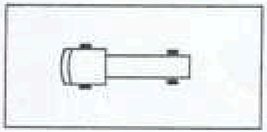
Truck Configuration



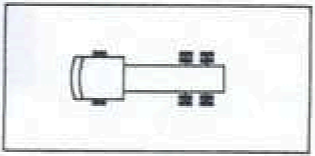
2 Axle Truck – 16t



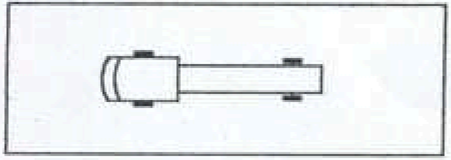
5 Axle Truck – 40t



LCV



3 Axle Truck – 24t



4 Axle Semi Articulated – 34t

Standard Axle

Single axle with dual wheels carrying a load of 80 kN (8 tonnes) is defined as standard axle

80 kN

Standard Axle

Evaluation Of Pavement Component Layers

- **Sub-grade**
  - **To Receive Layers of Pavement Materials Placed over it**
  - **Plate Bearing Test**
  - **CBR Test**
  - **Triaxial Compression**

Flexible Pavement Design Using CBR Value Of Sub-grade Soil

- California State Highways Department Method
- Required data
  - Design Traffic in terms of cumulative number of standard axles(CSA)
  - CBR value of subgarde

Traffic Data

- ➢ Initial data in terms of number of commercial vehicles per day (CVPD).

- ➢ Traffic growth rate during design life in %
- ➢ Design life in number of years.

- ➢ Distribution of commercial vehicles over the carriage way

Traffic – In Terms Of CSA (8160 Kg) During Design Life

- **Initial Traffic**
  - ➢ **In terms of Cumulative Vehicles/day**
  - ➢ **Based on 7 days 24 hours Classified Traffic**
- **Traffic Growth Rate**

  - ➢ **7.5 % may be Assumed**

Design Life

- National Highways – 15 Years
- Expressways and Urban Roads – 20 Years
- Other Category Roads – 10 – 15 Years

Vehicle Damage Factor (VDF)

- **Multiplier to Convert No. of Commercial Vehicles of Different Axle Loads and Axle Configurations to the Number of Standard Axle Load Repetitions indicate VDF Values**

- **Normally = $(\text{Axle Load}/8.2)^n$**

  $n = 4 - 5$

INDICATIVE VDF VALUES

Initial Traffic in terms of CV/PD	Terrain	
	Plain/Rolling	Hilly
0 – 150	1.5	0.5
150 – 1500	3.5	1.5
> 1500	4.5	2.5

Distribution Of Traffic

Single Lane Roads:

→ Total No. of Commercial Vehicles in both Directions

Two-lane Single Carriageway Roads:

→ 75% of total No. of Commercial Vehicles in both Directions

Four-lane Single Carriageway Roads:

→ 40% of the total No. of Commercial Vehicles in both Directions

Dual Carriageway Roads:

→ for two lane dual carriage way75% of the No. of Commercial Vehicles in each Direction

→For three lane-60%

→For four lane-45%

Computation of Traffic for Use of Pavement Thickness Design Chart

$$N = \frac{365 \times A[(1+r)^n - 1]}{r} \times D \times F$$

N = Cumulative No. of standard axles to be catered for the design in terms of msa

D = Lane distribution factor

A = Initial traffic, in the year of completion of construction, in terms of number of commercial vehicles per day

$=p(1-r)^x$

P=no. of commercial vehicle as per last count

X=no. of year between the last count and the year of completion of construction

F = Vehicle Damage Factor

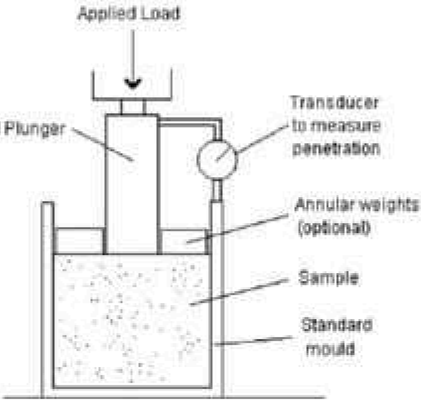
n = Design life in years

r = Annual growth rate of commercial vehicles

CBR Testing Mach

Definition:

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

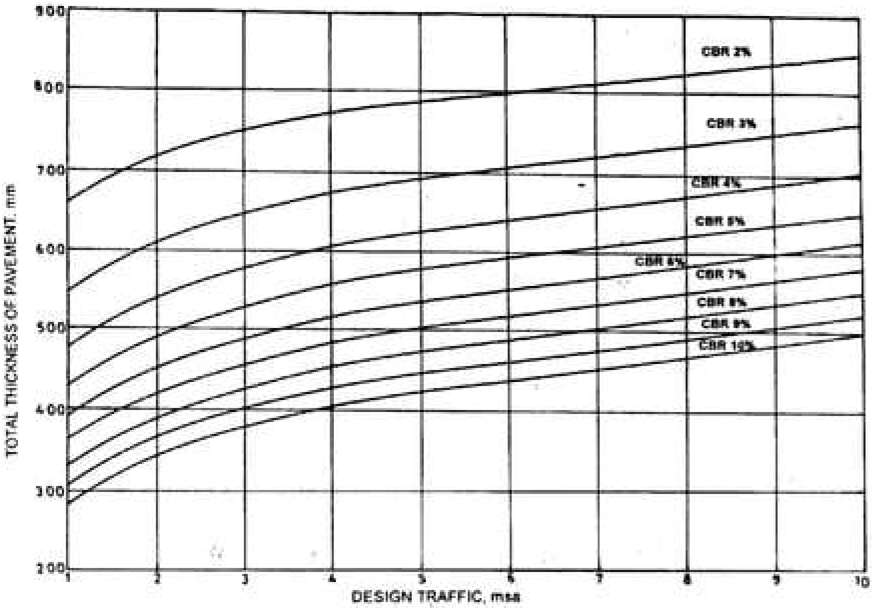


Subgrade

- Soak the Specimen in Water for FOUR days and CBR to be Determined.
- Use of Expansive Clays NOT to be Used as Sub-grade
- Non-expansive Soil to be Preferred.

Subgrade

- **Subgrade to be Well Compacted to Utilize its Full Strength**
- **Top 500 mm to be Compacted to 97% of MDD (Modified Proctor).**
- **Material Should Have a Dry Density of 1.75 gm/cc.**



Pavement Thickness Design Chart for Traffic 1-10 msa

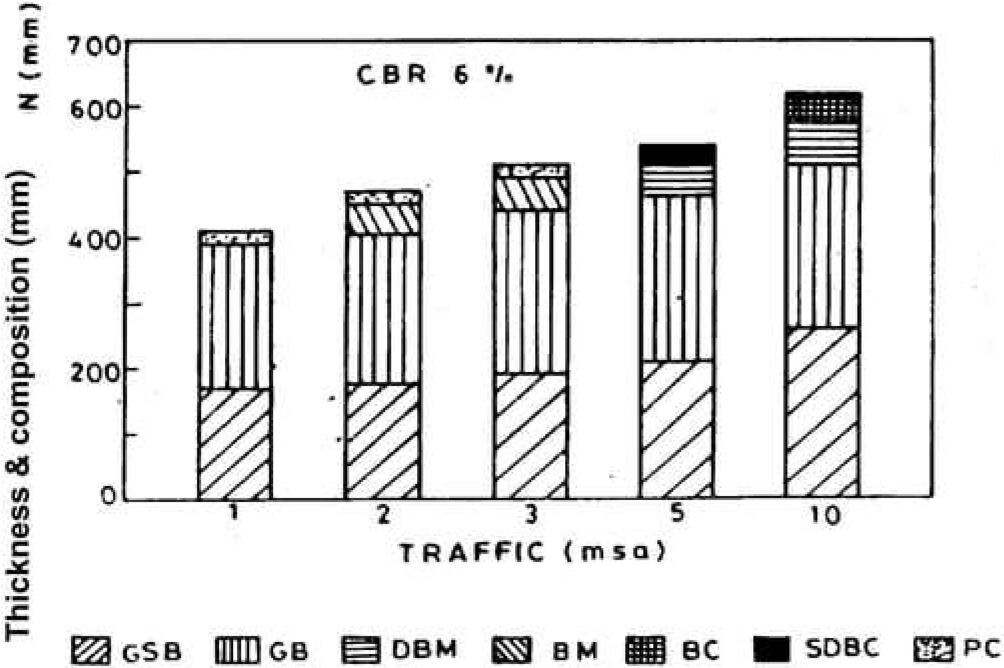
Flexible pavement design chart (IRC) (for CSA< 10 msa)

PAVEMENT DESIGN CATALOGUE

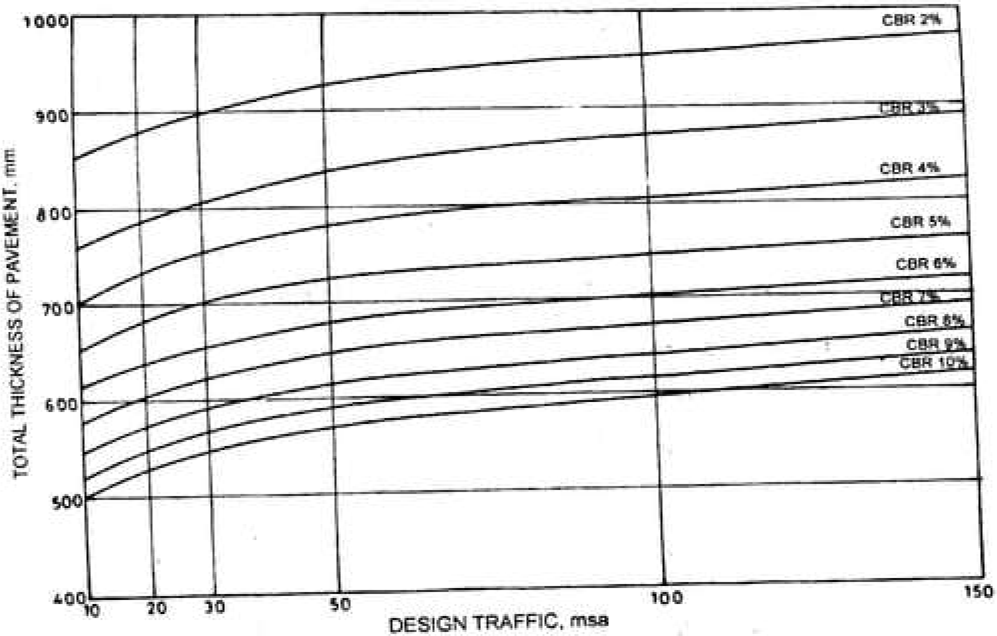
RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 6%					
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)
		Wearing Course (mm)	Binder Course (mm)		
1	390	20 PC		225	165
2	450	20 PC	50 BM	225	175
3	490	20 PC	50 BM	250	190
5	535	25 SDBC	50 DBM	250	210
10	615	40 BC	65 DBM	250	260

Flexible Pavement Layers (IRC) (CSA< 10 msa)



Flexible Pavement Layers (IRC) (CSA< 10 msa)



Pavement Thickness Design Chart for Traffic 10-150 msa

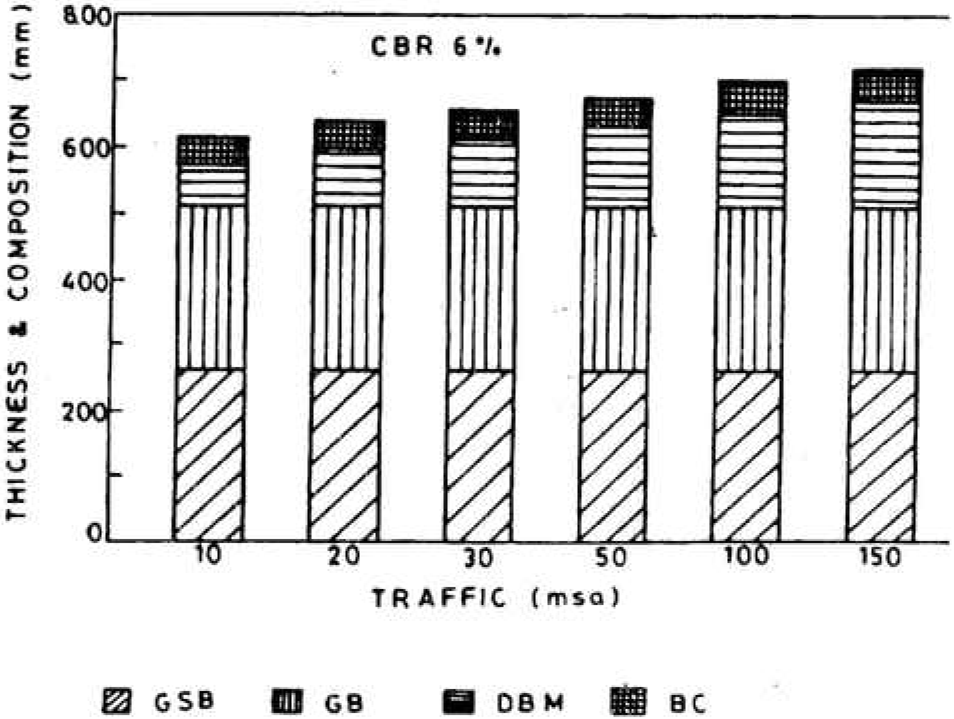
Flexible pavement design chart (IRC)

PAVEMENT DESIGN CATALOGUE

RECOMMENDED DESIGNS FOR TRAFFIC RANGE 10-150 msa

CBR 6%				
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION		
		Bituminous Surfacing		Granular Base & Sub-base (mm)
		BC (mm)	DBM (mm)	
10	615	40	65	Base = 250 Sub-base = 260
20	640	40	90	
30	655	40	105	
50	675	40	125	
100	700	50	140	
150	720	50	160	

Flexible pavement layers (IRC)



Flexible pavement layers (IRC)

Sub-base

- **Material – Natural Sand, Moorum, Gravel, Laterite, Kankar, Brick Metal, Crushed Stone, Crushed Slag, Crushed Concrete**
- **GSB- Close Graded / Coarse Graded**
- **Parameters – Gradation, LL, PI, CBR**
- **Stability and Drainage Requirements**

Sub-base

- **Min. CBR 20 % - Traffic up-to 2 msa**
- **Min. CBR 30 %- Traffic > 2 msa**
- **If GSB is Costly, Adopt WBM, WMM**
- **Min. Thickness – 150 mm - <10 msa**
- **Min. Thickness – 200 mm - >10 msa**

Sub-base

- Min. CBR – 2 %
- If CBR < 2% - Pavement Thickness for 2 % CBR + Capping layer of 150 mm with Min. CBR 10% (in addition to the Sub-Base)
- In case of Stage Construction – Thickness of GSB for Full Design Life

Base Course

- Unbound Granular Bases – WBM / WMM or any other Granular Construction
- Min. Thickness – 225 mm – < 2 msa
- Min. Thickness – 250 mm - > 2 msa
- WBM – Min. 300 mm (4 layers – 75mm each)

Example-1

- Design the pavement for construction of a new bypass with the fallowing data:

  - ✓ **Two lane single carriage way**
  - ✓ **Initial traffic in a year of completion of construction work**

    (sum of both directions) = 400 CVPD
  - ✓ **Traffic growth rate per annum = 7.5 percent**
  - ✓ **Design life = 15 years**
  - ✓ **Vehicle damage factor = 2.5**

    (standard axles per commercial vehicle)
  - ✓ **Design CBR value of sub-grade soil = 4 %**

Example-2

- Design the flexible pavement For Widening An Existing 2-lane NH-5 To 4-lane Divided Road

  ✓ **4-lane divided carriageway**

  ✓ **Initial traffic in a year of commencement of construction work (sum of both directions) = 5600CVPD**

  ✓ **Completion of construction work=2.5 years**

  ✓ **Design life= 10/15yrs**

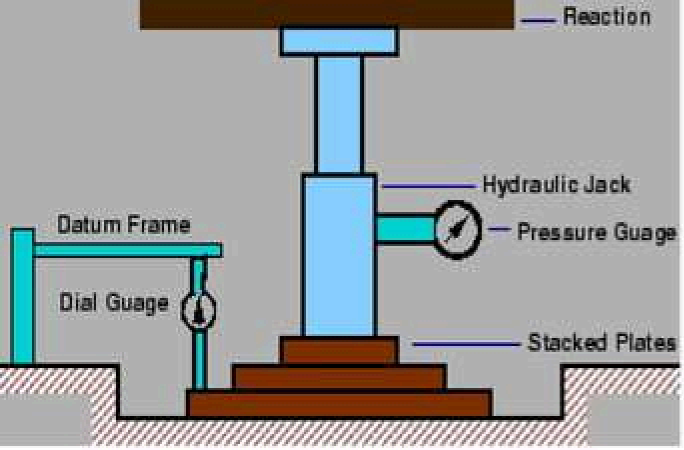
  ✓ **Design CBR of sub-grade soil = 5 %**

  ✓ **Traffic growth rate = 8 %**

  ✓ **Vehicle damage factor = 4.5 (Found out from axle road survey axles per CV on existing road)**

Design of rigid pavement as per IRC-58:2002

- Stress acting on the rigid pavement are:
- Wheel load stress
  - ✓Interior loading
  - ✓Edge loading
  - ✓Corner loading
- Temperature stress
  - ✓Warping stress
  - ✓Frictional stress


Reaction
Hydraulic Jack
Datum Frame
Pressure Guage
Dial Guage
Stacked Plates

Radius of relative stiffness:

$$\boxed{l = \left[\frac{Eh^3}{12k\left(1-\mu^2\right)}\right]^{\frac{1}{4}}}$$

- Where
- l= Radius of relative stiffness
- E= modulus of elasticity of cement concrete , kg/cm^2
- μ= poisson's ratio for concrete= 0.15
- h= slab thickness, cm
- K= modulus of subgrade reaction, kg/cm^3

Westergaard's stress equation for wheel load

- Stress at the interior(s_i)

$$s_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right)+1.069\right]$$

- Stress at the edge (s_e)

$$s_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right)+0.359\right]$$

- Stress at the corner (s_c)

$$s_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

Where,

- P= design wheel load, kg
- l= Radius of relative stiffness
- E= modulus of elasticity of cement concrete , kg/cm^2
- μ= poisson's ratio for concrete= 0.15
- h= slab thickness, cm
- K= modulus of subgrade reaction, kg/cm^3
- b= radius of equivalent distribution of pressure, cm
  - ➢ b=a , if $a/h \geq 1.724$
  - ➢ $b= \sqrt{(1.6\, a^2+h^2)} - 0.675\, h$, when $a/h < 1.724$
- a= radius of load contact, cm

Modified Westergaard's stress equation for wheel load

- Modified by '*Teller*'

$$\boxed{s_e = \frac{0.572P}{h^2}(1+0.54\mu)\times\left(4\log_{10}\left(\frac{l}{b}\right)+\log_{10}b-0.4048\right)}$$

- Modified by '*Kelley*'

$$\boxed{s_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]}$$

Warping stress(given by '*Bradbury*')

- Stress at the interior(st_i)

$$\boxed{st_i = \frac{Eet}{2}\left[\frac{c_x + \mu c_y}{1-\mu^2}\right]}$$

- Stress at the edge (st_e)

$$\boxed{st_e = \frac{C_x Eet}{2}} \quad \text{Or} \quad \boxed{st_e = \frac{C_y Eet}{2}}$$

Whichever is higher

- Stress at the corner (st_c)

$$\boxed{st_c = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}}$$

Where,

- E= modulus of elasticity of cement concrete , kg/cm^2
- e= thermal coefficient of concrete per ^{o}C
- t= temperature difference between the top and bottom of the slab in degree C
- μ= poisson's ratio for concrete= 0.15
- Cx = Bradbury coefficient based on L/l in desire direction (IRC-58:2002)
- Cy = Bradbury coefficient based on B/l in right angle to the desire direction (IRC-58:2002)
- L = length of slab, m
- B= width of slab, m

Frictional stress

- Frictional stress(s_f)

$$\boxed{s_f = \frac{WLf}{2\times10^4}}$$

- Where,
- s_f = unit stress developed in CC pavement, kg/cm²
- W= unit wt. of concrete, (about 2400 kg/cm²)
- L= length of slab, m
- B= width of slab, m

Example-1

- Calculate the stress at interior, edge and corner regions of a cement concrete pavement using westergaard's equation. Use the fallowing data
    - ✓ Wheel load, P=5100kg
    - ✓ Modulus of elasticity of concrete, E=3.0x10^5 kg/cm^2
    - ✓ Pavement thickness, h=18cm
    - ✓ Poisson's ratio=0.15
    - ✓ Modulus of subgrade reaction=6.0 kg/cm3
    - ✓ Radius of contact area=15 cm

Example-2

- Compute the radius of relative stiffness of 15 cm thick cement concrete slab from the fallowing data
    - E=21000kg/cm2
    - Poisson's ratio=0.13
    - K=3KG/cm2 or 7.5 kg/cm2

Example-3

- Determine the warping stress at interior, edge and corner regions in a 25 cm thick cement concrete pavement with transverse joint at 9 m interval and longitudinal joint at 3.6 m intervals. The modulus of subgrade reaction is 6.9 kg/cm² . Assume temperature difference for day condition to be 0.6°c per cm of the slab thickness. Assume radius of loded area as 15 cm for computing warping stress at the corner.
- E= 3 x 10^5 kg/cm²
- e= 10 x 10^ -6 per °c
- μ= 0.15

Example-4

- A CC pavement slab thickness 20cm is constructed over a granular subbase having modulus of subgrade reaction 15 kg/cm^2. the maximum temperature difference between the top and bottom of the slab during summer day and night is found to be 18°c. The spacing between the transverse contraction joint is 4.5 m and that between the longitudinal joint is 3.5 m. the design wheel load is 5100 kg, radius of contact area is 15 cm. the coefficient of thermal expansion of CC IS 10x10^-6 per °c and friction coefficient is 1.5.calculate the warping stress at edge,interior ,corner and also calculate the friction stress.
- $E= 3x10^5 \ kg/cm^2$
- $\mu=0.15$

Bibliography

- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros.*
- *IRC Codes.*

Traffic Engineering

- It is the science of measuring traffic and travel, the study of the basic laws relating to traffic flow and generation and application of this knowledge to the professional practice of planning, designing and operating traffic systems to achieve safe and efficient movement of persons and goods.
- Objective of traffic engineering:
  - Achieve efficient 'free and rapid' flow of traffic
  - Reduce the no. of accidents.
- Various phases of traffic engineering are: (3Es)
  - Engineering (constructive i.e. geometric design of road)
  - Enforcement (traffic laws, regulation and control)
  - Education (publicity and through school and television)

Scope of traffic engg.

- Traffic characteristics:-improvement of traffic facilities(vehicle , human[road user])
- Traffic studies and analysis
- Traffic operation-control and regulation:- laws of speed limit, installation of traffic control device
- Planning and analysis
- Geometric design:-Horizontal and vertical curve design
- Administration and management:- '3E'concept

Traffic characteristics

- Road user characteristics
  - ➢ Physical
  - ➢ Mental
  - ➢ Psychological
  - ➢ Environmental
- Vehicular characteristics
  - ➢ Vehicle dimension
  - ➢ Weight of loaded vehicle
  - ➢ Power of vehicle
  - ➢ Speed of vehicle
  - ➢ Braking characteristics

Traffic studies

- Traffic studies are carried out to analyse the traffic characteristics. These studies helps in deciding the geometric design features traffic control for save and efficient traffic movement.
- The various traffic survey studies generally carried out are:
  - ✓ Traffic volume study
  - ✓ Speed study
    - ✓ Spot speed study
    - ✓ Speed and delay study
  - ✓ Origin and destination study
  - ✓ Traffic flow characteristics
  - ✓ Traffic capacity study
  - ✓ Parking study
  - ✓ Accident studies

Traffic volume study

- It is the number of vehicles crossing a section of road per unit time at any selected period.
- It is used as a quantity measure of flow: the commonly units are vehicles/day or vehicles/hour
- The objects and the used of traffic volume study are:
  - ➢ It is generally accepted as a true measure of the relative importance of roads and in deciding the priority for improvement and expansion.
  - ➢ It is used in planning, traffic operation and control of existing facilities and also for planning the new facilities.

Cont..

- It is used in the analysis of traffic patterns and trends.
- Useful in structural design of pavement
- Used in planning one-way streets and other regulatory measure.
- Turning movement study used in the design of intersections, in planning signal timings, channelization and control devices.
- Pedestrian traffic volume study is used for planning side walk, cross walks, subway and pedestrian signals.

Counting of traffic volume

- Mechanical count
  - These may be fixed type or portable type, it is automatically record the total number of vehicle crossing a section of the road in a desired period.
  - Other methods of working the mechanical detectors are by videos, radar detector.
  - Advantage is that it can work throughout the day and night for the desired period.
- Manual count
  - It is possible to obtain data which can not be collected by mechanical counter such as vehicle classification, turning movement.

Presentation of traffic volume data

- Average annual flow: (veh/year)
- Annual average daily traffic(AADT or ADT): Average daily traffic (ADT) represents the total traffic for a year divided by 365, or the average traffic volume per day.(veh/day)
- Hourly average traffic: (veh/hr)
- Thirtieth highest hourly volume or the design hourly volume is found from the plot between hourly volume and the number of hours in a year that the traffic volume is exceeded. The 30^{th} highest hourly volume is the hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the years will be less than this volume. The 30^{th} highest traffic volume is found to be satisfactory from both facility and economic considerations.

SPEED STUDY

- Spot speed:- it is the instantaneous speed of a vehicle at a specified location.
- Average speed:- it is the average of spot speed of all vehicles passing at given points on the highway.
- Space mean speed:- (harmonic mean)Average speed of vehicles in a certain road length at a given instant.

$$V_s = \frac{n}{\sum_{i=1}^{n} \frac{1}{V_i}}$$

Where,
V_s= space mean speed
n= no. of vehicles
V= speed of the vehicle

$$V_s = \frac{nL}{\sum_{i=1}^{n} t_i}$$

Time mean speed:-(arithmetic mean)

- Mean speed of vehicle at a point in space over a period of time or It is the average of instantaneous speeds of observed vehicles at the spot.

$$\boxed{V_t = \frac{\sum_{i=1}^{n} V_i}{n}}$$

Where,

V_t= time mean speed

n= no. of vehicles

V= speed of the vehicle

- Running speed:- it is the average speed maintained by a vehicle over a particular stretch of road, while the vehicle is in motion ; this is obtained by dividing the distance covered by the time during which the vehicle is actually in motion.
- Journey speedor travel speed:- it is the effective speed with which a vehicle traverse a particulars route between two terminals, it includes delay and stoppages.

Types of speed study

1. Spot speed study
2. Speed and delay study

Use of spot speed study

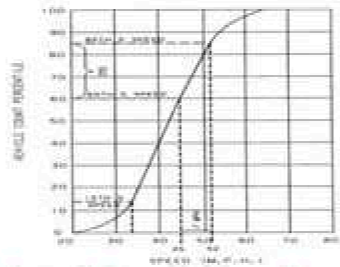
- To use in planning traffic control and in traffic regulation.
- To use in geometric design for redesigning the existing highway.
- To use in accident studies.
- To study the traffic capacity.

Speed and delay study

- The speed and delay studies give the running speeds, overall speeds, fluctuations in speeds and the delay between two stations of a road.
- It gives the information such as the amount, location, duration and cause of delay in the traffic stream.
- The result of the spot and delay studies are useful in detecting the spot of congestion.
- The delay or time lost traffic during the travel period may be either due to fixed delays or operational delays.
- Fixed delay occurs primarily at intersections due to traffic signals and at level crossings.
- Operational delays are caused by the interference of traffic movement, such as turning vehicles, parking vehicles, pedestrians ..etc.

Presentation of spot speed data

- A graph is plotted with the average value of each speed group on X-axis and the cumulative percent of vehicles travelled at or below the different speeds on Y-axis. From the graph(i.e. Cumulative frequency distribution curve) followings can be obtained.
  - 98th percentile speed-Design speed
  - 85th percentile speed-Maximum speed
  - 50th percentile speed-Median speed
  - 15th percentile speed-Minimum speed



- Modal average speed(frequency distribution curve):
  - A frequency curve of spot speed is plotted with average value of each speed group of vehicle in X-axis and the percentage of vehicle in that group on the Y-axis.
  - The speed corresponding to peak value of curve is denoted as modal speed

Methods of speed and delay study

- Floating car or riding check method
- License plate or vehicle number method
- Interview method
- Elevated observations
- Photographic technique

Floating car or riding check method

- In the floating car method a test vehicle is driven over a given course of travel at approximately the average speed of the stream, thus trying to float with the traffic stream. A number of test runs are made along the study stretch and a group of observers record the various details. One observer is seated in the floating car with two stop watches. One of the stop watch is used to record the time at various control point like intersections, bridges or any other fixed points in each trip.
- The other stop watch is used to find the duration of the individual delays. The time, location and cause of these delays are recorded by the second observer.
- the number of vehicle overtaking the test vehicle and the overtaken by the test vehicle are noted in each trip by third observer.
- The no. of vehicles travelling in the opposite direction in each trip is noted by fourth observer.
- In this method the detailed information is obtained concerning all phases of speed and delay including location, duration and causes of delay.

Floating car or riding check method

$$\bar{t} = t_w - \frac{n_y}{q}$$

$$q = \frac{n_a + n_y}{t_a + t_w}$$

where,

$\bar{t}$ = average journey time in minute

q= flow of vehicle(average volume) in one direction of the stream

n_a = average number of vehicles counted in the direction of the Stream when the test vehicle travels in the opposite directions

n_y= the average no. of vehicles overtaking the test vehicle minus the no. of vehicles overtaken when the test is in the direction of 'q'

T_w= average journey time, in minute when the test vehicle is travelling with the stream 'q'

T_a= average journey time, in minute when test vehicle is running against the stream 'q'

Example-1

The consolidated data collected from speed and delay studies by floating car method on a stretch of urban road of length 3.5 km, running North- South are given below. Determine the average values of volume, journey speed and running speed of the traffic stream along either direction.

Trip No.	Direction of trip	Journey time Min- Sec	Total stop delay Min- Sec	No. of vehicles overtaking	No. of vehicle overtaken	No. of vehicles from opposite direction
1	**N-S**	6-32	1-40	4	7	268
2	**S-N**	7-14	1-50	5	3	186
3	**N-S**	6-50	1-30	5	3	280
4	**S-N**	7-40	2-00	2	1	200
5	**N-S**	6-10	1-10	3	5	250
6	**S-N**	8-00	2-22	2	2	170
7	**N-S**	6-28	1-40	2	5	290
8	**S-N**	7-30	1-40	3	2	160

solution

direction	Journey time Min- Sec	stopped delay Min- Sec	Number of vehicle		
			overtaking	overtaken	In opposite direction
N-S	6-32	1-40	4	7	268
	6-50	1-30	5	3	280
	6-10	1-10	3	5	250
	6-28	1-40	2	5	290
TOTAL					
Mean					
S-N	7-14	1-50	5	3	186
	7-40	2-00	2	1	200
	8-00	2-22	2	2	170
	7-30	1-40	3	2	160
TOTAL					
Mean					

Origin and destination studies

- The object of this study is
  - Plan the road network and other facilities for vehicular traffic
  - Plan the schedule of different modes of transportation for the trip demand of commuters.
- It gives the information like the actual direction of travel, selection of routes and length of trip.
- Used in planning new highway facilities and in improving some of the existing system.
- To plan the transportation system and mass transit facilities in cities including route and schedules of operation
- To locate expressway or major routes along the desire lines.
- To locate terminals and to plan terminal facilities.

Cont…

- To locate new bridge as per traffic demands.
- To locate intermediate stops of public transport.

Methods of ‘O’ and ‘D’ survey:

- Road- side interview method
- License plate method
- Return post card method
- Tag-on-car method
- Home interview method

Traffic flow characteristics and studies

- The basic traffic maneuvers are diverging, merging, crossing and weaving.
- Traffic Flow(q):- the rate at which vehicles pass at a fix point (vehicles per hour)= N(3600/t).
- Traffic Density(k):- no. of vehicles(N) over a stretch of roadway(L) i.e. vehicles per kilometer = N/L
- Time headway:- Time interval between the passage of the fronts of the successive vehicles at a specified point.

Cont…

- Average time headway= average travel time per unit distance x average space headway

Space headway:- distance between front of successive vehicles.

- Average space headway= space mean speed x average time headway

Flow Density Relationship

- **Flow= density x space mean speed**
  - **q= K x V**
- **Density = 1/ space headway**
  - **1/hs**
- **Space mean speed = flow x Space headway**
  - **q x hs**
- **Density = flow x time per unit distance**
  - **K = q x t**

Traffic capacity studies

Traffic capacity:

- The ability of a roadway to accommodate traffic volume. It is expressed as the maximum number of vehicle in a lane or a road that can pass a given point in unit time, usually an hour.
- Volume represent an actual rate of flow where as capacity indicates a maximum rate of flow with a certain level of service.

Basic capacity:

- It is the maximum no. of passenger car that can be pass a given point on a roadway during one hour under the most nearly ideal roadway and traffic conditions. It is otherwise known as theoretical capacity.

Possible capacity:

- It is the maximum no. vehicle that can pass a given point on a roadway during one hour under prevailing roadway and traffic conditions.

Practical capacity:

- It is the maximum no. of vehicle that can pass a given point on a roadway during one hour, without traffic density being so great as to cause unreasonable delay, hazard or restriction to the driver freedom to maneuver under the prevailing roadway and traffic conditions.
- $C = 1000\ V/S$
- S= average spacing of vehicle in m, C is the capacity in vehicle per hour per lane.

Peak-Hour Factor

- It is basically represent the variation in traffic flow with in an hour.
- Observations of traffic flow consistently indicate that the flow rates are found in the peak.
- A 15 minute period within an hour is not sustained through out the entire period and that is why we need to use the peak-hour factor.
- Normally on freeways the peak-hour factor values range from 0.80 to 0.95.

Passenger Car Unit (PCU)

- The different vehicle classes have a wide range of statics characteristics and dynamic characteristics, apart from these the driver behavior of the different vehicle classes is also found to vary considerable. Therefore mixed traffic flow characteristics are very much complex when compare to homogeneous traffic and it is difficult to estimate the traffic volume , capacity of roadway under the mixed traffic flow, unless the different vehicle classes are converted to one common standard vehicle unit.
- Therefore it is a common practice to consider the passenger car as the standard vehicle unit to convert the other vehicle classes and this unit is called passenger car unit.

PCU value depends upon the several factors, such as:

- Vehicle characteristics
- Transverse and longitudinal gaps or clearance between moving vehicles.
- Speed distribution of the mixed traffic stream, volume to capacity ratio.
- Roadway characteristics.
- Regulation and control of traffic.
- Environmental and climatic conditions.

Passenger car equivalency factor(PCU)

- As per IRC:86-1983

S.L. No.	Vehicle class	Equivalency factor
1	Motor cycle, Scooter and Pedal cycle	0.5
2	Passenger car, Tempo, auto rickshaw, Agricultural tractor, Pick-up van	1.0
3	Cycle -rickshaw	1.5
4	Truck, Bus, Agricultural tractor-trailer	3.0
5	Horse-drawn vehicle	4.0
6	Small bullock-cart and Hand-cart	6.0
7	Large bullock-cart	8.0

Relation between speed, travel time, volume, density and capacity

Refer page no.-208,209 and 210 of highway Engg. by S.K. Khanna & C.E.G Justo

Cont…

- Maximum flow occurs when the speed is Vsf/2 and the density is Kj/2

$$\boxed{q_{\max} = \frac{V_{sf} \times K_J}{4}}$$

- Where,
- Kj = jam density= 1000/spacing of vehicle
- Vsf = free mean speed
- K= q/v
- q= average volume of vehicle, (veh./hr)
- V= space mean speed of vehicle,kmph

Level of service(LOS)

- It is define as a qualitative measure describing the operational condition within a traffic stream, and their perception by motorist and passengers.
- Or Rating of acceptable level of congestion
- LOS definitions
  - A: Free flow, low traffic, high speed
  - B: Stable flow, noticeable traffic
  - C: Stable flow, traffic interactions,
  - D: Unstable flow, High density, movement restrictions
  - E: Unstable flow, lower speed, volume is nearly equal to capacity, little freedom
  - F: Unstable flow, no freedom, traffic volume can drop to zero, stop & go

Cont…

LOS- A

- ✓ Free-flow operation
- ✓ no restriction in maneuvering.

LOS- B

- ✓ Reasonably free flow
- ✓ Ability to maneuver is only slightly restricted
- ✓ Effects of minor incidents still easily absorbed

Cont....

LOS- C

- ✓ Speeds at or near FFS
- ✓ Freedom to maneuver is noticeably restricted
- ✓ Queues may form behind any significant blockage.

LOS- D

- ✓ Speeds decline slightly with increasing flows
- ✓ Density increases more quickly
- ✓ Freedom to maneuver is more noticeably limited
- ✓ Minor incidents create queuing

Cont…

LOS- E

- ✓ Operation near or at capacity
- ✓ No usable gaps in the traffic stream
- ✓ Operations extremely volatile
- ✓ Any disruption causes queuing

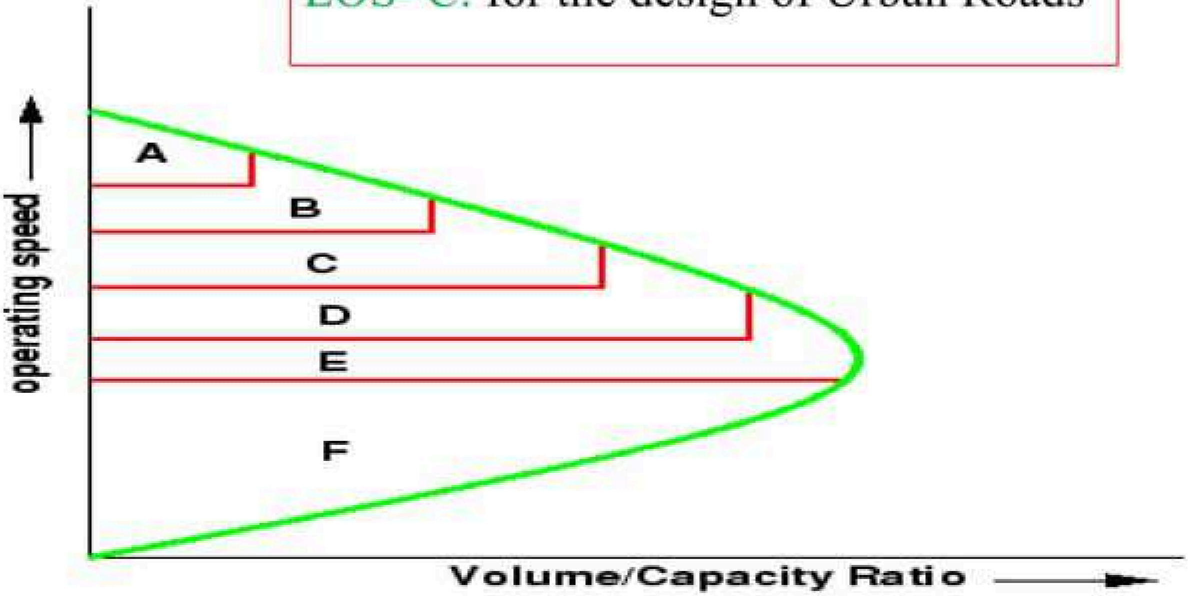
LOS- F

- ✓ Breakdown in flow
- ✓ Queues form behind breakdown points
- ✓ Demand > capacity

In India, As per IRC

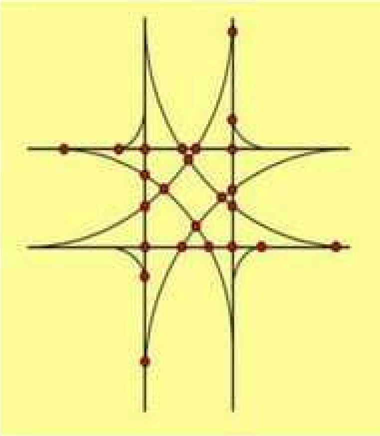
LOS- B: for design of Rural Roads

LOS- C: for the design of Urban Roads



Traffic operations

- Number of conflicts at intersection
  - Crossing conflicts
  - Merging conflicts
  - Diverging conflicts



Number of lanes		Number of potential conflicts		
Road- A	Road- B	Both road two-way	A- Oneway B- twoway	Both roads Oneway
2	2	24	11	6
2	3	24	11	8
2	4	32	17	10
3	3	24	13	11
4	4	44	25	18

Bibliography

- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros*.
- *IRC Codes*.

RAILWAY ,BRIDGES AND TUNNELS

1. **CHAPTER-1**

RAILWAYS

INTRODUCTION

Railways have been an important part of our transport infrastructure since the 19th century, and their development has enabled the use of trains as an effective and efficient means of travel.

The emergence of railways from around the 1820's marked the beginning of the end for canals, as trains could carry more goods, more people and travelled much faster. The first steam locomotive to carry passengers began operation in 1825, designed by engineer George Stephenson, on a line between Stockton and Darlington.

Stephenson also developed the Liverpool and Manchester Railway (L&MR), a significant improvement on the first steam locomotive. 'The rocket', was much more efficient, producing more steam and with horizontal pistons directly driving the wheels. The L&MR opened in 1830.

Railways spread rapidly throughout the UK with the increased demand for coal and steel, and for distribution of things such as newspapers and post. The railways were built by 'navvies' who would dig foundations, lay stones and fix the track. Most of the work was done by hand, using a pick axe.

SYSTEMS OF RAILWAYS

1. Surface Railways
2. Elevated Railways
3. Under Ground railways

4- Tube Railways

Surface Railways

Surface railways are the cheapest and most extensively used form of railway service in the world. In such a system, the track is laid on a ground that has a suitable embankment or cutting, depending upon the topography of the area. Metropolitan railways use electric traction because of the following advantages.

(a) Electric traction does not pollute the environment.

(b) The acceleration and deceleration of trains is faster.

(c) Electric traction ensures the availability of power for improved and modern signalling.

(d) An electric locomotive can haul a train with the same efficiency in both the directions and there is no need for reversing the direction of the locomotive.

(e) This system uses special type of coaches called electric multiple units (EMUs), which can carry more traffic than conventional coaches.

Elevated Railways

An elevated railway (also known as an El rail, El train or simply an El for short, and, in Europe, as an overhead railway) is a rapid transit railway with the tracks above street level on a viaduct or other elevated structure (usually constructed of steel, concrete, or brick). The railway may be broad gauge, standard gauge, narrow gauge, light rail, monorail, or a suspension railway. Elevated railways are usually used in urban areas where there would otherwise be a large number of level crossings. Most of the time, the tracks of elevated railways that run on steel viaducts can be seen from street level.

Under Ground Railways

An underground system is defined as an electric railway public transport network (a metro or subway system) that runs both above and underground.

Tube Railways

The term tube railway may refer to:

- an atmospheric railway, a railway that uses differential air pressure to provide power for propulsion of a vehicle.
- an underground railway constructed in a circular tunnel by the use of a tunnelling shield.
- by extension of the previous definition, the London Underground, most (but not all) of whose lines are so constructed.

The advantages & disadvantages of railway transport.

Railway transport occupies a significant role in the transport system of a country because the development of trade, industry and commerce of a country largely depends on the development of railways.

Advantages:

i. It facilitate long distance travel and transport of bulky goods which are not easily transported through motor vehicles.

ii. It is a quick and more regular form of transport because it helps in the transportation of goods with speed and certainty.

iii. It helps in the industrialization process of a country by easy transportation of coal and raw-materials at a cheaper rate.

iv. It helps in the quick movement of goods from one place to another at the time of emergencies like famines and scarcity.

v. It encourages mobility of labour and thereby provides a great scope for employment.

vi. Railway is the safest form of transport. The chances of accidents and breakdown of railways are minimum as compared to other modes of transport. Moreover, the traffic can be protected from the exposure to sun, rain snow etc.

vii. The carrying capacity of the railways is extremely large. Moreover, its capacity is elastic which can easily be increased by adding more wagons.

viii. It is the largest public undertaking in the country. Railways perform many public utility services. Their charges are based on charge what the traffic can bear principles which helps the poor. In fact, it is a national necessity.

Disadvantages:

i. The railway requires a large investment of capital. The cost of construction, maintenance and overhead expenses are very high as compared to other modes of transport. Moreover, the investments are specific and immobile. In case the traffic is not sufficient, the investments may mean wastage of huge resources.

ii. Another disadvantages of railway transport is its inflexibility. It routes and timings cannot be adjusted to individual requirements.

iii. Rail transport cannot provide door to door service as it is tied to a particular track. Intermediate loading or unloading involves greater cost, more wear and tear and wastage of time. The time cost of terminal operations are a great disadvantage of rail transport.

iv. As railways require huge capital outlay, they may give rise to monopolies and work against public interest at large. Even if controlled and managed by the government, lack of competition may breed in inefficiency and high costs.

v. Railway transport is unsuitable and uneconomical for short distances and small traffic of goods.

vi. It involves much time and labour in booking and taking delivery of goods through railways ascompared to motor transport.

vii. Because of huge capital requirements and traffic, railways cannot be operated economically in rural areas. Thus, large rural areas have no railway even today. This causes much inconvenience to the people living in rural areas.

CHAPTER-2 RAILWAY SURVEY

Infuencing The Railways Route

Our industry is experiencing widespread change, driven by wide-ranging and varied influences.

With these changes come both opportunities and challenges, and SmartRail World has set out to identify some of these key trends to help you better shape your strategic, long-term planning.We asked experts, canvassed opinion on social media and discussed the area at the SmartRail global event series and have identified nine key trends. Some you will be familiar with, some less so.

1. Climate Change.

Rail networks have been designed and built using historical records of climate and weather events. Now with the ‘Inconvenient truth’ of climate change, these projections are no longer a reliable predictor. Even what sound like modest changes in the average temperature can translate to large and potentially dangerous shifts in climate and weather.

Flooding on the tracks north of MNRs Garrison Station, New YorkHigh temperatures can cause rail tracks to expand and buckle, and may lead to more regular repairs, speed restrictions, delays and disruption. Storms can damage or deposit debris on lines and at stations and floods or high-tides can submerge them as well. This is particularly true in underground tunnels as seen in New York after Hurricane Sandy.

The rail industry now has to plan for a different weather future, and build accordingly with a 'predict and prevent' ethos looking forward rather than back. Our networks, standards and systems now have to be built for the world of the 2050s and beyond, a world which could be very different.

2. Urban growth.

Today, 54 per cent of the world’s population lives in urban areas, a proportion that is expected, according to United Nations figures to increase to 66 per cent by 2050. Projections show that urbanization combined with the overall growth of the world’s population could add another 2.5 billion people to urban populations by 2050, with close to 90 percent of the increase concentrated in Asia and Africa.

The rapid pace of urbanisation puts added pressure on already strained infrastructure – anyone who travels at peak-time in a major city will attest to this. As a result infrastructure needs to be designed to be able to be able to absorb such growth, and be as efficient and rapid is possible. Along with the pressures, though come opportunities – the increased size of cities widens their power and tax base and enables a greater investment in public transport, an example being the Crossrail project currently underway in London (pictured above).

Hand in hand with the rising populations is the growth of megacities (those with over 10 million people) predominantly in Asia. As of 2015, there are 35 megacities in existence, in 1950 there was just one (New

York). The sheer size and complexity of these multiplying megacities gives rise to enormous challenges.

Meeting the challenges and opportunities of urban growth is one of the key themes of Smart Metro (incoporating the 9th Annual CBTC World Congress, which returns to Paris on 29th - 31st October 2018.

3. Rise of the start-ups

At the recent SmartRail Europe Congress in Amsterdam, the pace of change was a regular point of discussion across all the streams. Same as always right? Well it's always a key point in any project, but what is shifting the parameters of the discussion is the entry of small, lean start-ups into the industry. Without the baggage and legacy of larger traditional firms, they don't play the conventional rules of the business. Digital rather than physical solutions can be rolled out in days or weeks, not months or years. And the perennial issues of ticketing, overcrowding and train organisation are some of the issues in the sights of start-ups aided by a recent blooming in hackathons and a first rail accelerator opening in London.

In the rebuilding of New Orleans after Hurricane Katrina Lt. General Russel Honore famously told a subordinate who he viewed was moving too slowly, "You're looking at your calendar and I'm looking at my watch."

4. Digitisation takes over.

Closely connected to the development of the start-up community within rail is a widening digitalisation of the processes behind many of the key systems behind rail operations. The digital revolution arrived in rail later than in other industries, but is quickly becoming the establishment. Any commercially focussed railway is now able to utilise a host of digital initiatives. Amongst many areas is the Internet of Things (IoT) enabling on-board sensors to deliver real time analysis and monitoring, identify problems before they cause delays, facilitate automated and preventive maintenance and ensure dispatchers have an entirely accurate view of the train's location.

Digitisation is often made possible by the presence and use of Big Data, and to pick just one example, the commuter train network in Stockholm, Sweden is using a predictive model, called 'the commuter prognosis' that uses Big Data to visualize the entire commuter train up to two hours into the future. This enable a forecast of disruptions in the service, with the traffic control centre able to prevent the ripple effects that cause most delays. In the future the algorithm will be potentially adaptable for more types of public transportations and cities.

These issues will be discussed at our SmartTransit Congress which takes place in Philadelphia on October 23-25, 2018

5. New players offering integrated travel solutions.

Uber and rail - a growing relationship.A recent study prepared for the American Public Transportation Association (APTA) through the Transit Cooperative Research Program has revealed that the people using services like Uber and Lyft are actually more and not less likely to travel on public transport. The survey taken by 4,500 people in seven different US cities showed that 50% of people travelled by train and 45% used buses frequently. The study can be viewed as insight into the impact of ride-sourcing on public transport.

There are some who view the likes of Uber and Lyft as the solution to the first-mile / last-mile challenge and to help overcome the concern that potential riders avoid public transport because of difficulties getting to or from the train or metro. And instead they end up driving. Ride-sourcers can help solve this by offering the optimal combination of walking, transit and their own transport.

There's huge potential for rail and metro to partner with companies Lyft or Uber, but caution must also be maintained that they don't become more attractive than public transport. And the performance of rail and metro, particularly in payments and booking must be improved to head off any future threat.

6. Powered by different energy sources.

Environmental concerns (see also Climate Change), fears over energy security and the lowering costs of implementation mean that rail is looking at new ways of powering itself.

On the train itself, options for possible replacements for diesel include hydrogen and perhaps the most appealing, LNG, already being tested by some railways and offering a competitive price, and lower carbon emissions plus an established regulatory structure when compared to its fossil and renewable fuel rivals. Whilst Alstom is currently developing entirely new types of fuel cell trains which aim to be completely emission-free.

Stations themselves are also looking to be powered differently. In the USA, the renovated Yawkey Station near Fenway Park in Boston will become a "zero net energy" commuter rail station when construction is finished in 2017. Solar panels and a shared-use garage on which a solar photovoltaic power plant will be installed is designed to provide all the energy required to power the station.

7. The station becoming a destination.

St Pancras International, in LondonRail stations are changing. For a long time they appeared to be an after-thought for many train operators, designed simply to get as many passengers in and out as quickly and safely as possible, But no more. Stations are evolving and offering more to its passengers, making them a place to stay in and enjoy, an amenity all to itself, rather than a building to quickly head away from or arrive with little time to spare before catching a train. The central position of stations, also puts them at the heart of urban regeneration schemes and a crucial link between commercial, leisure and residential spaces.

Many stations at aiming to take advantage of the huge footfall they experience (and help pay for their investments) by developing a dazzling area of retail and catering outlets to serve every taste (and pocket).

Whilst ergonomic design is becoming an increasing factor in the planning of stations ensuring that large numbers of travellers can move freely and efficiently to, through and from a station is an essential to maintaining the operational effectiveness of the transport system as a whole. Station developments now consider ergonomic and human factors, in particular looking in a scientific way at people and their needs, and then providing analytical evidence based on psychological, behavioural and physical factors to improve experiences.

8. Long distance travel makes a return.

Air travel hasn't been kind to long-distance rail, with many classic lines now redundant or operating on a limited, nostalgia focussed basis. However, a number of factors are pushing its growth and are likely to over future years. Improvements to booking and ticketing allied with high-speed trains (see below) and on-board service are also widening the uptake of trains to travel across continents.

As one example cross-Channel high-speed train operator Eurostar will be running a service between London and Amsterdam in late 2017. And whilst the United States lags behind in these stakes, Amtrak and new entrants have ambitious plans. China and Japan, which have focused on building high-speed networks that can compete and beat air travel.

Another trend helping support long distance rail travel, is the growth of codesharing, long found in the aviation industry where a marketing arrangement is created with an airline placing its designator code on a flight operated by another airline and selling tickets for that flight in order to strengthen or expand their market presence and competitive ability. This is now being seen in an intermodal form in partnerships with the rail industry. This kind of link-up between airlines and rail lines, known formally as air-rail alliance or informally 'Rail & Fly' are increasingly popular.

9. High-Speed and Hyper-Speed Rail

For anyone reading this in the United Kingdom or California they will be well versed in arguments about the development of high-speed rail but we could soon be entering the world of hyper-speed rail travel. High-speed rail has already revolutionized national and international transportation in many parts of the world, in particular in Japan, China and continental Europe. And now plans are being developed to go even faster.

Few will have escaped the media coverage of Elon Musk's 'Hyperloop', a innovative new form of transportation, consisting of an elevated, reduced-pressure tube that contains pressurized capsules driven within the tube by a number of electric motors, Musk claimed it would "never crash, be immune to weather, go twice as fast as an airplane, four times as fast as a bullet train, and – to top it off – run completely on solar power." Whilst the Hyperloop may currently lack the financial or political will to make it a reality there's no doubt that super high-speed rail is a reality.

In China, the Shanghai Maglev Train has been in operation since 2003 and has been recorded at a top speed of 311 mph, Japan's famed bullet train, the Shinkansen runs on a high-speed network of over 1400 miles hitting speeds of up to 275mph and in Europe, France's TGV Réseau which generally runs at 199mph has been serving passengers since 1992. The slow but continued growth of High-Speed rail not only opens up a host of further technical developments but offers a strong countermeasure to other forms of transport.

Track Alignment

Track geometry is three-dimensional geometry of track layouts and associated measurements used in design, construction and maintenance of railroad tracks. The subject is used in the context of standards, speed limits and other regulations in the areas of track gauge, alignment, elevation, curvature and track surface. Although, the geometry of the tracks is three-dimensional by nature, the standards are usually expressed in two separate layouts for horizontal and vertical.

Layout

Horizontal layout

Horizontal layout is the track layout on the horizontal plane. This can be thought of as the plan view which is a view of a 3-dimensional track from the position above the track. In track geometry, the horizontal layout involves the layout of three main track types: **tangent track** (straight line), **curved track**, and track transition curve (also called **transition spiral** or **spiral**) which connects between a tangent and a curved track.

In Australia, there is a special definition for a **bend** (or a **horizontal bend**) which is a connection between two tangent tracks at almost 180 degrees (with deviation not more than 1 degree 50 minutes) without an intermediate curve. There is a set of speed limits for the bends separately from normal tangent track.

Vertical layout

Vertical layout is the track layout on the vertical plane. This can be thought of as the elevation view which is the side view of the track to show track elevation. In track geometry, the vertical layout involves concepts such as cross level, cant and gradient.

Reference rail

The reference rail is the base rail that is used as a reference point for the measurement. It can vary in different countries. Most countries use one of the rails as the reference rail. For example, the United States uses the reference rail as the **line rail** which is the east rail of tangent track running north and south, the north rail of tangent track running east and west, the outer rail (the rail that is further away from the center) on curves, or the outside rails in multiple track territory. For Swiss railroad, the reference rail for tangent track is the center line between two rails, but it is the outside rail for curved track.

Track Gauge

Track gauge or rail gauge (also known as track gage in the United States[5]) is the distance between the inner sides (gauge sides) of the heads of the two load bearing rails that make up a single railway line. Each country uses different gauges for different types of trains. However, the 1,435 mm (4 ft 8 1⁄2 in) gauge is the basis of 60% of the world's railways.

Transverse Elevation

Crosslevel (or 'cross level') is the measurement of the difference in elevation (height) between the top surface of the two rails at any point of railroad track. The two points (each at the head of each rail) are measured at by the right angles to the reference rail. Since the rail can slightly move up and down, the measurement should be done under load.

It is said to be zero crosslevel when there is no difference in elevation of both rails. It is said to be reverse crosslevel when the outside rail of curved track has lower elevation than the inside rail. Otherwise, the crosslevel is expressed in the unit of height.

The speed limits are governed by the crosslevel of the track. In tangent track, it is desired to have zero crosslevel. However, the deviation from zero can take place. Many regulations have specification related to speed limits of certain segment of the track based on the crosslevel.

For curved track, most countries use the term cant or superelevation to express the difference in elevation and related regulations.

Warp

Warp is the difference in crosslevel of any two points within the specific distance along the track. The warp parameter in the track geometry is used to specify the maximum in the crosslevel difference of the track in any segment (tangents, curves and spirals).

Without the maximum warp parameter, the regulation on crosslevel alone may not be sufficient. Consider rails with a positive crosslevel followed by a negative crosslevel followed by a sequence of alternating positive and negative crosslevels. Although, all of those crosslevels are in permissible parameter, when operating a train along such track, the motion will be rocking left and right. Therefore, the maximum warp parameter is used to prevent the critical harmonic rock-off condition that may result in the trains rocking back and forth and derailing following wheel climb.

In the United States, the specific distance used for measurement to ensure that the difference in crosslevel of the track is within the permissible warp parameter is 62 feet. The design warp is zero for both tangent and curved track. That means, ideally, the crosslevel should not change between any two points within 62 feet. There are some deviations to allow crosslevels along the track to change (such as change for superelevation in curves). Different levels of those deviations from the zero warp specify the speed limits.

The specification that focuses on the rate of change in crosslevels of curved track is contained within the area related to cant gradient.

Longitudinal

elevation Track

gradient

The term **track gradient** is relative elevation of the two rails along the track. This can be expressed in the distance traveled horizontally for a rise of one unit, or in terms of an angle of inclination or a percentage difference in elevation for a given distance of the track.

The allowable gradients may be based on the **ruling gradient** which is the maximum gradient over which a tonnage train can be hauled with one locomotive. In some countries, **momentum gradient** which is a steeper but shorter gradient may be allowed. This is usually when there is a track gradient is connected to a leveled tangent track that is long enough with no signal between them so that train can build momentum to push through steeper grade than it can be without momentum.

In curved track (with or without cant), there will be curve resistance to push the trains through the curve. The allowable gradients may be reduced on curves to compensate for the extra curve resistance. The gradient should be uniform along the track.

Vertical curve

Vertical curve is the curve in vertical layout to connect two track gradients together whether it is for changing from an upgrade to a downgrade (summit), changing from a downgrade to an upgrade (sag or valley), changing in two levels of upgrades or changing in two levels of downgrades.

Some countries do not have specification on the exact geometry of vertical curves beyond general specification on vertical alignment. Australia has specification that the shape of vertical curves should be based on quadratic parabola but the length of a given vertical curve is calculated based on circular curve.

Curvature

In most countries, the measurement of curvature of curved track is expressed in radius. The shorter the radius, the sharper the curve is. For sharper curves, the speed limits are lower to prevent an outward horizontal centrifugal force to overturn the trains by directing its weight toward the outside rail. Cant may be used to allow higher speeds over the same curve.
In the United States, the measurement of curvature is expressed in degree of curvature. This is done by having a chord of 100 feet (30.48 m) connecting to two points on an arc of the reference rail, then drawing radii from the center to each of the chord end points. The angle between the radii lines is the degree of curvature.[7] The degree of curvature is inverse of radius. The larger the degree of curvature, the sharper the curve is. Expressing the curve in this way allows surveyors to use estimation and simpler tools in curve measurement. This can be done by using a 62-foot (18.90 m) string line to be a chord to connect the arc at the gauge side of the reference rail. Then at the midpoint of the string line (at the 31st foot), a measurement is taken from the string line to the gauge of the reference rail. The number of inches in that measurement is approximated to be the number of degrees of curvature.

Due to the limitation of how specific train equipment can make a turn at maximum speeds, there is a limitation of minimum curve radius to control the sharpness of all curves along a given route. Although most countries use radius for measurement of curvature, the term maximum degree of curvature is still used outside of the United States such as in India, but with the radius as the unit.

CANT

In curved track, it is usually designed to raise the outer rail, providing a banked turn, thus allowing trains to maneuver through the curve at higher speeds that would otherwise be not possible if the surface was flat or level. It also helps a train steer around a curve, keeping the wheel flanges from pressing the rails, minimizing friction and wear. The measurement of the difference in elevation between the outer rail and the inner rail is called cant in most countries. Sometime the cant is measured in term of angle instead of height difference.[9] In the United States, it is measured in height difference and called crosslevel, even for the curved track.

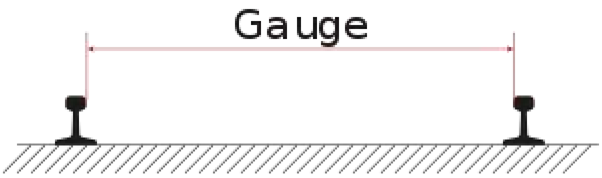
When the outside rail is at higher elevation than the inside rail, it is called positive cant. This is normally the desired layout for curved track. Most counties achieve the desired level of positive cant by raising the outside rail to that level which is called superelevation. For Swiss railroads, the cant is done by rotating at the track axis (center of the two rails) to have outside rail super elevated (raised) at the half rate of the desired cant and the inside rail under elevated (lowered) at the same half rate of the desired cant.

When the outside rail is at lower elevation than the inside rail, it is called negative cant (or reverse crosslevel in the United States). This is not usually a desired layout but it may be unavoidable in some situations such as curves involving turnouts.
There are regulations which limit the maximum cant. This is to control the unloading of the wheels on the outside rail (high rail), especially at low speeds.

CHAPTER-3 RAIL GAUGE

Introduction

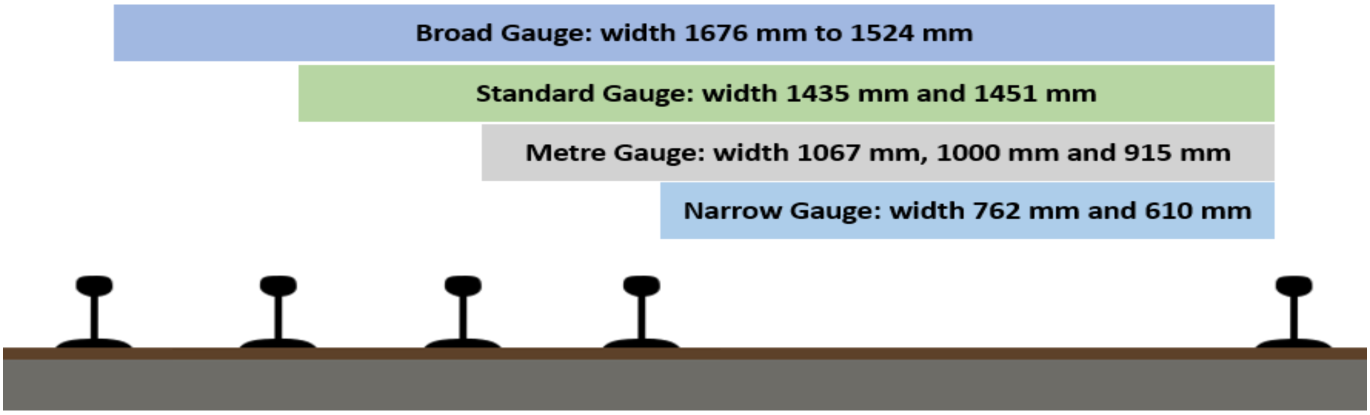
Rail gauge is the distance from the inside of one rail on a railroad track to the inside of the other. Most tracks use a standard gauge of 1,435 mm (4 ft, 8 1/2 in). Wider gauges are called broad gauge, smaller gauges are called narrow gauge. Broad gauge may be used where the track needs to have big things moving on it. Narrow gauge, such as metre gauge, is used to build railroads for less money, because the smaller track costs less. Places where different gauges meet are called break of gauge.



Types of Rail Gauges

The different gauges can broadly be divided into the following four categories:

1. Broad Gauge: width 1676 mm to 1524 mm or 5’6” to 5’0”
2. Standard Gauge: width 1435 mm and 1451 mm or 4’-8½”
3. Metre Gauge: width 1067 mm, 1000 mm and 915 mm or 3’-6”, 3’-33/8” and 3’-0”
4. Narrow Gauge: width 762 mm and 610 mm or 2’-6” and 2’-0”.



Following are the factors affecting the choice of a gauge:

1. Traffic Condition: If the intensity of traffic on the track is likely to be more, a gauge wider than the standard gauge is suitable.
2. Development of Poor Areas: The narrow gauges are laid in certain parts of the world to develop a poor area and thus link the poor area with the outside developed world.
3. Cost of Track:

a. The cost of railway track is directly proportional to the width of its gauge.
b. If the fund available is not sufficient to construct a standard gauge, a metre gauge or a narrow gauge is preferred rather than to have no railways at all.

4. Speed of Movement:

a. The speed of a train is a function of the diameter of wheel which in turn is limited by the gauge.
b. The wheel diameter is usually about 0.75 times the gauge width and thus, the speed of a train is almost proportional to the gauge.
c. If higher speeds are to be attained, the broad gauge track is preferred to the metre gauge or narrow gauge track.

5. Nature of Country:

a. In mountainous country, it is advisable to have a narrow gauge of the track since it is more flexible and can be laid to a smaller radius on the curves.
b. This is the main reason why some important railways, covering thousands of kilometers, are laid with a gauge as narrow as 610 mm.

Advantages and disadvantages of different track gauges

Narrow gauge railways usually cost less to build because they are usually lighter in construction, using smaller cars and locomotives (smaller loading gauge), as well as smaller bridges, smaller tunnels (smaller structure gauge) and tighter curves. Narrow gauge is thus often used in mountainous terrain, where the savings in civil engineering work can be substantial. It is also used in sparsely populated areas, with low potential demand, and for temporary railways that will be removed after short-term use, such as for construction, the logging industry, the mining industry, or large-scale construction projects, especially in confined spaces.

Broader gauge railways are generally more expensive to build, but are able to handle heavier and faster traffic.

750 mm narrow gauge railway in Waldenburg, Switzerland.

Meter gauge tracks, Istanbul nostalgic tramways, Turkey.

In approximately 55% of the world's railways are used standard gauge (1435 mm).

Inclined lift with a gauge of 8.2 metres in Lärchwand Schrägaufzug.

CHAPTER- 4 RAILS

Definition of Rails

A rail is a steel bar extending horizontally between supports which is used as a track for rail road, cars or other vehicles.

Types of Rails

Rails can be divided in three types

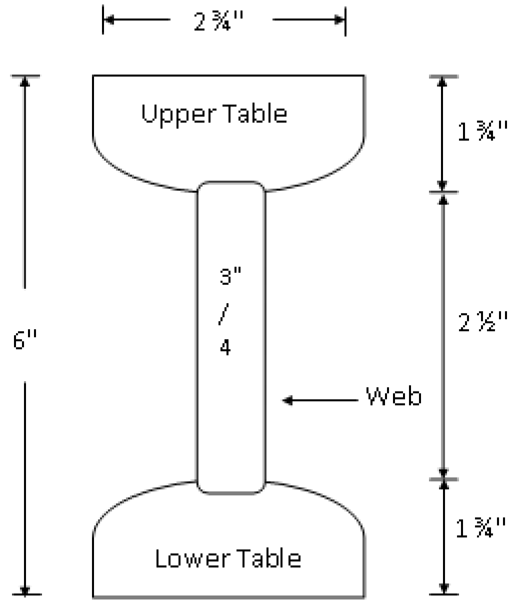
1. Double Headed Rails
2. Bull Headed Rails
3. Flat Footed Rails

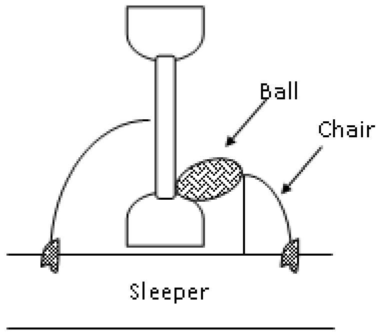
1. Double Headed Rails

These rails indicate the early stage of development. It essentially consists of three parts,

- Upper Table
- Web
- Lower Table

Both the upper and lower tables were identical and they were introduced with the hope of double doubling the life of rails. When the upper table is worn out then the rails can be placed upside down reversed on the chair and so the lower table can be brought into use. But this idea soon turned out to b wrong because due to continuous contract of lower table with the chair made the surface of lower table rough and hence the smooth running of the train was impossible. Therefore, this type of rail is practically out of use. Nowadays, these rails vary in lengths from 20 – 24. A 100 lb double headed rail is shown in the figure.



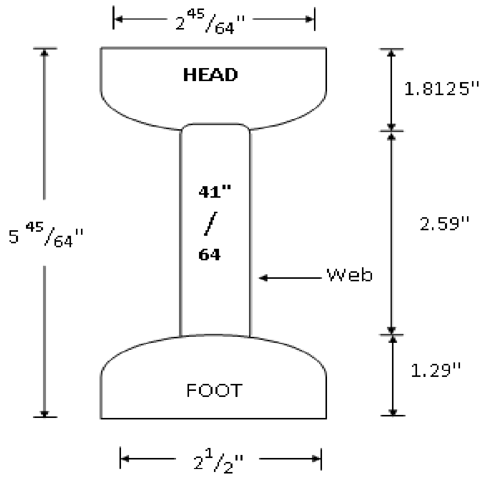


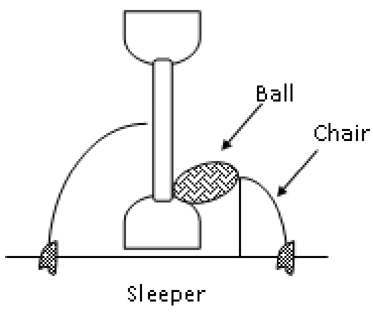
2. Bull Headed Rails

This type of rail also consists of three parts,

- The Head
- The Web
- The Foot

These rails were made of steel. The head is of larger size than foot and the foot is designed only to hold up properly the wooden keys with which rails are secured. Thus, the foot is designed only to furnish necessary strength and stiffness to rails. Two cast iron chairs are required per each sleeper when these rails are adopted. Their weight ranges from 85lb to 95lb and their length is up to 60 ft.



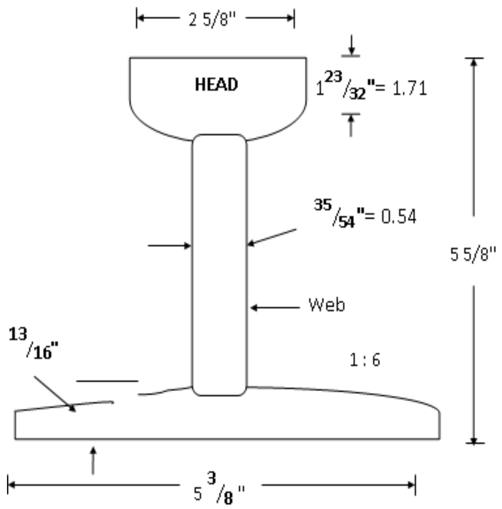


3. **Flat Footed Rails**

These rails were first of all invented by Charles Vignoles in 1836 and hence these rails are also called vignols rails. It consist of three parts

- The Head
- The Web
- The Foot

The foot is spread out to form a base. This form of rail has become so much popular that about 90% of railway tracks in the world are laid with this form of rails.



Flat footed rails has the following advantages

1. They do not need any chair and can be directly spiked or keyed to the sleepers. Thus they are economical.
2. They are much stiffer both vertically and laterally. The lateral stiffness is important for curves.
3. They are less liable to develop kinks and maintain a more regular top surface than bull headed rails.
4. They are cheaper than bull headed rails.
5. The loads from wheels of trains are distributed over large number of sleepers and hence larger area which results in greater track stability, longer life of rails and sleepers, reduced maintenance, costs, less rail failure and few interruptions to traffic.

Wear of Rails

The separation or cutting of rail due to friction and abnormal heavy load is called wear. There are three types of wears of rail.

1. Wear of Rails on top OR Head of Rail
2. Wear at the End of Rails
3. Wear at the side of head of Rails

Methods for Reducing Wear of Rails

The following methods are adopted for reducing wear of rails.

1. Use of Special Alloy Steel
2. Good Maintenance of Track
3. Reduction of Expansion Gap
4. Exchange of Inner and Outer Rails on Curves
5. Use of Lubricating Oil

Coning of Wheel

The rim or flanges of the wheels are never made flat but they are in the shape of a cone with a slope of about 1 to 20. This is known as coning of wheels. The coning of wheels is manly done to maintain the vehicle in the central position with respect to the track. When the vehicle is moving on leveled track then the flanges of wheels have equal circumference.

But when the vehicle is moving along a curved path then in this case the outer wheel has to cover a greater distance then that of inner wheel. Also as the vehicle has a tendency to move sideways towards the outer rail, the circumferences of the flanges of the inner wheel and this will help the outer wheel to cover a longer distance than the inner wheel. In this ways smooth riding is produced by means of coning of wheels.

Coning Wheels Disadvantages

Coning wheels has the following disadvantages:

1. In order to minimize the above below disadvantages the tilting of rails is done. i.e. the rails are not laid flat but tilted inwards by using inclined base plates sloped at 1 in 20 which is also the slope of coned surface of wheels.
2. The pressure of the horizontal component near the inner edge of the rail has a tendency to wear the rail quickly.
3. The horizontal components tend to turn the rail outwardly and hence the gauge is widened sometimes.
4. If no base plates are provided, sleepers under the outer edge of the rails are damaged.
5. In order to minimize the above mentioned disadvantages the tilting of rails is done. i.e. the rails are not laid flat but tilted inwards by using inclined base plates sloped at 1 in 20 which is also the slope of coned surface of wheels.

Advantages of Tilting of Rails

1. It maintains the gauge properly.
2. The wear at the head of rail is uniform.
3. It increases the life of sleepers and the rails.

RAIL CORRUGATION

Rail corrugation is a phenomenon of great diversity but appears now to be substantially understood. This review proposes some differences in classification of the phenomenon to take account of work undertaken since a widely cited review was published by Grassie and Kalousek in 1993, it attempts to fill holes in an overall understanding of the problem, and answers questions that remained open in 1993 and several that have arisen since. All types of corrugation that have been documented to date are essentially constant-frequency phenomena. By treating the vehicle—track system in its entirety, treatments are proposed that impinge upon track and vehicle design as well as upon the wheel—rail interface where corrugation appears. There is no neat solution to rail corrugation, but it can be treated comprehensively and in many cases also prevented by using products that are already commercially available. Since the frequency of common wavelength-fixing mechanisms varies roughly in the range 50—1200 Hz, trains travelling at different speeds can produce corrugation of substantially similar wavelength by different mechanisms in different locations. Although historical data can no longer be checked, this is the most likely explanation of the belief that rail corrugation was a substantially constant-wavelength phenomenon.

Rail Creep

Creep in rail is defined as the longitudinal movement of the rails in the track in the direction of motion of locomotives. Creep is common to all railways and its value varies from almost nothing to about 6 inches or 16cm.

Causes of Creep

The causes of rail creep can be broadly classified into two categories

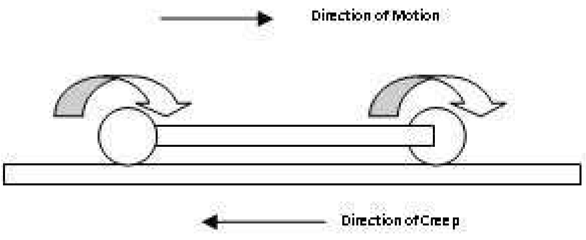
Major Causes o Creep

Minor Causes of Creep

Major Causes of Creep

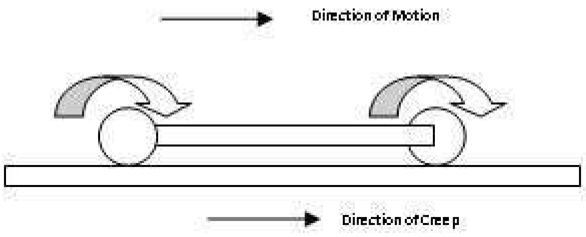
Major causes of creep also known as principal causes of creep. Follows are the major causes of creep in rail

1. Creep may be developed due to forces that come into operation when the train is starting or stopping by application of brakes. Increase of starting the wheels pushes the rail backward and hence the direction of creep is in backward direction.



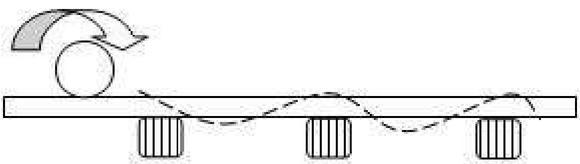
Train Starting Point

When brakes are applied then the wheels of the vehicles push the rails in forward direction and hence the creep is in forward direction.



Train Stopping Point

2. Creep is also developed due to wave motions. When the wheels of the vehicles strikes the crests, creep is developed.



3. Another reason creep develops because of unequal expansion and contraction owing to change in temperature.

Minor Causes Creep

Some of the minor causes of creep in rail are below:

1. Rails not properly fixed to sleepers
2. Bad drainage of ballast
3. Bad quality of sleepers used
4. Improper consolidation of formation bed
5. Gauge fixed too tight or too slack
6. Rails fixed too tight to carry the traffic
7. Incorrect adjustment of super elevation on outer rails at curves

8. Incorrect allowance for rails expansion
9. Rail joints maintained in bad condition

Magnitude and Direction of Creep

Creep is not constant over a given period, it is not continue in one direction or at uniform rate. Both the rails of the track may creep in same direction, perhaps both the rails reverse the direction of creep or one rail creep in opposite direction to that of other

CHAPTER-5 RAIL FASTENINGS

Rail Fastenings

Any device used to secure running rails into chairs or baseplates or directly to sleepers, bearers or other rail supports. Rail fastenings keeps rails fastened to sleepers (transfer of forces), provides a proper slope of rail foot (1:20, 1:40) in the transverse plane, prevents the rail from longitudinal movement, damps noise and vibration coming from rails.

General Requirements for Rail Fastenings

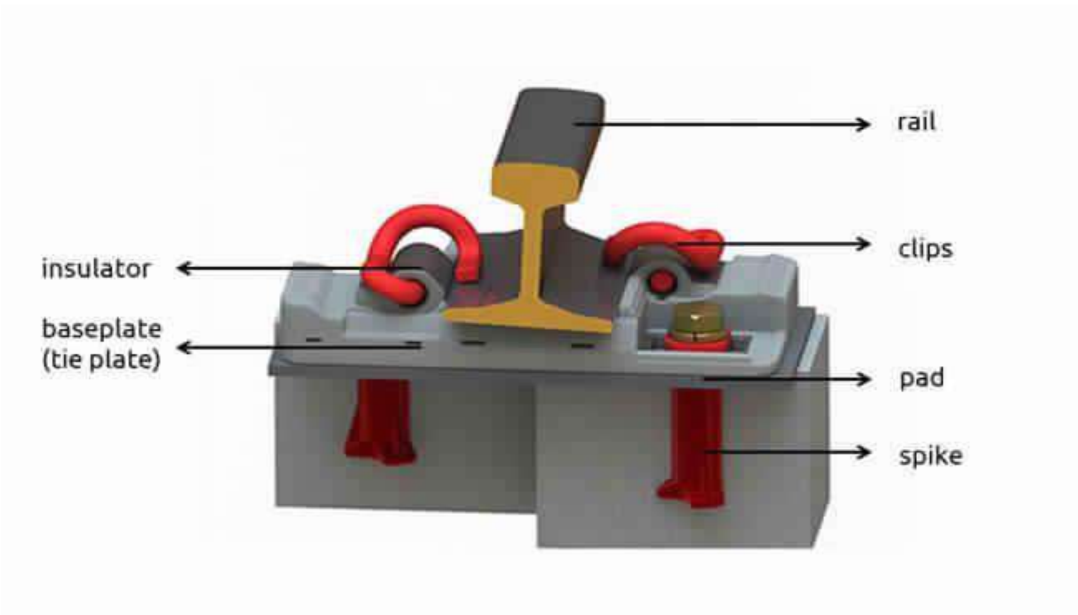
Rail fastenings shall:

1. hold rails securely in the rail seat.
2. limit the rotation of the rail about the outer edges of the rail foot.
3. minimise longitudinal movement of rails through creep and thermal forces.
4. assist in retention of track gauge.
5. not cause damage to the rail.

Where practicable, rail fastenings shall either be self-tensioning or permit tightening of the fastening to a predetermined load.

Where existing rail fastenings are not effective in minimising longitudinal movement of rails, it is permissible to fit rail anchors as a method of meeting this requirement.

Rail Fastenings Components



Clips

Clips are used to fasten the rails to the underlying baseplate.

Spike

Rail screw is a large (~6 in or 152 mm length, slightly under 1 in or 25 mm) metal screw used to fix a tie plate or fasten rail.

Tie Plate

A tie plate is also called a baseplate or sole plate. Rail tie plate is used in rail construction to support the rails. Tie plates are generally used to take the load of rail and distribute the load to the sleepers offering proven economies.

Insulator

Rail insulator is used to adjust rail gauge and insulate the rail from ties and clips.

Pad

The rail pad, originally called sole plate, is used when rail is attached to concrete, rather than timber, ties or sleepers. Rail pads function to reduce fatigue cracking of the concrete ties, believed to be driven by impact and vibration from the passing train.

The raid pad prevents rail-sleeper abrasion and the crushing of the sleeper under the rail foot. Rubber rail pads are normally designed to a specified load-deflection characteristic. The initial stiffness of the rail pad is designed to be low so that that their deformations under the springs toe loads is quite substantial. This ensures that the rail pad remains in intimate contact with the rail despite any vertical movements of the latter. When the wheel is over the pad, the latter's stiffness must be high to prevent large movements which can result in the metal spring becoming loose. Such a load-deflection characteristic can be obtained by introducing grooves in the rubber rail pads. Rubber pad or grooved rubber rail pad are made up of rubber or plastic to dampen the shocks of vibrations of a passing train.

Compatibility of Components

Components that are to be used together (including rail supports, rail fastenings, pads and rail foot insulators) shall be compatible.

Selection of Components

The selection of components shall take into account the following factors:

1. track geometry
2. permissible and enhanced permissible speeds
3. track category
4. loads arising from braking and acceleration of trains
5. vehicle axle loads
6. electrical insulation requirements
7. underlying formation and structures supporting the track
8. the form of track construction.

Fixtures And Fastenings:

Fixtures and fastenings are fitting to require for joining of rails end to end and also for fixing the rails to sleepers on a track.

FUNCTIONS OF FIXTURES AND FASTENINGS:

- To join the rails end to end to form full length of track
- To fix the rails to sleepers.

- To maintain the correct alignment of the track.
- To provide proper expansion gap between rails.
- To maintain the required tilt of rails.
- To set the points and crossings in the proper position.

All those fittings which are required for connecting the rails end to end and for fixing the rails to the sleepers in a track are known as fixtures and fastenings.

They include -

1) Fish plates

2) Spikes

3) Bolts

4) Chairs

5) Keys

6) Blocks

7) Bearing plates

The different functions of these fitting are :

1) To keep the rails in the proper positions.

2) Connection of rail to rail.

3) To set points and crossings properly

4) To allow for expansion and contraction of rails.

The various types of fixtures and fastenings listed above are briefly described below :

FISH PLATES : These plates are used to maintain proper alignment of the rail line. They maintain the continuity of the rails and also allow expansion or contraction of rails caused due to temperature variations. Generally these plates are made of mild steel and 20 mm in thickness.

They are 45.6 cm long and provided with 4 no. of 32 mm diameter holes at 11.4 center to center.

Indian railways generally adopt following two types of fish plates :-

1) Bone shaped fish plate

2) Increased depth fish plate

Bone shaped fish plate is used for connecting flat footed rails. The increased depth fish plate is generally used for connecting Bull-headed rails.

SPIKES : They are used to hold the rails to the wooden sleeper. A good spike should have following qualities :

1) It should have sufficient strength to hold the rail in position.

2) It should help in maintaining proper gauge.

3) It should be easy to fix and replace from the sleepers. Indian Railways use following types of spikes :-

1. Dog spikes
2. Screw spikes
3. Round spikes
4. Standard spikes
5. Elastic spikes

BOLTS : They are used for connecting :

1) Fish plates to the rails at each rail joint.

2) Chairs or bearing plates to timber sleepers.

3) Sleepers to bridge girders,etc

The different types of bolts used in Indian Railways are :

1. Hook bolts
2. Fish bolts
3. Fang bolts
4. Rag bolts

Hook bolts are used for fixing timber sleepers to bridge girders. They are popularly known as dog bolts.

Fish bolts are used to connect fish plates to the rails at rail joints.

Fang bolts are used for fixing side chairs to the sleepers.

Rag bolts are generally used to connect longitudinal timber sleeper or concrete sleepers to the walls of ash pits.

CHAIRS : They are used to hold the double headed and bull headed rails in required position. They are made of cast iron having two jaws and a rail seat. In order to fix the double headed or bull headed rail to a chair, the rail is placed between the two jaws of the chair.

KEYS : They are small tapered pieces of timber or steel to connect rails to chairs on metal sleepers.

Types of keys generally used are :

1) timber keys

2) metal keys

3) Stuart's keys

4) Morgan keys

BLOCKS : They are inserted in between the two rails running close to each other and bolted to maintain the required distance They may touch either the webs or the finishing faces or both.

BEARING PLATES : They are the plates placed in between the flat footed rails and timber sleepers on a track. They serve as chairs for flat footed rails. They are made of cast iron, wrought iron or steel.

Generally, they are of following types :

1) Flat bearing plates

2) canted bearing plates

Flat bearing plates are used at locations where rails are laid flat. Also they are used in turn out tracks under points and crossings.

Canted Bearing plates are used on soft timber sleepers beneath outside rail on curves, on sleepers placed on either side of rail joints, bridges etc. where rails are laid at an inward tilt of 1 in 20.

Ballast

Railway Ballast is the foundation of railway track and provide just below the sleepers. The loads from the wheels of trains ultimately come on the ballast through rails and sleepers.

Functions of Ballast

Some of the important functions of railway ballast are:

1. To provide firm and level bed for the sleepers to rest on
2. To allow for maintaining correct track level without disturbing the rail road bed
3. To drain off the water quickly and to keep the sleepers in dry conditions
4. To discourage the growth of vegetation
5. To protect the surface of formation and to form an elastic bed
6. To hold the sleepers in position during the passage of trains
7. To transmit and distribute the loads from the sleepers to the formation

8. To provide lateral stability to the track as a whole

Requirements for Ideal Ballast

The ideal material for ballast should fulfill the following requirements

1. It should be possible to maintain the required depth of the material in order to distribute the load of passing train on the formation ground
2. The material to be used for ballast should not be too rigid but it should be elastic in nature
3. The material for ballast should be of such nature that it grips the sleepers in position and prevent their horizontal movement during passage of train
4. It should not allow the rain water to accumulate but should be able to drain off the water immediately without percolating
5. It should be strong enough a resistance to abrasion

Materials for Ballast

The following materials are used for ballast on the railway track.

1. Broken Stone
2. Gravel
3. Cinders / Ashes
4. Sand
5. Kankar
6. Moorum
7. Brick Ballast
8. Selected Earth

CHAPTER-6 SLEEPERS

INTRODUCTION

Railway sleepers, also called railroad ties, railway ties or crossties, are an important railway component. Generally, the rail sleeper is always laying between two rail tracks to keep the correct space of gauge.

Having been developed for more than one hundred years, the railway ties need to meet the different requirements of the various railway tracks. In the past time, railroad ties were usually made of wood and had continued for about 50 years.

Then with the development of steel tracks, steel sleepers appeared. And later, the first concrete sleeper experiment was made in Germany in 1906 between the line Nuremberg and Bamberg.

In the recent time, concrete sleepers are widely used, especially in Europe and Asia. And in UK, steel ties are common. Besides, plastic composite ties are also employed in the rail track transportation.

Historically, wooden ties were made of a variety of softwood and some popular hardwoods such as oak, jarrah, and karri. They are only suitable for low-speed lines with a speed limit of 160 km/h. As to acceptable species of wood for sleepers, the types are European oak, beech, pine etc. But nowadays, wooden sleepers are mostly replaced by concrete sleepers in some countries.

Wooden sleeper advantages:

- Easy to manufacture and handle
- Electrically insulated
- Easily adapted to non-standard situations

Disadvantages:

- Non reusable
- Expensive of the limit wood resource

In recent times, steel sleepers mostly handle heavy loads and can be designed to suit different rail track specifications. Weighing the same as timber, steel sleeper can replace wood sleepers and be used on a ballasted bridge, providing a more durable and stronger solution without increasing bridge load.

Steel sleeper advantages:

- Easy to install and manufacture
- Handle more weight

Disadvantages:

- Sensitive to the chemical attacks
- Hard to maintain
- Low transverse resistance

Compared with wooden sleepers, which are increasingly difficult and expensive to source in sufficient quantities and quality, concrete ties are cheaper and easier to obtain.

In general, it can also be divided into pre-stressed mono block concrete sleepers and reinforced twin block concrete sleepers. Due to the greater weight, which helps sleepers remain in the correct position longer, concrete ties require less maintenance than timber and have a longer service life.

In some countries, concrete sleepers occupy an important position. For example, on the highest line categories in the UK, pre-stressed concrete ties are the only ones permitted by Network Rail standards.

Concrete sleeper advantages:

- Cheaper
- Easier to obtain
- Less maintenance required
- Longer service life

Disadvantages:

- Hard to handle due to large weight
- Difficult to maintain longitudinal level due to higher inertia moment and lower elasticity

1. Wooden Sleepers

These are commonly 254mm wide by 127mm thick in cross section by 2600 mm long. The sleepers are first seasoned (drying for up to 12 months so that to remove the juice/sap) and treated with preservative. Creosote is an oil generally used/ sprayed on the surface. They are either hard wood or soft wood type.

Wooden sleepers are the ideal type of sleeper. Hence they are universally used. The utility of timber sleepers has not diminished due to the passage of time.

Switch Ties: The primary use for switch ties is to transfer load (as from the name) and are made of hard wood. This type is preferably used in bridge approaches, heavily traveled, railway crossovers and as transition ties.

Softwood Ties: softwood timber is more rot (decay) resistant than hardwood, but does not offered resistance to spike hole enlargement, gauge spreading, also are not as effective in transmitting the load to the ballast section as the hardwood tie. Softwood ties and hardwood ties should not be mixed on the main track. Softwood ties are typically used in open deck bridges.

Concrete Ties: Concrete ties are rapidly gaining acceptance for heavy haul mainline use as well as for curvature greater than 2 degree. They are made of RCC or pre-stressed concrete containing reinforcing steel wires.

An insulator plate is placed between rail and tie to isolate the tie electrically.

Advantages of Wooden Sleepers

1. They are cheap and easy to manufacture
2. They are easy to handle without damage
3. They are more suitable for all types of ballast
4. They absorb shocks and vibrations better than other types of sleepers.
5. Ideal for track circuited sections
6. Fittings are few and simple in design
7. Good resilience
8. Ease of handling
9. Adaptability to non standard situation
10. Electrical insulation

Disadvantages of Wooden Sleepers

1. They are easily liable to attack by vermin and weather
2. They are susceptible to fire
3. It is difficult to maintain gauge in case of wooden sleepers
4. Scrap value is negligible
5. Their useful life is short about 12 to 15 years.

2. Steel Sleepers

- Steel ties are used where wood or concrete is not favorable, for example in tunnels with limited headway clearance
- They are also used in heavy curvature prone to gage widening.
- This type of steel ties can cause problem to signals control system
- Some problem of fatigue cracking have also experienced.
- Due to the increasing shortage of timber in the country and other economic factors have led to the use of steel and concrete sleepers on railways.

In the design of Steel sleeper, the following are considered:

- It should maintain perfect gauge
- Can fix the rail and there should be no movement longitudinally
- Should have sufficient effective area to transfer load from rail to ballast.
- The metal of sleepers should be strong enough to resist bending
- The design life should be 35 years

Advantages of Steel Sleepers

1. It is more durable. Its life is about 35 years
2. Lesser damage during handling and transport

3. It is not susceptible to vermin attack
4. It is not susceptible to fire
5. Its scrap value is very good

Disadvantages of Steel Sleepers

1. It is liable to corrosion.
2. Not suitable for track circuiting
3. It can be used only for rails for which it is manufactured
4. Cracks at rail seats develop during the service.
5. Fittings required are greater in number

3. Cast Iron Railway Sleepers

They are further divided into two categories:

1. Cast iron pot type sleepers
2. Cast iron plate type sleepers

Advantages of Cast Iron Sleepers

1. Service life is very long
2. Less liable to corrosion
3. Form good track for light traffic up to 110 kmph as they form rigid track subjected to vibrations under moving loads without any damping
4. Scrap value is high

Disadvantages of Cast Iron Sleepers

1. Gauge maintenance is difficult as tie bars get bent up
2. Not suitable for circuited track
3. Need large number of fittings
4. Suitable only for stone ballast
5. Heavy traffic and high speeds (>110kmph) will cause loosening of keys and development of high creep

4. Concrete Railway Sleepers

They have design life of up to 40 years. They can easily be moulded into the required/design shape to withstand stresses induced by fast and heavy traffic.

The added weight helps the rail to resist the forces produced due to thermal expansion and which can buckle the track. The weight of concrete sleepers is about 2.5 to 3 time the wooden sleepers. Pre-tensioned concrete sleepers are usually preferred now days

Reinforced Concrete and prestressed concrete sleepers are now replacing other types of sleepers except in some special circumstances like bridges etc. where wooden sleepers are used. Concrete sleepers may be of two types:

1. Mono Block Concrete Sleepers
2. TWIN BLOCK Concrete sleepers

Advantages of Concrete Sleepers

1. It is more durable having greater life (up to 50years)
2. It is economical as compare to wood and steel.
3. Easy to manufacture.
4. It is not susceptible to vermin attack
5. It is not susceptible to fire

6. Good for track circuited areas

Disadvantages of Concrete Sleepers

1. It is brittle and cracks without warning.
2. It cannot be repaired, and required replacement.
3. Fittings required are greater in number.
4. No scrap value

Bridges

Classification of Bridges

1.Classification of Bridges (According to form (or) type of superstructures)

•Slab bridge
•Beam bridge
•Truss bridge
•Arch bridge
•Cable stayed (or)suspended bridge

2.Classification of bridges (According to material of construction of superstructure)

•Timber bridge
•Concrete bridge
•Stone bridge
•R.C.C bridge
•Steel bridge
•P.C.C bridge
•Composite bridge
•Aluminum bridge

3. Classification of bridges (According to inter-span relationship)

•Simply supported bridge
•Cantilever bridge
•Continuous bridge

4. Classification of bridges (According to the position of the bridge floor relative to superstructures)

•Deck through bridge
•Half through or suspension bridge

5. Classification of bridges (According to method of connection of different part of superstructures)

•Pinned connection bridge
•Riveted connection bridge
•Welded connection bridge

6.Classification of bridges (According to length of bridge)

•Culvert bridge(less than 6 m)
•Minor bridge(less than 6 m-60m)
•Major bridge(more than 60 m)
•Long span bridge(more than 120 m)

9.Classification of bridges (According to function)

•Aqueduct bridge(canal over a river)
•Viaduct(road or railway over a valley or river)
•Pedestrian bridge
•Highway bridge
•Railway bridge
•Road-cum-rail or pipe line bridge

Bridge scour

It is the removal of sediment such as sand and rocks from around bridge abutments or piers.

Scour, caused by swiftly moving water, can scoop out scour holes, compromising the integrity of a structure.

Tunnels

A tunnel is an essentially horizontal, artificial underground opening, with a generally regular cross-section and a length that greatly exceeds its other dimensions. Tunnels are used for a wide variety of purposes. They **provide essential links in many highways, railroads, and urban rapid transit systems**.

Uses of Tunnels

Tunnels have many uses: **for mining ores, for transportation—including road vehicles, trains, subways, and canals—and for conducting water and sewage**.

Reinforced Cement Concrete Design

UNIT-1 (INTRODUCTION)

Topic 1.1. Concept of PCC & RCC with their unit weight?

Ans. PCC-: Plain Cement concrete, it is the mixture of cement, sand, aggregate with suitable per portions of water & its unit weight is-24KN/M^3 or 24000N/M^3

RCC-: Reinforced cement concrete, it is the mixture of cement, sand, aggregate & Steel Bars with suitable per portions of water & its unit weight is-25KN/M^3 or 25000N/M^3

Que1. Differentiate Between RCC & PCC?

Ans.

RCC	PCC
1. Reinforced cement concrete. 2. Material= Cement+ Sand+ Aggregate+ Steel + Suitable per portions of water 3. Ratio Used = CEMENT: SAND: AGGREGATE 1 : 1 : 2 1 : 1.5 : 3 1 : 2 : 4 4. Unit Weight= 25KN/M^3 5. Uses- Column, Beam, Slab, Stairs etc.	1. Plain cement concrete. 2. Material= Cement+ Sand+ Aggregate with suitable per portions of water 3. Ratio= CEMENT: SAND: AGGREGATE 1 : 4 : 8 1 : 5 : 10 4. Unit weight= 24KN/M^3 5. Uses- foundations and floors of buildings. They provide Plain surface over foundation etc.

Topic 1.2. Define reinforcing material?

Ans. The material which develops a good bond with concrete to increase its tensile strength called R/F material.

Reinforcing material can be mild steel bars, Tor steel bars, etc.

Topic 1.2.1. Suitability of steel as a reinforcing material.

OR

Why steel is considered as a best reinforcing material in concrete?

Ans. Steel is used as a most common reinforcing material because of the following reason:-

1. Steel develops a very good bond with concrete.
2. Steel is very strong in tension, compression, shear and tension.
3. The steel bars can be cut, bent, welded easily.
4. Steel has longer life and it is easily available throughout India.
5. Co-efficient of linear expansion of steel is nearly same as concrete.

Steel-11.7x10$^{-6/0C}$

Concrete-9.9x10$^{-6/0C}$

Topic 1.2.2 Explain properties of Mild Steel and HYSD.

PROPERTIES OF MILD STEEL	PROPERTIES OF HYSD
1. The mild steel bars are plane round and hot rolled bar.	1. HYSD means High Yield Strength Deformed Bars. It is also known as TOR steel.
2. These bars are more ductile as compare with HYSD. (due to less % age of carbon)	2. These bars are less ductile as compare with mild steel. (due to high % age of carbon)
3. To develop sufficient bond with concrete.	3. HYSD provide good bond with concrete due to ribs. (Projections are provided on the surface of bars as a rib)
4. They required hooks & bends at their ends for proper anchorage.	4. They do not require hooks or bends at ends hence these bars are economical.
5. Mild steel bars are also known as Fe-250 because of its yield strength is 250 N/mm^2.	5. HYSD bars may be hot rolled high yield strength bars or cold worked high strength deformed bars.
6. It is available in market in Fe-250 grade.	6. It is available in market in following grades. Fe-415, Fe-500, Fe-550, Fe-600
7. A mild steel bar gives sufficient warning before failure.	7. Tensile strength of HYSD is very high.

NOTE:-Nowadays TMT and CRS are available in the market.

- ✓ **TMT (Thermo Mechanically Treated) Bars:-**

  TMT steel is new generation high strength steel having superior properties as compared to common HYSD bars.

  In India, SAIL (Steel Authority of India Limited) is producing TMT steel.

  The TMT bars have following advantages:

  1. High yield strength
  2. Better weld ability
  3. Excellent ductility
  4. Better corrosion resistance

- ✓ **CRS (Corrosion Resistant Steel) Bars:-**

  The latest development in steel bars is the production of CRS bars.

  The carbon content in the bars is 0.18% as compared to 0.2% of HYSD bars.

  In India, SAIL and TISCO (Tata Iron and Steel Company) are Producing CRS bars.

Topic 1.2.3 -: State loading on structure as per IS-875.

Ans. The various types of loads act on a structure as per IS-875 are:-

1. Dead load
2. Live load (Superimposed Load)
3. Wind load
4. Snow load
5. Seismic load (Earthquake Load)

1. **Dead load-** The dead loads are due to self weight of the structure. These are permanent loads of finishing and filling material etc depends upon the unit weight of material. Example- floor, beams, column etc.

2. **Live load-** loads which are varying in magnitude and position are called live loads. It is called superimposed loads. Example- loads of people, furniture and movable equipments etc.

3. **Wind load-** The force exerted by horizontal component of wind is to be considered in the design of building. It depends upon the velocity of wind, shape and size of building. It should be considered as the design of multi-story building, towers, and poles. (Upto height 30m wind pressure is considered to act uniformly). (Above 30m height, the wind pressure is increases).

4. **Snow loads-** Building which are located in the regions where snow fall is very common are to be designed for snow load.

5. **Seismic load-** Seismic loads are caused by the shocks due to earthquakes which are calculated as per IS-1893-2000.
   Now it is mandatory to follow the recommendations regarding seismic loads in the design of structures, if the structure is situated in the seismic areas.

   Que: - Define Characteristics Compressive strength of concrete.
   Ans: - It is that strength below which not more than 5 percent of the test results are expected to fall

   Que: - **Explain M 25**.
   Ans: - "M" refers to the mix and 25 represents that the characteristics compressive strength of 150 mm size concrete cube at 28 days, expressed in N/mm^2

   Que: - **What is Yield strength of Fe-250**?
   Ans: - Yield strength of Fe 250 steel is 250 N/mm^2

UNIT-2
(INTRODUCTION TO METHODS OF RCC DESIGN)

Topic 2.1: - **Define Working Stress Method**

Ans: - This method is based on the linear elastic theory and assumes that both steel and concrete are elastic and obeys Hooks Law. Therefore, this method is also known as “Elastic Method of design” or “Modular ratio Method”

- **Basic assumptions of Working Stress Method?**
  1. At any cross-section, Plain Section before bending remain plain after bending.
  2. The concrete is assumed to be homogeneous.
  3. Tensile strength of concrete is ignored.
  4. There is a Perfect bond between steel and concrete.
  5. There is no initial stress in concrete and steel.
  6. The modular ratio(m)=280/3 σcbc
  7. All tensile stress taken up by steel none by concrete.

Topic 2.2: - **Define Limit state Method**

Ans: - This is the most rational method which is based on safety at ultimate loads and serviceability at working load. The acceptable limit of safety and serviceability requirements before failure of a structure takes place is known as a limit state.

The important limit states which are to be considered in design are:-

(1) Limit State of Collapse

(2) Limit state of Serviceability

(1) **Limit State of collapse: -** limit state of collapse is also known as ultimate limit state as it corresponding to the maximum load carrying capacity.

Limit state of collapse occur when the structure as a whole or part of the structure collapses under following condition:-

I. Limit state of collapse in flexure (Bending).
II. Limit state of collapse in compression.
III. Limit state of collapse in shear.
IV. Limit state of collapse in Torsion.
V. Limit state of collapse in Bond.

(2) **Limit State of Serviceability: -** This limit state is introduced to prevent excessive deflection and cracking.

Limit state of serviceability based on the structure under working loads (Service load)

- **Basic assumptions of Limit State Method?**

1. Plain sections normal to the axis remain plain after bending.
2. The Maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending.
3. Design compressive strength in concrete=0.67fck/1.5 = 0.45fck
4. The tensile strength of concrete is ignored.
5. For design purpose, the partial safety factor for material (Ym)=1.5 for concrete & (Ym)=1.15 for Steel is considered.
6. The Relationship between stress-strain distribution in concrete is assumed to be parabolic as shown in fig. 2.1

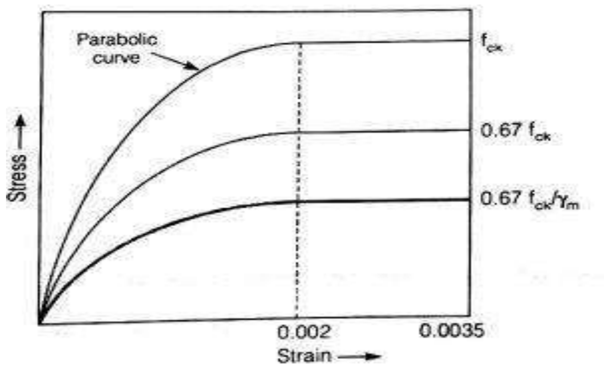


Fig. 21 : Stress-strain curve for concrete

- **Difference between WSM and LSM.**

Working stress Method	Limit state method
1. It is based on the behaviour of structure under working load.	1. The structure is designed on the basis of critical limit.
2. Factor of safety is considered for concrete FOS=1.75 for steel FOS=3 for concrete	2. Partial safety factor is considered For Concrete=1.5 For Steel=1.15
3. It is known as deterministic method.	3. It is known as in deterministic method.
4. Stress distribution is assumed to be linear.	4. Stress distribution is non-linear.
5. In working stress method required higher quantity of steel reinforcement.	5. Required less quantity of steel reinforcement.
6. Safety against ultimate load is not known	6. It satisfies all the limit state of collapse and serviceability
7. This method is also known as “Elastic Method of design” or “Modular ratio Method”	

UNIT-3
(Shear and Development Length)

- **Define nominal shear stress:-** shear force per unit cross-sectional area of a beam at any section is known as nominal shear stress.
  It is denoted by (τ_v).
  τ_v =V/bd N/mm^2 V=WL/2 τ_v= Nominal shear stress
  L= clear span V= Shear force in beam b= width of beam d= depth of beam

- **Define diagonal tension:-** the tension which is caused in the tensile zone of the beam, due to shear at or near the supports are called as diagonal tension. Due to this cracks at 45^0 occur in beams.

- **Shear strength of concrete without shear reinforcement:-**
  (As per IS 456-2000 clause number B-5.2)
  The design of shear strength t_c depends basically on the grade of concrete (f_{ck}) and the percentage of tensile steel (P_t).
  τ_c= permissible shear stress in concrete N/mm^2

- **Define maximum shear stress and shear reinforcement:-** Maximum shear stress ($\tau_{c\ max}$) the value of $\tau_{c\ max}$ is limited to the value in IS 456-2000.
  Clause No: 5.2.3 Pg 73/table 20
- **Conditions for shear reinforcement-**
  1. If τ_v< τ_c no shear R/F provided. (Provided only nominal shear R/F).
  2. If τ_v> τ_c then reinforcement provided.
     Check: τ_v & τ_c is not more than $\tau_{c\ max}$

- **Why shear reinforcement is provided: -** Shear reinforcement is provided in beam to avoid cracks due to shear.

- **Why minimum shear R/F (nominal shear R/F) is provided: -** If τ_v< τ_c no shear R/F provided. But as per IS 456-2000, even in such cases minimum shear R/F (nominal shear R/F) in the form of vertical stirrups shall be provided due to the following reasons:-
  1. It confines the concrete and hence increases its strength.
  2. It holds the reinforcement in place while pouring concrete.
  3. It act as effective tie for the compression steel

- **What are the functions of the vertical stirrups:-**
1. They hold the reinforcement both compression and tension.
2. They keep the bars in place while placing concrete.
3. They prevent brittle shear failure.
4. If the bond between steel and concrete is lost, even then shear reinforcement can sudden failure.
5. It helps in reducing the cracks due to tension.

- **What are different forms of provided shear reinforcement-:** Shear R/F Provided in the beam in any of the following forms

1. In the form of vertical bars is known as stirrups.
2. In the form of bent-up bars.
3. In the form of combination of stirrups and inclined bars.

- **Define development length:-** The minimum length of bar which must be embedded in concrete beyond any section to develop its full strength. It is denoted by L_d.

  $L_d = \phi\sigma_{st}/4\tau_{bd}$ does not exceed $M_1/V+L_0$

  M_1= moment of resistance of section

  V= shear force at section due to design load

  Φ= diameter of bar

  L_0 = sum of anchorage

- **Define bond and bond stress: -** Bond refers to adhesion between concrete and steel which resists the slipping of steel bar from the concrete. On other hand the shear stresses developed along the contact surface between steel bar and the surrounding concrete which prevents the steel bars from slipping out of concrete is known as bond stress. It is denoted by τ_{bd}.

UNIT-4
(Concept of Limit State Method)

- **What is partial factor of safety for material (Υ_m):-** In which partial safety factors for material divide by characteristics strength of material to get design value.
  It is denoted by **(Υ_m)**

  Values of partial safety factor (Υ_m) for strength of material

Material	limit state of collapse	Limit state of serviceability	
		Deflection	Cracking
Concrete	1.5	1.0	1.3
Steel	1.15	1.0	1.0

- **What is partial factor of safety for load.**
  It is denoted by **(Υ_f).** (SEE CODE) Page No. 68. TABLE 18

- **Write design value for material and load?**
  Design values: - are obtained when partial safety factor are applied to characteristic strength of material and characteristic load.
  These are obtained as below:-

a) **Design value for material:-** it is denoted by (f_d) is given by **$f_d = f/\Upsilon_m$**
Where f_d= design strength of material
f = characteristic strength of material
Υ_m= partial safety factor for material (1.5 for concrete and 1.15 for steel)

<u>**Note:-**</u> For Concrete=$0.67f_{ck}/1.5$ ($0.45f_{ck}$)
For Steel= $f_y/1.15$ ($0.87f_y$)

b) Design value for load:- it is denoted by (F_d) is given by **$F_d = F \times \Upsilon_f$**
Where F_d = design load or factor load
f = characteristic load
Υ_f = partial safety factor for load (SEE CODE) Page No. 68. TABLE 18

- **Which is the limit states considered in design:-**

  The most important limit states which are considered in design are:-

  A). limit state of collapse-it is also known as ultimate limit state as its correspondence to maximum load carrying capacity. It includes

  1. Limit state of collapse in flexure
  2. Limit state of collapse in compression
  3. Limit state of collapse in shear
  4. Limit state of collapse in torsion
  5. Limit state of collapse in bond

  B). limit state of serviceability- it is introduced ton prevent excessive deflection and cracking. The two important limit state of serviceability are

  1. Limit state of deflection
  2. Limit state of cracking

- **Define characteristics strength of material: -** Characteristics strength means that value of strength of material below which not more than 5% of test result are accepted to fall.

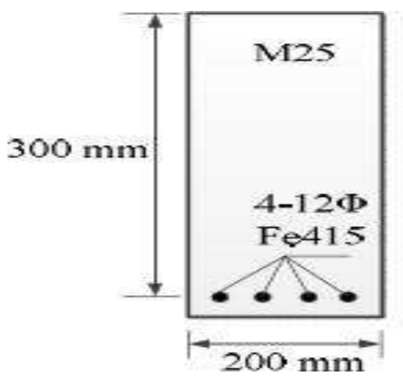
  Characteristics strength of material is designated by (f) **as per IS: 456-2000 Clause 36.1**

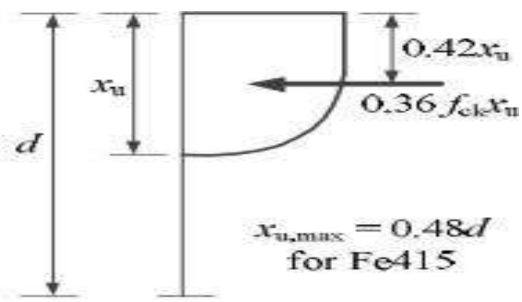
  A). Characteristics strength of concrete (f_{ck})-: **See IS: 456-2000 Clause 6.1.1**

  B). Characteristics strength of steel (f_y)

- **Characteristics strength of steel**:- It is denoted by (f_y) N/mm^2 and defined as that value of yield stress in case of mild steel or 0.2 to proof stress in case of HYSD bars which not more than 5% of the test specimen are expected to fall.

- **State stress block parameter:-** for the stress-strain curve, the design stress block parameters are as follows:





Where area of stress block= $0.36f_{ck}.x_u$
f_{ck}= characteristic compressive strength of concrete
x_u = depth of neutral axis

UNIT-5
(Singly Reinforced Beam)

- **Define singly reinforcement beam:-** Singly reinforcement beam in which the main reinforcement is provided in tension zone and other bars in compression zone.

- **Define neutral axis:-**The axis at which the stresses are zero in the section and it divides the cross section into a tension and compression zone.

- **Depth of Neutral Axis (X_u)**

Total tension (T) =Total Compression (C)

$$0.87\ f_y\ A_{st} = 0.36\ f_{ck}.b.x_u$$

$$X_u = 0.87\ f_y\ A_{st} / 0.36\ f_{ck}.b$$

- **Maximum depth of Neutral Axis ($X_{u,\ max}$)**

Grade of Steel	f_y (N/mm^2)	$X_{u,\ max.}$
Fe 250	250	0.53d
Fe 415	415	0.48d
Fe 500	500	0.46d

- **Limiting (Maximum) Percentage of steel ($P_{t,lim}$):-**

$$(P_{t,lim})\ \% = \frac{0.36 f_{ck}.x_{umax}\ \ X\ 100}{0.87 fy.\ d}$$

- **Limiting Moment of Resistance($M_{u(lim)}$):-**

$$(M_{u(lim)}) = 0.36 f_{ck}.b.x_{u(max)}\ (d-0.42.x_{umax})$$

Value of Limiting Moment of Resistance ($M_{u(lim)}$)

Grade of Steel	Value of ($M_{u(lim)}$)
Fe=250 (f_y=250 N/mm^2)	0.148 f_{ck}.b.d^2
Fe=415 (f_y=415 N/mm^2)	0.138 f_{ck}.b.d^2
Fe=500 (f_y=500 N/mm^2)	0.133 f_{ck}.b.d^2

- **Explain types of beams:-**Types of beam sections depending upon the tensile steel. Hence, they can be classified into three categories:-

  A. Balance section
  B. Under R/F section
  C. Over R/F section

A. BALANCE SECTION:-

1. It may be defined as a section in which the maximum stress in concrete and tensile stress in steel reach their permissible value simultaneously.
2. $Xu = Xu_{max}$
3. pt=pt(limiting max.)
4. $Mu_{(limi)}=0.3f_{ck}.b.Xu_{max}(d-0.42Xu_{max})$

B. UNDER R/F SECTION

1. In which the percentage or area of steel is provided less than required for a balance section.
2. In this section steel is fully stressed and concrete is under stressed.
3. $Xu < Xu_{max}$
4. pt<pt (limi)
5. $Mu = 0.87f_yA_{st.}\ (d-0.42Xu)$

C. OVER R/F SECTION

1. In which the % age or area of steel provided is more than that required for balance section.
2. In this section concrete is fully stressed and steel is under stressed.
3. $xu>xu_{(max)}$
4. $pt> pt_{(limi)}$
5. $Mu=Mu_{(limi)}$, $0.36f_{ck}.b.xu_{(max)}X(d-0.42xu_{max})$

- **Reinforcement in beams:-**

i) Maximum reinforcement:- maximum tensile reinforcement shall not exceed 0.04 bD,

Where b= width of beam

D= overall depth

ii) Minimum reinforcement:-

$A_{st}= 0.85bd/f_y$

f_y = characteristics strength of reinforcement (N/mm^2)

- **Side face reinforcement:-** when depth of the beam exceeds 750mm, then it is necessary to provide shear force reinforcement @ 0.1% of web area.

UNIT-6

(Doubly Reinforced Beam)

- **Doubly reinforced beam**: - A beam reinforced with steel both in tension and compression zone are called doubly reinforced beam.
- **Under what circumstances doubly R/F beam are provided:-**
  A doubly reinforced beam section is generally provided under following circumstances:-

  1. When the depth of beam is restricted due to any obstruction.
  2. When Mu > Mu $_{(lim.)}$ then doubly R/F beam are provided.
  3. When stiffness of beam is required to increase then doubly R/F beam is provided.
  4. When the member is subjected to shocks or impact forces.
  5. When the member is subjected to eccentric load.
  6. In seismic area D.R.B. are designed.

- **Depth of Neutral Axis (X_u)**

$$X_u = 0.87\, f_y\, A_{st} - f_{sc}\, A_{sc} / \, 0.36\, f_{ck}.b$$

- **Area of tensile steel (A_{st}):-** $A_{st} = A_{st1} + A_{st2}$

  $A_{st1} = M_{u\ lim} / \, 0.87 f_y.(d - 0.42 x_{umax})$ (where $M_{u\ lim} = M_{u1}$)

  $A_{st2} = M_{u2} / \, 0.87 f_y.(d - d')$ (where $M_{u2} = M_u - M_{u1}$)

- **Area of tensile steel (A_{sc}):-**

$$A_{sc} = M_{u2} / \, f_{sc}.(d - d')$$

- **Ultimate moment of resistance(M_u):-**

  $M_u = 0.36\, f_{ck}.b\, x_u.(d - 0.42 x_u) + f_{sc}\, A_{sc}\, (d - d')$

Maximum Design stress f_{sc} (N/mm^2) in compression

Grade of Steel	d'/d						
	0.050	**0.075**	**0.100**	**0.125**	**0.150**	**0.175**	**0.200**
Fe-415	355	354	353	347.5	342	335.5	329
Fe-500	424	418	412	403.5	395	382.5	370

UNIT-7
(Behaviour of T-beam)

- **Define flanged beam**: - When the slab and beam are cast monolithically (a portion of slab cast with the beams in the forms of T and L beams to increase the stiffness of the slab.

- **Define T and L beam**:- When the slab and beam are cast monolithically then the intermediate beam are T-beam. (in T-beam having slab extending on both sides of it.)

  When the slab and beam are beam cast monolithically then the end beam are called L-beam.

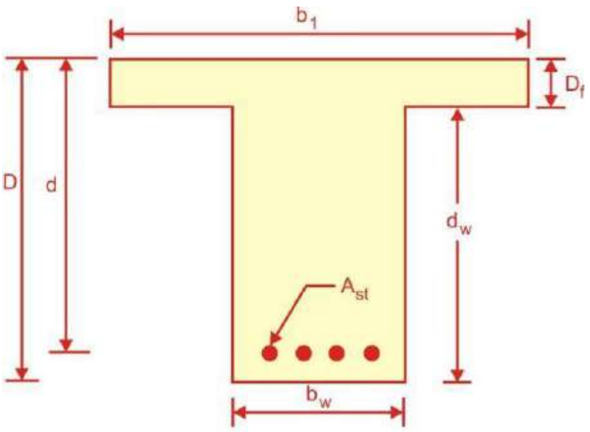


Fig. 2.12. T-beam.

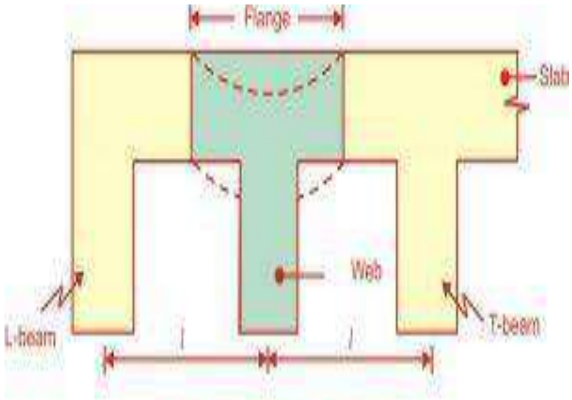


Fig. 2.11. T-beams and L-beams.

- **Why a T-beam is considered better as compared to a rectangular beam: -**
  In a rectangular RCC beam, concrete below the N.A does not resist any bending moment But simply holds the tensile R/F. Also, some portion of the concrete just above the N.A carries only very little compressive stress. Because the intensity of compressive stress there is very small magnitude.

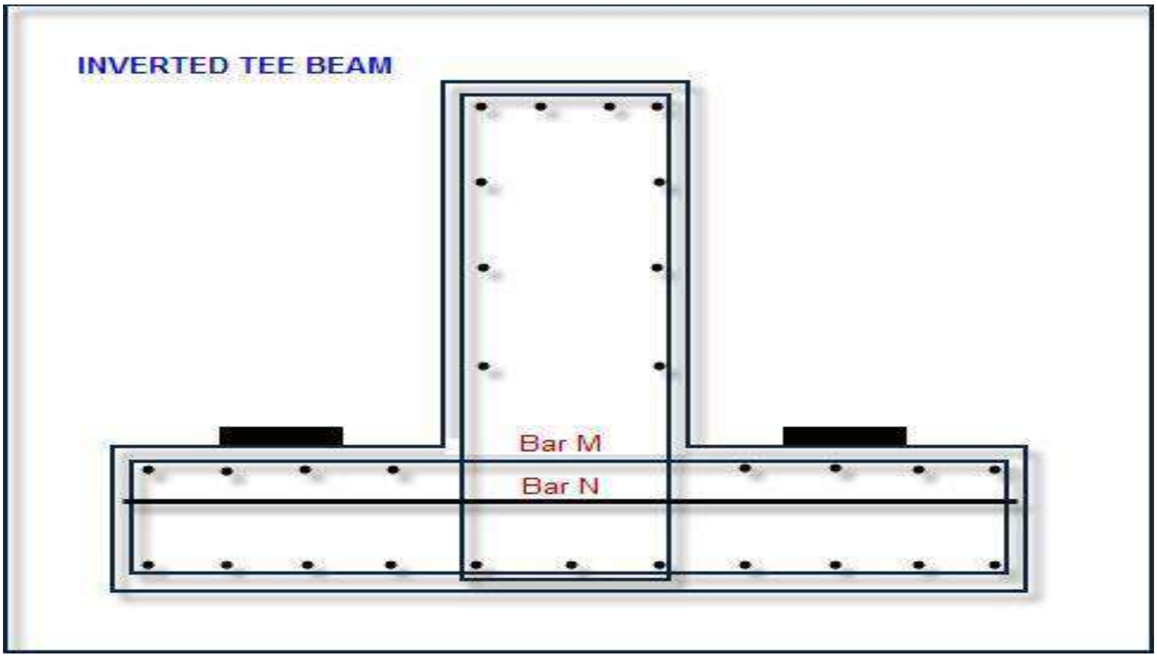
  These suggest that the section of beam should be such that it has greater width at the top in comparison to the width below the N.A.

  In this way concept of a flanged beam evolved which has larger width at the top in comparison to width at the bottom.

- **Define inverted T- beam. Why sometime the inverted T-beam is provided:-**

  When the beam is provided above the slab it is called inverted T-beam.

  In some cases, the portion of beam below the slab may be undesirable from architectural and other point of view, or want of clear space between floor and ceiling . In that case beam is provided above the slab .Hence, inverted T-beam are provided.



UNIT- 8 & 9
(One Way & Two Way Slab)

- **Define one way slab**: - The ratio of larger span to shorter span is equal to 2 are called one way slab. These slabs are also known as edge supported slab.

- **Define two way slab**: - The ratio of longer span to shorter span less than 2 are called two way slabs. Two way slab are supported on the four edges.

- **Differentiate between one way slab and two way slab**

Sr. No	ONE WAY SLAB	TWO WAY SLAB
1	Longer span/Shorter Span Ly/Lx > 2	Longer span/Shorter Span Ly/Lx < 2
2	Bending take place along shorter span only	Bending takes place along both spans.
3	Main bars are provided along Shorter span.	Main bars are provided in both the Spans
4	Distribution steel is provided along longer spans.	No distribution R/F provided
5	Thickness of slab is more as compared to two way slabs.	Thickness of slab is less.
6	Steel required is more.	Steel required is less.
7	Less economical.	More economical.

- **Define Restrained and Unrestrained slab:-**
- **Restrained slab:-**When the two way slabs is loaded the corners gets lifted up. These corners can be prevented from lifting by provided fixity at the supports by beams or wall. Such type of slab in which corners are prevented from lifting are called as restrained slab.
- **Unrestrained slab:-**The two way slab in which corners are not prevented from lifting are called unrestrained slab. It is also known as slabs with corners not held down.
  When simply supported slabs are subjected to external loads they have the tendency to lift at corners due to Torsional moment in the slab. When there is no adequate provision to resist torsion at corners, slabs are called simply supported beam.

- **Which types of reinforcement is provided in one way slab:-** There are two types of reinforcement provided in one way slab:
  1. Main reinforcement
  2. Distribution reinforcement
  3.
- **Write the R/F detail in slab as per IS 456-2000:-** As per IS: 456-2000 the area of reinforcement in either direction in slabs should not be less than:
  1. For HYSD bars- 0.12bD/100
  2. For Fe 250 steel- 0.15bD/100

- **Why two way slab is more economical as one way slab:-**In two way slab, total load is divided along the spans as compared with one way slab. Thus, the maximum bending moment, shear force and deflection for such a slab is much smaller than that of a one way slab. Therefore, smaller thickness of slab with lesser quantity of steel is required in two way slab. Hence, two way slab are more economical than one way slab.

- **Why distribution R/F is provided in one way slab: -** The steel which distributes the load and stress coming over it. It is known as distribution steel. It is provided perpendicular to main steel.

  The main function of steel is:-
  (a) To the concentrated load on slab.
  (b) To resist shrinkage & temperature stressed.
  (c) To keep the main R/F in position.

- **Write the design steps of One Way Slab:-**

  Step 1. Assume 1m width of slab.(i.e b=1m)

  Step 2. Assume effective depth of slab(d)= span/25 to span/30.

  Step 3. Find the effective span(l) of the slab.

  Step 4. Calculate factored design load (w_u) on the slab.(w_u) (factored load per unit length)

  $$(w_u)=1.5XW \qquad (W=D.L,L.L,F.L)$$

  Step 5. Find the factored maximum bending moment (M_u)

  $$M_u= w_u l^2/8$$

  Step 6. Design the slab as a balanced section:

  For a balanced section $M_u= M_{u\ lim}$

  Step 7. Calculate the area of main steel (A_{st}) from the equation:

  $$M_u= 0.87\ f_y\ A_{st}(d- f_y\ A_{st}/f_{ck}b)$$

  Step-8. Calculate the area of distribution reinforcement:

  Area of distribution steel: **0.12bD/100 (for HYSD steel)**

  0.15bD/100 (for Fe 250 steel)

  Step 9. Check for shear

  Step 10. Check for development length at supports.

UNIT- 10
(Axially loaded Column)

- **What is a column: -** A column is defined as a vertical compression member whose effective length exceeds three times the least lateral dimension (b).
- **What is a pedestal: -** A vertical compression member whose effective length is less than 3 times the least lateral dimension is called pedestal. It may be cast with plane cement concrete.
- **Define slenderness ratio:-**The ratio of effective length of column to its least lateral dimension (b).
- **NOTE-** When the slenderness ratio increase the strength of column decrease.

- **Define effective length of column**: - It is defined as that length of column which takes part in buckling under the action of loads. It is denoted by L_{eff}.
- **Consider effective lengths of column as per IS 456-2000** (Annexure-E Page no;-92)

- **Explain the classification of column**:- Column are classified on the four types:-

1. On the basis of material of construction

(a) Timber column

(b) Masonry column

(c) Steel column

(d) R.C.C column

2. On the basis of shape of column

(a) Square column

(b) Rectangular column

(c) Circular column

(d) Hexagonal column

3. On the basis of line of action of load

(a) **Axially loaded column**
(b) **Eccentrically loaded column**

a.) **Axially Loaded Column**- The column in which the line of action of loads is along the longitudinal axis or centroid of column.

✓ **NOTE-** In axially loaded column are loaded to direct compressive stress only. No bending stress develops in the column section.

b.) **Eccentrically loaded column-** The columns in which the line of action of loads is away from the longitudinal axis of the column. It is denoted by eccentricity (e). These columns subjected to bending stress, developed due to **eccentricity.**

4. On the basis of length of column

(a) **Short column**
(b) **Long column**

a) **Short column**- A column is considered as short column when its slenderness ratio (the ratio of effective length to its least lateral dimension) is less than or equal to 12.

Short Column= $l_{eff.}/b < 12$

b) **Long column**- A column is considered as short column when its slenderness ratio (the ratio of effective length to its least lateral dimension) is greater than 12.

Long Column= $l_{eff.}/b > 12$

- **Which type of steel R/F provided in column:-** There are two types of steel R/F used in a column:-

1. Longitudinal R/F
2. Transverse R/F

Longitudinal R/F: - The steel bars provided longitudinally in a column are known as longitudinal R/F. It is also known as main steel.

Note:- Limit of Longitudinal R/F in column shall be 0.8% to 6% of gross sectional area of column

Transverse R/F: - The reinforcement provided along the lateral dimension of the column in the form of ties or spirals enclosing the main steel. The transverse R/F does not contribute strength to the column. The main function of transverse R/F is to avoid buckling of longitudinal R/F.

- **Write the functions of longitudinal reinforcement:-**

  1.) To share the vertical compressive load along the concrete.

  2.) To resist any tensile stresses develop in the column due to bending, eccentric load etc.

  3.) To prevent sudden brittle failure of column.

  4.) To reduce the effect of creep and column.

  5.) To increase the ductility of column and prevent sudden failure.

- **Write the function of transverse reinforcement (lateral ties):-**

  1.) To hold the longitudinal R/F in position at the time of pouring.

  2.) To prevent longitudinal buckling of main steel.

  3.) To prevent longitudinal splitting of concrete.

  4.) To resist diagonal tension caused due to transverse shear develop.

- **Write IS 456-2000 specification regarding longitudinal reinforcement:-**

  1. Percentage of longitudinal steel varies between 0.8 to 6% of gross sectional area.
  2. Minimum diameter of bar to be used 12 mm.
  3. Longitudinal reinforcement help in taking compression association with concrete.
  4. Minimum numbers of bars required for square or rectangular column is 4 no's.
  5. For circular column minimum no's of bars is 6.
  6. Spacing of corner bars shall not exceed 300 mm

- **Write IS 456-2000 specification regarding of transverse reinforcement (lateral ties):-**

  Lateral ties either in the form of link or spirals

A. **For diameter of lateral ties:-** diameter of lateral ties bar shall be grater of the following:-

   I. ¼ x the diameter of grater longitudinal bar.

   II. 6 mm.

B. **Pitch or Spacing of lateral ties:-** spacing of lateral ties or pitch shall be least of the following:-

   I. 300 mm

   II. Least lateral dimension (b).

   III. 16 x diameter of main bar.

- **Minimum eccentricity:-** it is denoted by e_{min}

  $\mathbf{e_{min}}$ should be less than 0.05 D

  Where D= dimension of column under consideration

- **Load carrying capacity of axially loaded short column:-** it is denoted by $\mathbf{P_u}$ and it can be calculated by following formula.

$$\mathbf{P_u = 0.4\, f_{ck}.A_c + 0.67 f_f.\, A_{sc}}$$

- **Design steps of short axially loaded column:-** it includes following steps.

1. To determine the shape and size of column.
2. To determine the area of compression steel required.

   2.1 To choose the diameter of main bar.

   2.2 To find the no of bars.

   2.3 To check the percentage of main steel.
3. To design the lateral ties.

   3.1 to choose the diameter of lateral ties.

   3.2 To find the pitch of lateral ties.
4. Summarize and draw the cross-sectional details showing all the above found parameters.

UNIT-11
PRESTRESSED CONCRETE

- **What is Prestressed Concrete?**
  It is a method of applying pre-compression to control the stresses resulting due to external loads below the neutral axis of the beam.

  Pre-compression resulting either no tension or compression.

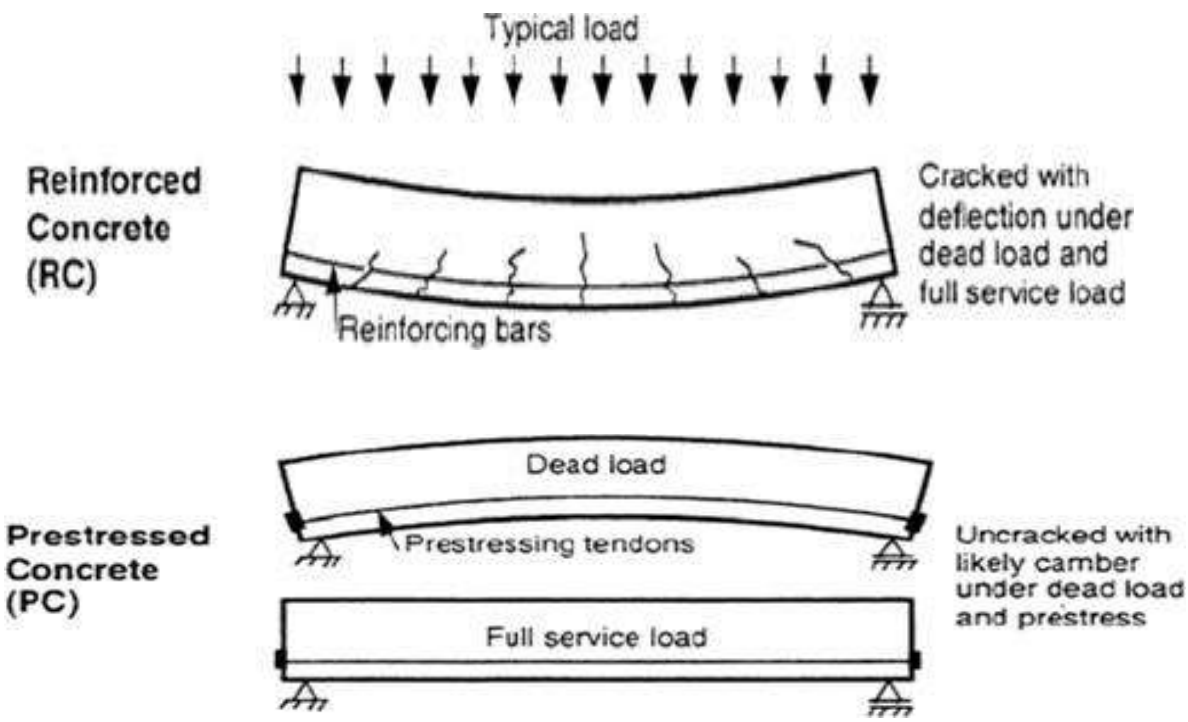
- **Pre stressed concrete: -** is the one in which internal stresses are induced in a planned manner, so that the stresses resulting from external loads are counteracted to a desired level.

- **Pre stressed concrete** is better as compared to RCC because of two major causes:

i) Minute cracks observed in RCC can be eliminated.
ii) High tensile steel can be used economically.

- ## Reinforced concrete:-

1. Concrete is strong in compression weak in tension.
2. Steel in strong in tension
3. Reinforced concrete uses concrete to resist compression and to hold bars in position and uses steel to resist tension.
4. Tensile strength of concrete is neglected (i.e. zero)
5. R.C beams allows crack under service load.



➢ **Basic Concept of pre-stressing**:-

- ✓ Prestressed concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from the external loads are counteracted to a desired degree.
- ✓ Pre-stress is introduced by stretching steel wire and anchoring them against concrete.
- ✓ The concept of pre stressing was invented years ago when metal brands were wound around wooden pieces to form barrels.
- ✓ The metal brands were tightening under tensile stress which creates compression between the staves allowing them to resist internal liquid pressure.

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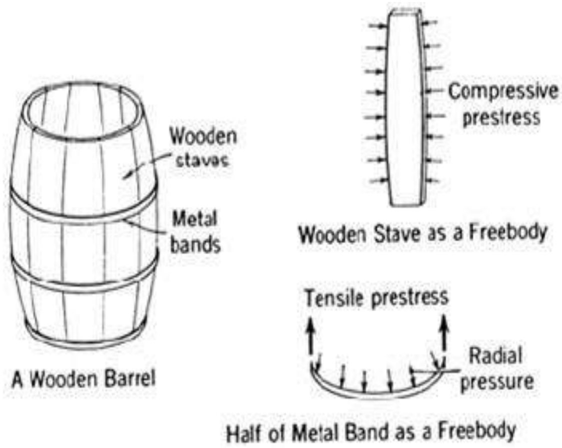


➢ **Principle of pre-stressing**:-

1. Pre-stressing is a method in which compression force is applied to the reinforced concrete section.

2. The effect of pre stressing is to reduce the tensile stress in the section to the point till the tensile stress is below the cracking stress. Thus the concrete does not crack.

3. It is then possible to treat concrete as a elastic material.

4. The concrete can be visualized to have two compressive force:-

a. Internal pre-stressing force.

b. External forces (Dead Load, Live Lode etc)

5. These two forces must counteract each other.

➢ Advantages of prestressed concrete in comparison with RCC:-

1. It needs about 1/3rd the quantity of steel and 1/4th the quantity of concrete as compared to RCC.
2. Lighter and slender members can be used.
3. Factory made members are possible in pre tensioning.
4. Members like railway sleepers, electric poles, boundary pillars, gantary girders can be made.
5. Pre-stressed member are tested before use.
6. Dead loads are get counter balanced by eccentric pre-stressing
7. Cracks can be eliminated in tension zone.
8. It has high fatigue resistance.
9. It has high ability to resist the impact.
10. It has high live load carrying capacity.
11. Use the entire section to resist the load
12. Take full advantages of high strength concrete and high strength steel
13. Need less materials
14. Better corrosion resistance
15. Good for water tanks and nuclear plant

➢ Disadvantages of pre stressed concrete are:-

1. Initial cost of equipment is very high.
2. Very long slender members are difficult to transport.
3. Requires high tensile steel which is 2.5 to 3.5 times costlier than mild steel.
4. Pre-stressed concrete is less fiber resistant
5. Required skilled builders & experienced engineers.
6. It requires high strength concrete & steel.
7. More complex technically
8. More expensive
9. Harder to re-cycle
10. Required complicated formwork.

Prestressing Materials

- **IS Specifications for materials used in pre-stressed concrete:-** As per Indian standard code of practice for pre-stressed concrete (IS: 1343) following specifications for materials must be kept in mind:

  The two main materials in pre-stressed concrete are:

  A) Concrete B) Steel

- **Concrete: -**The concrete to be used in pre-stressed concrete member should be strong enough so that full strength can be utilized.

  1. As per IS: 456-2000, a minimum grade of M40 for pre-tensioned system and M30 for post-tensioned system should be used. High strength concretes are preferred for pre-stressing works because:
  2. Water cement ratio should be about 0.45 i.e. 10 bags of cement per m^3 of concrete is required.

- **Pre-stressing steel: -** Steel to be used for pre stressing must have high tensile strength, good surface condition and good bonding with concrete.

  The steel used for pre-stressing available in three forms:-

  i) Single wires (also called as tendons)
  ii) Group of wires (also termed as strands or cables)
  iii) Alloy steel round bars

  1. **Single wires (tendons):-** Hard drawn high tensile steel wire of diameter ranging from 1.5mm to 8mm and having tensile steel and other properties as specified in following clauses may be used

  2. **Wire strands (cables):-** Hard drawn steel wires may be used in the form of cables known as wire strands. The diameter of strand cable varies from 7mm to 17mm.

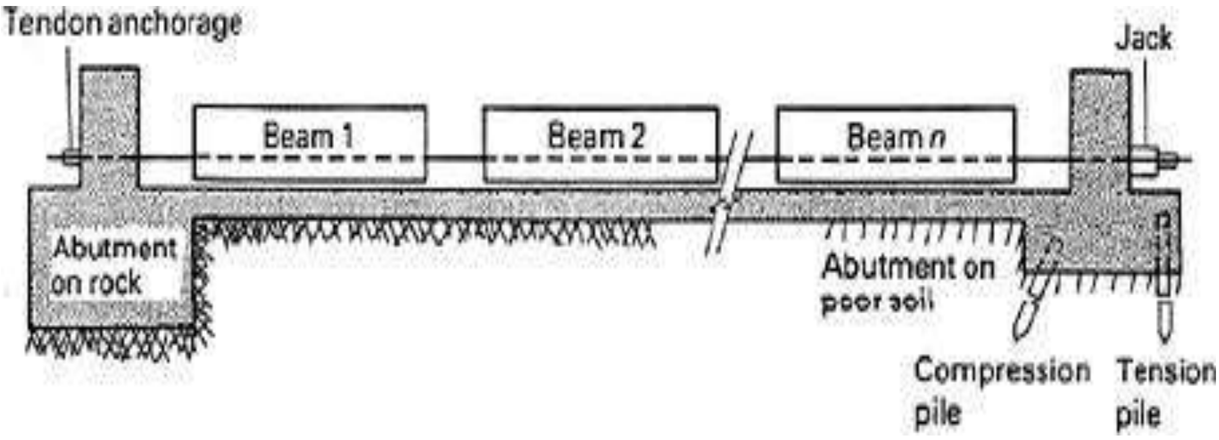
  3. **Round bars: -** High tensile alloy steel bars are used in pre-stressing systems. It is available in 10mm to 32mm diameter.

Prestressing Methods

- **Pre-stressed Concrete Methods: -** There are two basic methods of applying pre-stress to a concrete member.

1. Pre tensioning – steel is tensioned before the casting of concrete.
2. Post tensioning – steel is tensioned after the casting of concrete.

1. Pre-tensioning:- In Pre-tension, the tendons are tensioned against some abutments before the concrete is place. After the concrete hardened, the tension force is released. The tendon tries to shrink back to the initial length but the concrete resists it through the bond between them, thus, compression force is induced in concrete. Pretension is usually done with precast members.



- **Suitability/ Advantages of Pre tensioning method-:**

1. This Method is best suitable for factory production.
2. This method is very simple.
3. Many members can be casted at one time on same casting bed.
4. This method is economical.

- **Disadvantages of pre-tensioning method:-**

1. Size of member is restricted because long slender members are more difficult to transport.
2. Loss of pre-stress is more. (18-20%)

- **Procedure followed for the process of pre-tensioning :**

1) Anchoring the tendons against the end abutments.

2) Placing of jacks.

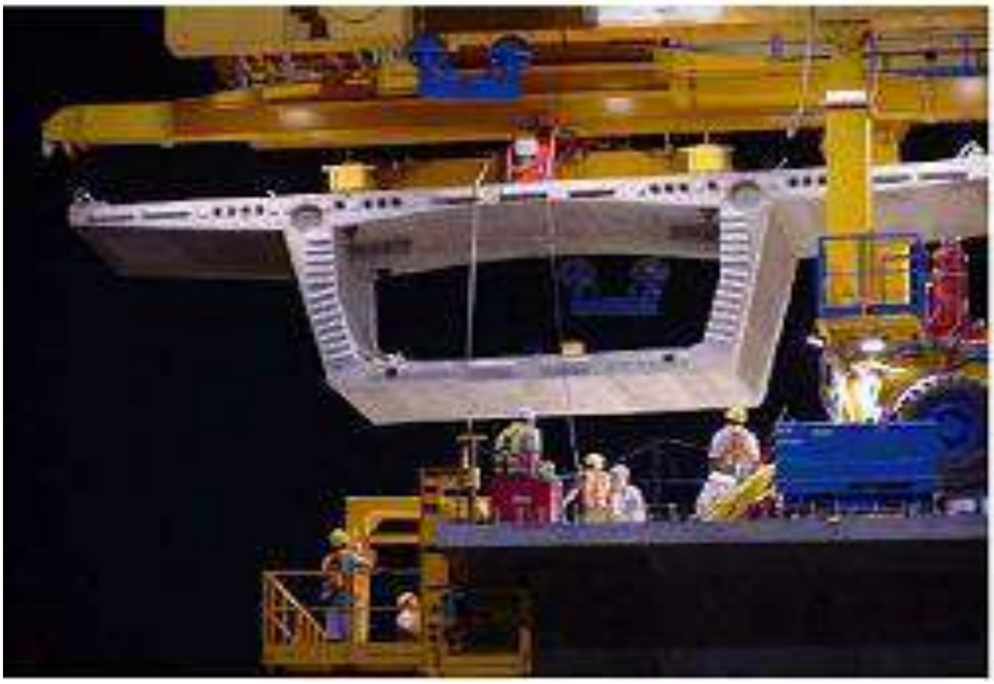
3) Applying tension to the tendons.

4) Casting of concrete.

5) Cutting of the tendons.

2. Post tensioning:-

In Post tension, the tendons are tensioned after the concrete has hardened. Commonly, metal or plastic ducts are placed inside the concrete before casting. After the concrete hardened and had enough strength, the tendon was placed inside the duct, stressed, and anchored against concrete. Grout may be injected into the duct later. This can be done either as precast or cast-in-place.



Precast Segmental Girder to be Posttensioned In Place

- **Suitability/Advantages of Post tensioning method:-**
    1. This is suitable for both cast in situ and pre cast members.
    2. Loss of pre-stress is less.(15-18%)
    3. There is no limit of casting as the method can be appllied at site also.
- **Disadvantages of Post tensioning method:-**
    1. This method is costly because of sheathing and grouting.

- **Methods of post-tensioning:**

    1) Casting of concrete.

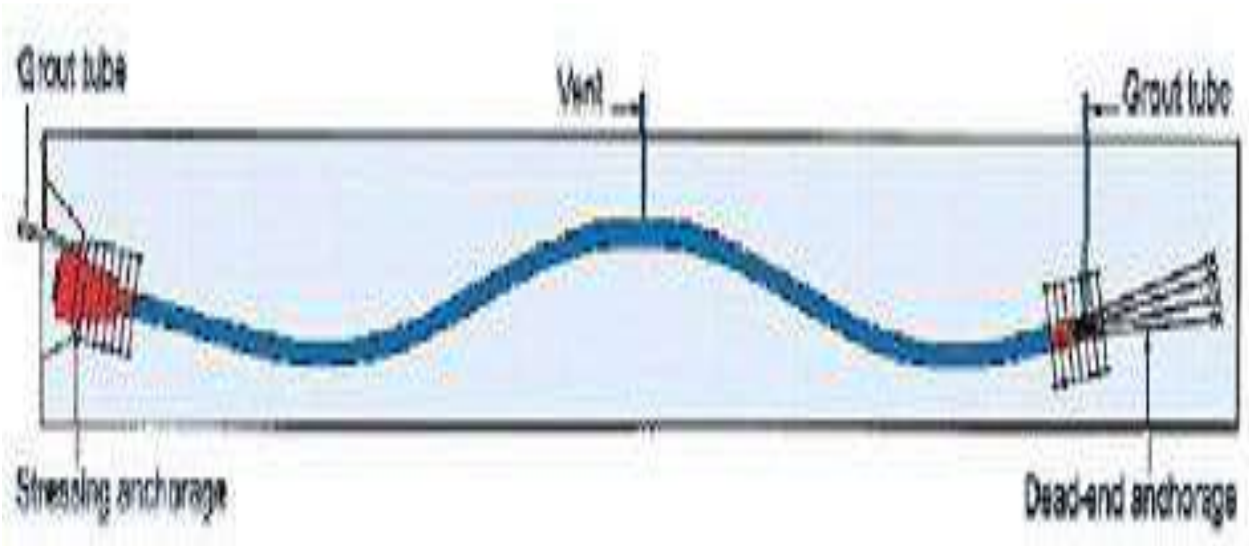
    2) Placement of tendons.

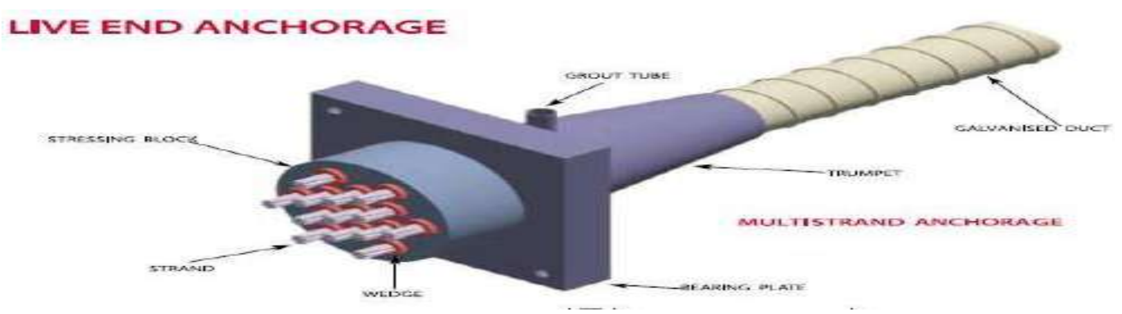
    3) Placement of the anchorage block and jack.

    4) Applying tension to the tendons.

    5) Seating of the wedges.

    6) Cutting the tendons.



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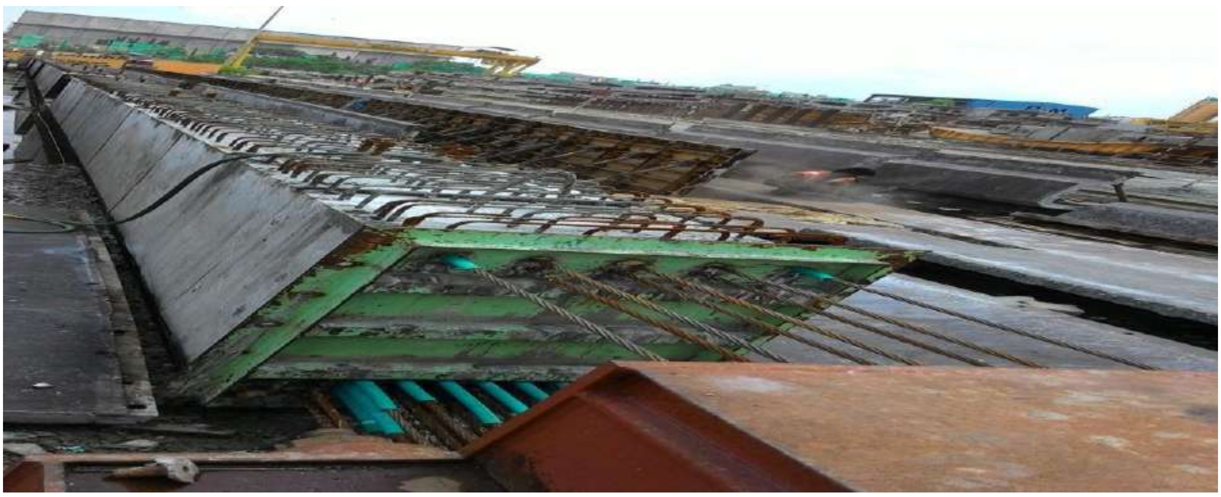


➢ Differentiate between pre-tensionng and post-tensioning methods:

S.NO:	Pre-tensioning method	Post-tensioning method
1.	Method is best suitable for factory production under controlled conditions.	This method is suitable for both cast-in-situ and pre-cast members.
2.	Loss of pre-stress is more. (18-20%)	Loss of pre-stress is less.(15-18%)
3.	Size of member is restricted because large members are more difficult to transfer.	Size of member is unrestricted therefore any size of member can be casted.
4.	This method is economical.	This method is costly because of use of sheathing and grouting.
5.	Minimum grade of concrete to be used is M40.	Minimum grade of concrete to be used is M30.

➢ **Loss in Pre-stress:-** The pre-stressed force applied to the member does not remain constant but decrease with passage of time due to various losses.

➢ Causes for loss of pre-stress:-

1. **Loss of pre stress due to friction:-**This type of loss occurs **(during the tensioning process)** only in the post tensioned members. The major losses due to friction occur between the tendons and its surrounding material (i.e. duct or spacer)These losses are due to length and curvature effect.**To reduce the loss due to friction cables can be lubricated, metal tubes may be provided at ends and stress may be applied from both ends.**

2. **Loss due to creep of concrete:-**Creep is a time dependent deformation which takes place due to continued compression of concrete.
   Pre tensioned member experiences more loss of pre stress due to creep of concrete then post tensioned members and amounts to 5%-10%.

3. **Loss due to shrinkage of concrete:-**Shrinkage in concrete is its contraction due to drying and chemical changes.**Loss of pre stress due to shrinkage of concrete may range from 4% to 6% for post tensioned members and 3% to 4% for pre tensioned members.**

4. **Loss due to elastic shortening (deformation) of concrete:** When pre stress is transferred to concrete, elastic stress and strains are induced in it. Due to this concrete members get shortened along with shortening of steel.**The loss due to elastic shortening of concrete may range from 3% to 6% in pre tensioned members and 4% in post tensioned members.**
   .

5. **Loss due to Stress relaxation in prestress steel:** Under a constant strain, there is a loss of stress in steel which is called relaxation.
   Loss of pre stress due to relaxation of steel amounts to 2% to 8% of the initial stress.

6. **Loss due to slippage of tendons and anchorage system:-**When the jacks are released a slight loss of pre stress occurs due to slippage of tendon and end anchorage system. Longer the length of tendon lesser will be the percentage loss. But in shorter tendons length this value may be greater importance. **This slippage generally varies from 2-5mm.**

NOTE: - Loss of pre stress is 18 – 20% in post tensioning and 15 – 18% in pre tensioning system.

Some Very short Questions of
(Reinforced Cement Concrete Design)

FILL IN THE BLANKS

1. Plain cement concrete is _____________
2. LSM stands for________________
3. Diagonal cracks are also known as _________________
4. Over reinforced sections fails in ______
5. Steel columns are generally termed as ____________
6. Beam is satisfactory when breadth is _____of depth.
7. In WSM factor of safety for steel is ______________
8. OPC is available in ___________grades.
9. Bent up bars are provided at an angle of_______
10. Minimum grade of concrete used in RCC work is______________.
11. All columns shall be designed for a minimum eccentricity of_____________
12. In two way slabs bending takes place in _________directions.
13. Two way slabs are provided if long span/short span ratio is _____________
14. Continuous edges of two way slabs resist _____________and permit___.
15. The minimum area of reinforcement in a slab is ______________of cross-sectional area of mild steel.
16. By using deformed bars ___________can be improved.
17. LSM is based on safety at____________
18. HYSD bars are also known as ___steel.
19. Partial factor of safety for concrete and steel are _______and ____________respectively for limit state collapse.
20. TMT bars have excellent______________
21. Limit state of serviceability are_______and________.
22. Limiting value of moment of resistance of Fe 415 steel is _________.
23. Over reinforced sections is _______in limit state method of design.
24. The major loss of prestress is caused due to ____________of concrete.
25. Minimum grade of concrete to be used for RCC works as per IS: 456-2000 is_____
26. Grades higher than _______should be used for Pre-tensioning in pre-stressed concrete.
27. Grade of steel is _____________proportional to shear strength.
28. Characteristic strength of steel reinforcement used for making stirrups should not exceed _____________.
29. In under reinforced sections _____is fully stressed.
30. In case of cantilever beams the tension portion lies ___________the neutral axis.
31. Design loads are termed as ________

32. The axis where stresses are zero in a beam section is called as_____________
33. The tension reinforcement in a beam is also known as ______________
34. The portion of beam consisting of slab is called as___________
35. Distribution of shear intensity over a rectangular section of a beam follows_____________
36. The minimum area of reinforcement in a slab is ______________of cross-sectional area of Fe415 steel.
37. The span to depth ratios of simply supported slabs should not exceed____________
38. When corners of two way slab are not held down it is known as ____________
39. In designs of columns the ______________strength of concrete is ignored.
40. The maximum area of longitudinal steel in an RCC column is _______
41. Steel is efficiently used in ___________section.
42. The lateral deflection of beam shall not exceed ________of the span.
43. A RCC slab should not ordinarily be thinner than______________
44. The radius of a bar bends to form a hook should not be less than _________the diameter.
45. For pre-stressed concrete beam the line along which the tendon is placed is called_____________
46. Area of compression reinforcement in beam shall not exceed _____________of bD.
47. ___________bars do not show a definite yield point.
48. For Fe 415 grade of steel, the value of f_y=____________
49. The ratio of width to overall depth of a beam is generally equal to _____.
50. If X_4>D_f, then neutral axis lies in ____________of a T-beam.
51. In one way slab the main steel is provided parallel to _____span.
52. When length of slab is ____________than twice its width it is known as two way slab.
53. Load carrying capacity of columns, reinforced with helical reinforcement is ___________than that of column provided with lateral ties.
54. Single wires used as steel reinforcement in pre-stressing are known as_______.

Solid Waste Management
(Civil Engg.)
e -content

1) Municipal Solid Waste Management: Generation Sources, Composition, Methods of Collection & Transportation.

2) Treatment:

3) Disposal:

4) 3 R's.

Solid Waste:-

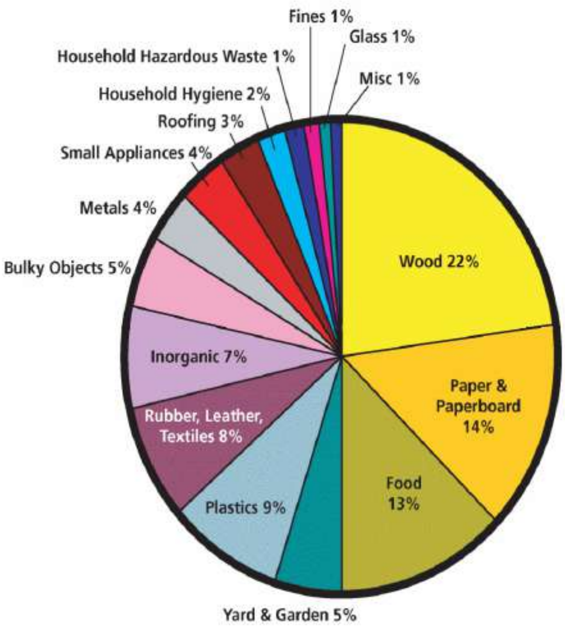
1) Discarded as **useless or unwanted things** or material arising from human & animal activities that are normally solid.

2) Substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the **provisions of the law**.

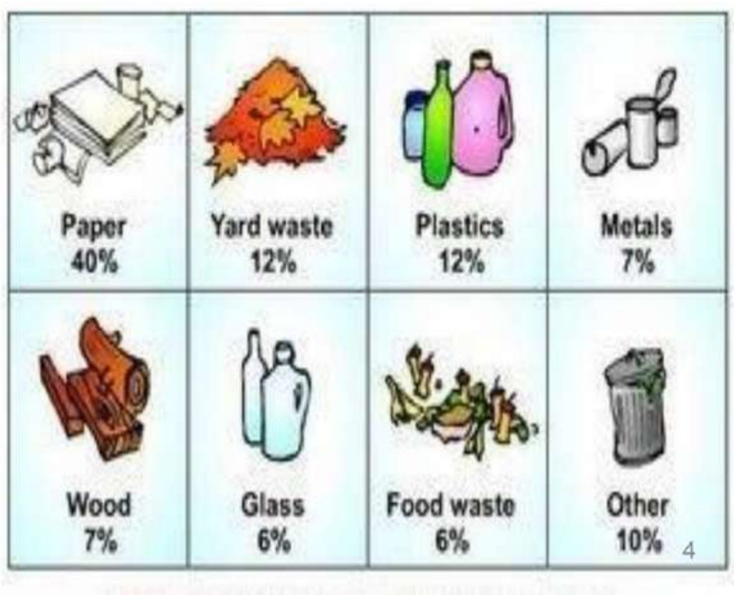
3) **Mismanaged things**.

4) United Nations Statistics Division (UNSD):- **Wastes are materials that are not prime products** (prime product - products produced for the market) for which the generator has no further use in terms of his own purposes of production, transformation or consumption, and of which he wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled or reused at the place of generation are excluded.

Solid Waste:-


Fines 1%
Glass 1%
Household Hazardous Waste 1%
Misc 1%
Household Hygiene 2%
Roofing 3%
Small Appliances 4%
Metals 4%
Bulky Objects 5%
Wood 22%
Inorganic 7%
Paper & Paperboard 14%
Rubber, Leather, Textiles 8%
Food 13%
Plastics 9%
Yard & Garden 5%


PAPER
GLASS
PLASTIC
METAL


Paper 40%
Yard waste 12%
Plastics 12%
Metals 7%
Wood 7%
Glass 6%
Food waste 6%
Other 10%
4


Agricultural wastes
Types of waste
Industrial wastes
• Household wastes
• Hospital waste
5

Classification of Solid Waste on the source of generation:-

1) Domestic/ Residential/ House Waste:

- Solid waste originates from domestic or residential area.
- Waste generated as consequences of household activities such as cooking, cleaning, repairing, etc.

2) Commercial Waste:

- Waste originates from offices, stores, hotels, markets, etc.

3) Institutional Waste:

- Waste originates from institutes, schools, universities, colleges, etc.

4) Municipal Waste:

- Waste originates from municipal activities.
- Includes street waste, commercial waste, & market waste, etc.
- Term commonly applied in a wider sense to incorporate domestic, institutional & commercial waste.

5) Street Waste:

- Waste that originates from street, walkways, alleys & vacant areas.
- Includes paper, plastic, leaves & other matter discarded by road users.

6) Construction & Demolition Waste:

- Waste generated by construction, repairing & demolition of building.
- Consist of earth stones, concrete, bricks, & other material.

7) Industrial Waste:

- Waste arising from industrial activities.
- Cover vast range of substances which are unique to each industry.

8) Sewage Waste:

- Waste generated from treatment plant.
- Mostly organic in nature.

9) Hazardous waste:

- Waste that poses great danger to human, animal & Plant b'coz of its toxicity, reactivity, corrosivity & ignitability.
- Requires special handling & good management.

10) Biomedical waste:

- Waste arising from hospital & pathological lab.
- Comes under category of hazardous waste.

11) Garbage:

- Contains putrescible organic matter.
- Decomposes quickly.

12) Rubbish:

- Dry non-putrescible solid waste excluding ash & garbage.

13) Agricultural Waste:

Classification of Wastes according to their Properties

Bio-degradable :

can be degraded (paper, wood, fruits and others)

Non-biodegradable:

cannot be degraded (plastics, bottles, old machines, cans, containers and others)

Classification of Wastes according to their Effects on Human Health and the Environment

Hazardous wastes :

Substances unsafe to use commercially, industrially, agriculturally, or economically and have any of the following properties:-

1) ignitability,
2) corrosivity,
3) reactivity &
4) toxicity.

Non-hazardous :

Substances safe to use commercially, industrially, agriculturally, or economically and do not have any of those properties mentioned above.

Classification of wastes according to their origin and type

1) **Municipal Solid wastes:** Solid wastes that include household garbage, rubbish, construction & demolition debris, sanitation residues, packaging materials, trade refuges etc. are managed by any municipality.

2) **Bio-medical wastes:** Solid wastes including containers, intermediate or end products generated during diagnosis, treatment & research activities of medical sciences.

3) **Industrial wastes:** wastes that are generated by manufacturing & processing units of various industries like chemical, petroleum, coal, metal gas, sanitary & paper etc.

4) **Agricultural wastes:** Wastes generated from farming activities. These substances are mostly biodegradable.

5) **Radioactive wastes:** Waste containing radioactive materials. Usually these are byproducts of nuclear processes. Sometimes industries that are not directly involved in nuclear activities, may also produce some radioactive wastes, e.g. radio-isotopes, chemical sludge etc.

6) **E-wastes:** Electronic wastes generated from any modern establishments. They may be described as discarded electrical or electronic devices. Some electronic scrap components, such as CRTs, may contain contaminants such as Pb, Cd, Be or brominated flame retardants.

Useful Options

1) Resource recovery
2) Composting
3) Vermi-composting
4) Energy recovery
5) Incineration
6) Pyrolysis
7) Gasification
8) Bio-methanation or anaerobic digestion

- Solid Waste Management should be **environmentally feasible** considering principles of **economy, aesthetics, energy** & other considerations.

- The activities involved with the management of solid wastes from the point of generation to final disposal have been grouped into a **six functional elements.**
    1) Generation
    2) Storage
    3) Collection
    4) Transport
    5) Processing
    6) Disposal

Six Functional Elements of Solid Waste Management:-

1) **Generation:-**
   - Activities in which materials are generated and identified as useless or unwanted materials.
   - Average generation rate is 0.33 kg/Person/Day. (0.3 to 0.6)

2) **Storage:-**
   - The generated wastes are stored near the point of generation for short period & then transfer to community storage bin.

3) **Collection:-**
   - Gathering of stored solid waste & then transfer to community storage bin.

4) **Transport:-**
   - The material collected in community bin is transferred to the processing or disposal site by transport vehicles.

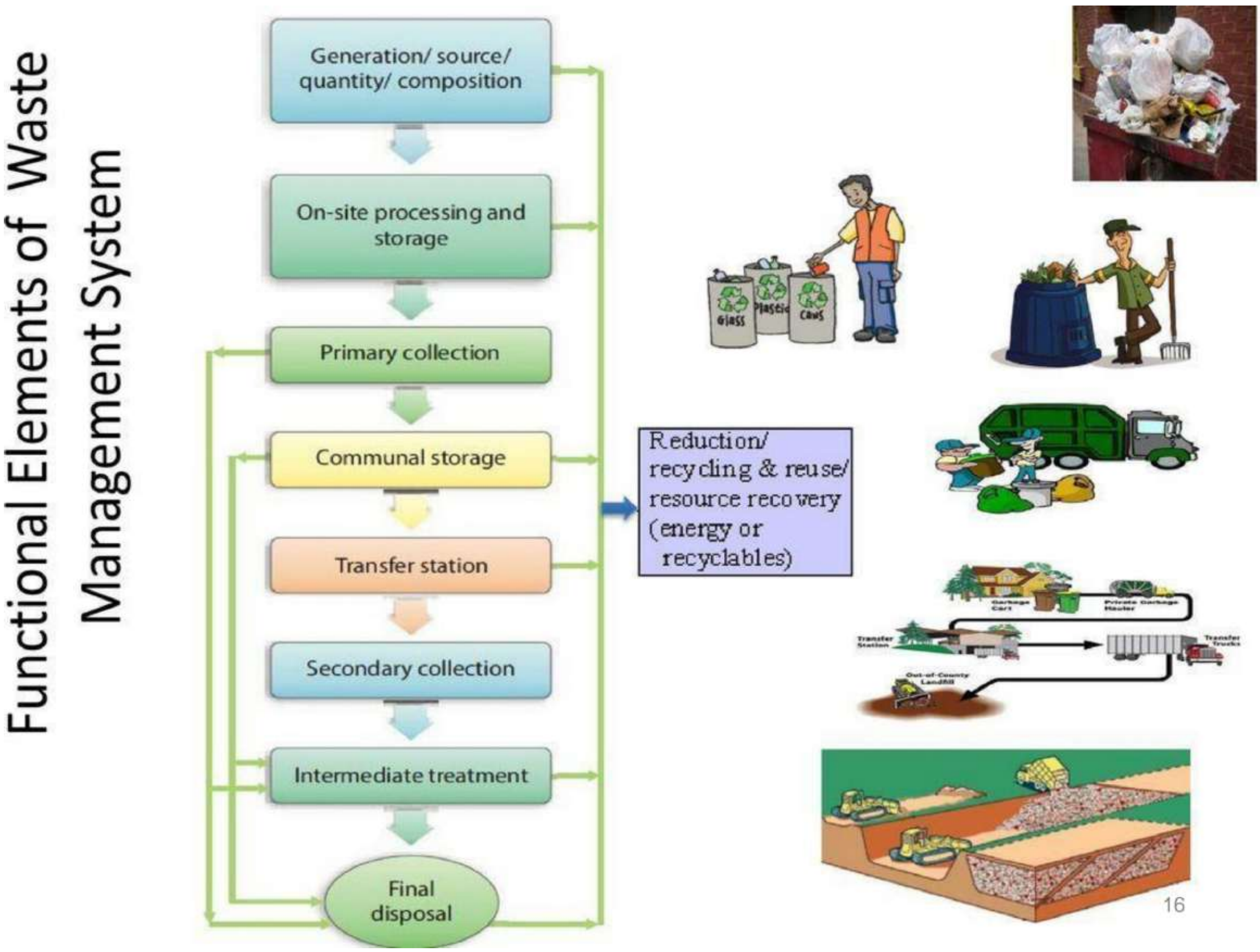
Six Functional Elements of Solid Waste Management:-

5) Processing:-

- It is the process to reduce its potential nuisance value (strength) and to recover usable material or energy from solid waste before its final disposal.

6) Disposal:-

- It is ultimate disposal of solid waste.
- After transportation or processing solid waste can be disposed on land or water logged areas for reclamation or low laying area or into sea etc.


Functional Elements of Waste Management System
Generation/ source/ quantity/ composition
On-site processing and storage
Primary collection
Communal storage
Transfer station
Secondary collection
Intermediate treatment
Final disposal
Reduction/ recycling & reuse/ resource recovery (energy or recyclables)
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Impacts of Waste :-

1) Chemical poisoning through chemical inhalation.
2) Cancer.
3) Neurological disease.
4) Nausea and vomiting.
5) Increase in hospitalization of diabetic residents living near hazard waste sites.
6) Mercury toxicity from eating fish with high levels of mercury.
7) Uncollected waste can obstruct the storm water runoff resulting in flood.
8) Low birth weight.
9) Congenital malformations.
10) Increase in mercury level in fish due to disposal of mercury in the rivers.
11) Resulted in high algal population in rivers and sea.

Impacts of waste on Environment

13) Waste breaks down in landfills to form methane, a potent greenhouse gas.

14) Change in climate and destruction of ozone layer due to waste biodegradable.

15) Littering, due to waste pollutions, illegal dumping, Leaching: is a process by which solid waste enter soil and ground water and contaminating them.

Composition of Solid Wastes:-

Composition of Solid Waste in %age by Net Weight for Indian Cities		
SN	**Solid Waste Content**	**Contribution or Composition**
1	Glass	0.3 %
2	Metal	0.3 %
3	Paper	2 - 7 %
4	Plastic	2 – 7 %
5	Ash & Inert	20 – 50 %
6	Total Compostable Matter	30 - 60 %

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NEWS
NEWS
PAPER
GLASS
ORGANIC
PLASTIC

Characteristics of Solid Waste:-

Characteristics of Solid Waste in %age by Net Weight for Indian Cities		
SN	**Solid Waste Characteristics**	**Contribution or Content in %**
1	Total Nitrogen	0.5 – 0.9 %
2	Organic Matter	20 - 40 %
3	Moisture Content	20 – 40 %
4	C/N ratio	20 – 40
5	Calorific Value	800 – 1800 kcal/kg
6	Density	300 – 600 kg/m3
7	Phosphorous, Potassium, Carbon, etc.	-------

Generation:-

1) Rate may vary widely from place to place.
2) In US – 2 Kg/C/Day
3) Japan – 1 Kg/C/Day
4) Canada – 3 Kg/C/ Day
5) **India – 0.3 to 0.5 Kg/C/Day**
6) Data includes refuse from residential, commercial, institutional & industrial sources.
7) Actual generation tare must be carefully determined for management.
8) Generation rate expected to be **double by 2025.**
9) Higher the income level greater will be generation rate.

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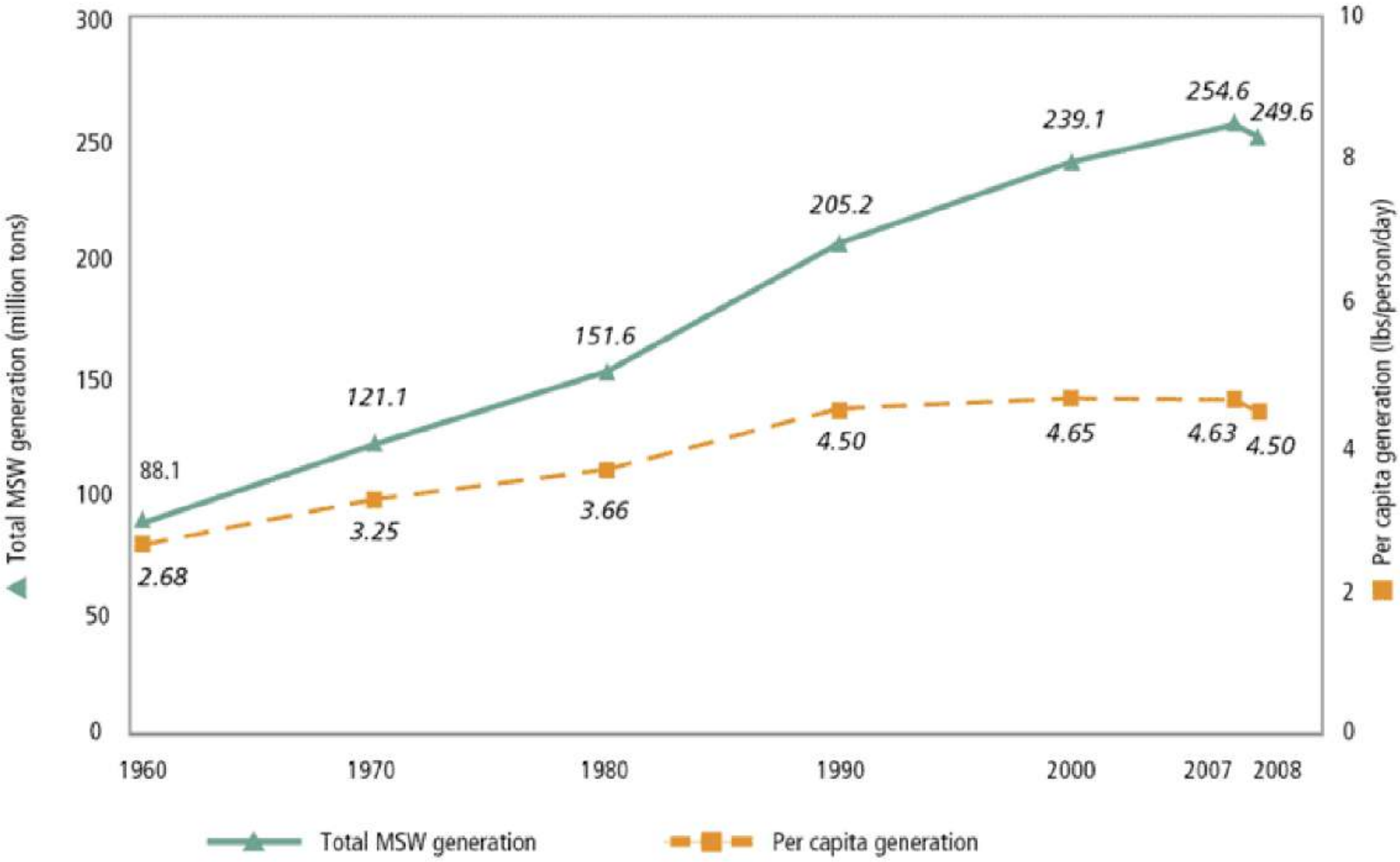
Factors affecting Generation Rate:-

1) Geographic Location.
2) Season of the Year. (Local Climate)
3) Facilities for Collection, Transportation, Processing & Disposal.
4) People or Public Habit.
5) Standard of Living.
6) Economic Development.
7) Commercial & Industrial Activities.
8) Legislation.
9) Types of Society or Culture or Religions.

U.S. MSW Generation Rates, 1960 to 2008



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Storage:-

1) Waste stored in premise must be kept in standardized containers for collection.
2) Depending upon where it is adopted & frequency of waste removal container must be designed.
3) Storage should be compatible for collection.
4) Use of no standardized container increase time for collection, risk of muscular strain or injury to labor.
5) Storage should be of plastic with detachable cover.
6) Precaution should be taken to ensure that the stored waste is not exposed & does not come in contact with moisture & vectors of diseases.
7) Dry & wet solid waste stored separately.
8) Recyclable & hazardous waste stored separately.
9) Wet solid waste should be stored in no corrosive container with lid & should be removed everyday from house..

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27

28

Collection:-

- Removal of waste from individual houses is termed as collection.
- Collection can be carried out by using various methods such as:
    1) **House to House Collection System**
    2) **Community Bin System.**
    3) **Bell Ringing System.**
    4) **Collection of Waste from Street.**
- Expenditure on collection of solid waste is 45 to 75 % of total cost of solid waste management.
- Municipal agencies are responsible for collection of waste from residential & commercial areas while in case of industrial area owners are responsible.

Collection of waste from street:-

1) In this system, workers sweep the roads & collect the material at specific points.

2) In addition to the waste generated in the premises, waste is also generated along the street.

3) Collection from street is deposited in storage bin from where separated vehicle collect and transport to processing or disposal site.

Community Bin System:-

1) This system commonly adopted in India.
2) Community bins are located at street corner and at specific frequencies along the roads.
3) Residents are expected to bring their waste & deposit the same in the community bin.
4) Locations of community bins are fixed according to convenience of local citizens.
5) The capacity of community bins are should be 50% in excess when collection is daily and 100% in excess when collection is weekly.
6) Spacing should be fixed on the basis of per capita quantity & Population contributing the waste.
7) However distance between community bins should not be more than 100m.

Bell Ringing System:-

1) In this system, the collection vehicle is provided with a bell & on reaching specified points it is rung.
2) Residents from adjoining areas come to vehicle & deposit the waste in the vehicle.
3) This system work efficiently, if the movement of the vehicle is appropriately & continuously control & citizens are also cooperative.

House to House Collection System:-

- In this method, generated & stored waste in individual premises is collected by following ways:

    1) **Curb Service.**
    2) **Alley Service.**
    3) **Set out, Set Out Back Service.**
    4) **Set Out Service.**
    5) **Backyard Service.**

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A) Set Out Set Back Service:-

- In this system, set out men go to individual houses, collect the container & empty them in the vehicle.
- Another group of persons return them to house owner yard.

B) Set Out Service:-

- In this system, the worker will collect the container from individual houses & empty them in vehicles.
- The house owner is required to take back the empty container.

C) Curb Service:-

- In this system, the house owner is responsible for placing the containers at the curb on the scheduled day.
- Workmen collect & empty the container in the vehicle & place them at the curb.
- The house owner is required to take back the empty containers to his house.

D) Alley Service:-

- In this system, The containers are placed at the alley line from where they are taken by workmen & deposited in the vehicle.

E) Backyard Service:-

- In this system, The worker carry a bin or handcart or sack to the yard and empty the solid waste container in it.
- The handcart or bin or sack is subsequently taken to solid waste collection vehicles where it is emptied.

Tools & Equipments Used in Collection of Solid Waste:-

- Collection & transportation of solid waste involves use of a variety of tools, equipments & facilities.
- It is essential that these are selected with due care so as to ensure optimum performance of the system.
- Most of the tools & equipments that are currently being used have not been specifically designed for solid waste collection work and are often adopted because they are readily available for some other service.
- To improve performance of the system following tools & equipments should be used for storage, collection & transfer of solid waste.

1. Brooms
2. Shovels
3. Mechanical sweepers
4. Handcarts
5. Household Storage
6. Commercial storage
7. Street waste Storage
8. Community Bins (Stationary & Moveable)

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Brooms:-

- These are mainly of two types short handled & long handled.

1. Short Handled Brooms:-

- It has wooden handled to which large number of short tufts are bound.
- For dislodging heavy deposit of dirt a large force has to be exerted which leads to the dust getting airborne & its consequent inhalation adversely affects health.
- It also strains the back of worker due to the stooping posture adopted by him for sweeping.

Brooms:-

- These are mainly of two types short handled & long handled.

2. **Long Handled Brooms:-**

- It consists of a bunch of long flexible fibers attached to a bamboo handled & are used by workers while standing erect.
- The brooms are used with long strokes to sweep the material on the roads.
- It clear most of the light material such as paper, plastic, etc.
- This broom is safer from the health point of view & hence preferred.

Shovels:-

- The collection of solid waste material is carried out by a shovel.
- A straight blade shovel & flat board shovel made of GI sheets are used.

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Mechanical Sweepers:-

1) Mechanical road sweepers are used in developed countries.
2) Also used in high income areas of a few Indian cities.
3) Equipment consists of one or more rapidly involving brushes which dislodge the material & direct the deposited material from the road surface to a single point from where it is sucked by a suction mechanism.
4) Engine for forward movement as well as for providing suction is the same in some units while in some units separate engines are provided.
5) Mechanical sweepers are likely to get easily damaged due to the uneven, rough surface & heavy objects.
6) It can be used only in certain situation and have to be supplemented by manual sweeping.
7) It obstructs the traffic due to their slow speed of movement.


34
UD TRUCKS

Household Storage:-

1) This type of storage stores waste in a container or bucket or plastic sack of 5-7 liters capacity which are adequate for an average family.
2) It is desirable to use plastic container with tight fitting lids.
3) Use of standardized storage will improve environmental condition as well as the collection of the waste.

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Commercial Waste Storage:-

- In commercial Waste Storage like colleges, offices, hotels markets, etc. large size storage of 50-100 liter capacity can be provided with handled for lifting & wheels for easy movement.

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Street Waste Storage:-

1) Litter Bins
2) It is used to store waste from streets.
3) The top part of storage is designed in such a way to prevent entry of rainwater & also to prevent lighter material getting airborne.
4) The spacing of storage will depend upon the quantity of waste generated, importance of the road & frequency of cleaning.

Community Bins:-

It can be divided into two categories stationary & moveable bins.

A. Stationary:-

1) Large size stationary storage bins are of two types covered & uncovered enclosure.
2) These bins are often constructed in brick masonry or concrete to various sizes.
3) People are expected to deposit the solid waste inside the enclosure.
4) Sometimes masonry enclosure have roofs on the top and shutter infront.
5) Due to enclosure waste is protected from rain.

B. Moveable:-

1) These are designed to be compatible with the transport vehicle.
2) Two system of large sized wheel-less containers are often used.
3) 8-10 m3 size container are used which when full are taken away to the disposal site after lifting them on vehicle.
4) Due to the large capacity of these containers a workers are often posted at site.

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ENSOL

Handcart:-

1) Handcart is used to collect & transport the solid waste to the community bin.
2) Handcarts are singled or doubled or three wheeled type.
3) To transport the same quantity lesser force is required in the 3 wheel handcart than in the 2 wheel handcart.
4) Light tabular frame is recommended for easy loading & unloading & to reduce the weight.
5) Wheels should be large as possible for easy movement.
6) Sometimes handcarts are also provided space for brooms, shovels, etc.

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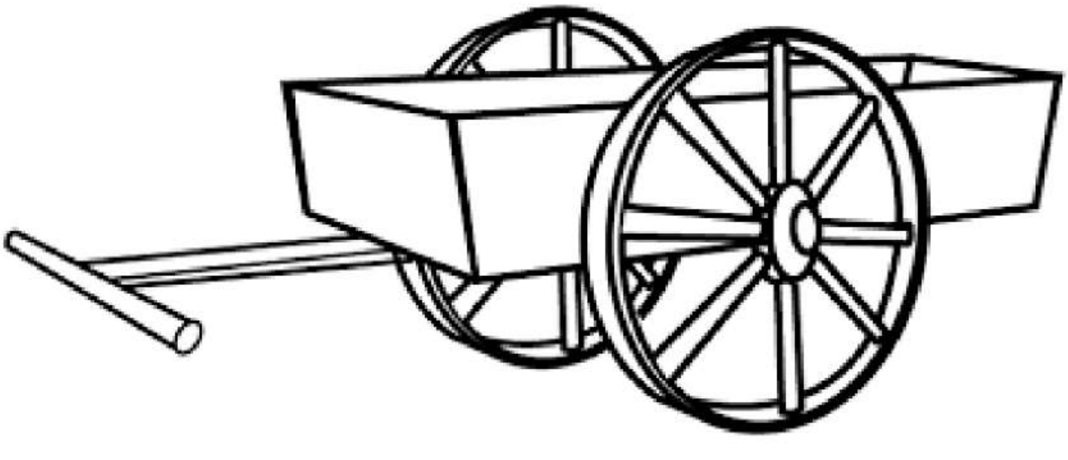

50

Transport:-

The waste collected in storage containers or community bins are carried to the processing or disposal site by using a variety of vehicles.

I. Vehicles which moves through narrow streets & after travelling a short distance discharge their contents into another vehicle (big) at the transfer station or directly at the processing or disposal site.

II. Vehicles which move through wider roads and after travelling over long distance discharge their contents at the processing or disposal site.

If transportation vehicles are selected properly then transportation cost can be reduced substantially by 20 – 45%

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Transport:

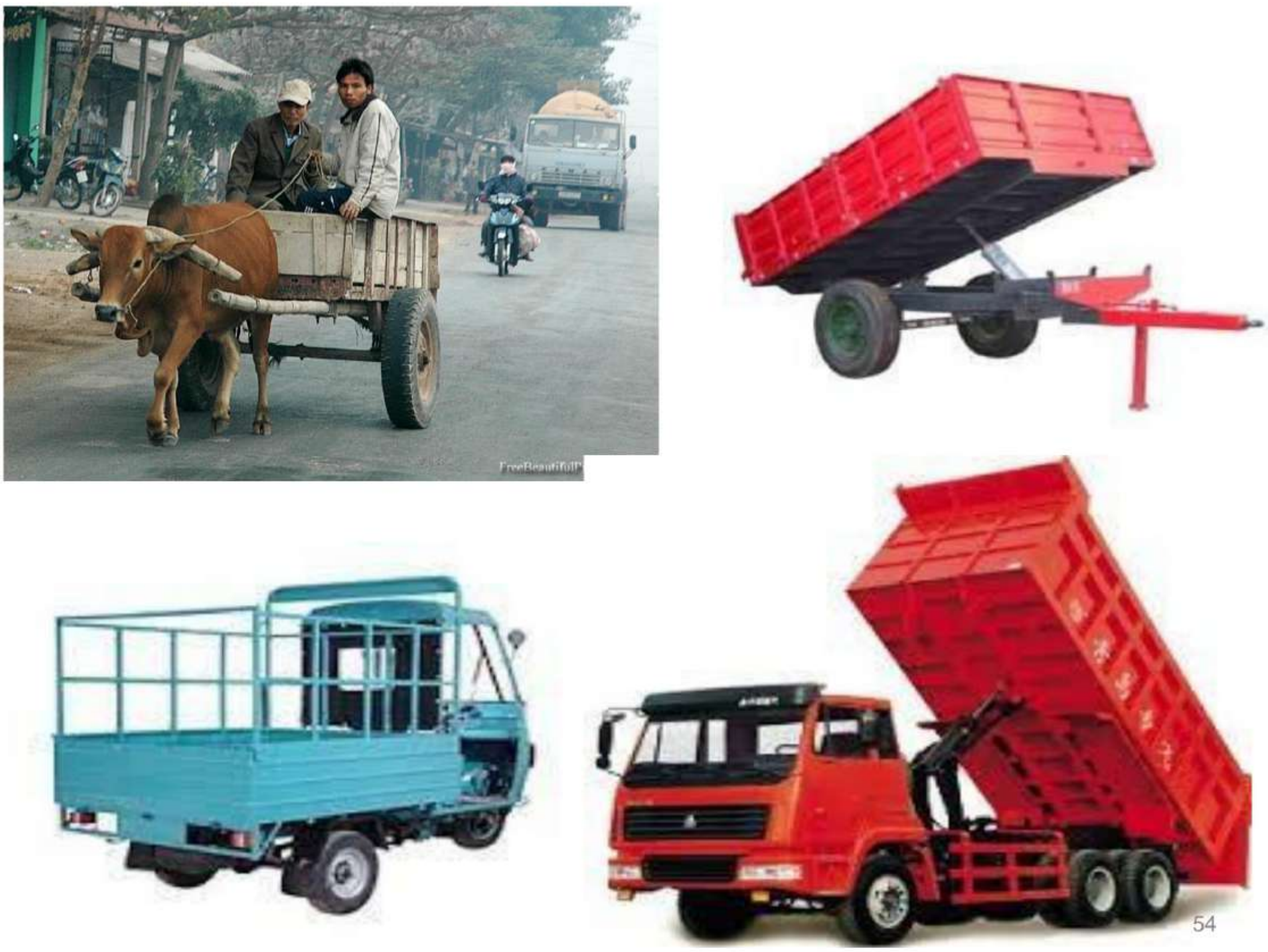
The vehicles should satisfy the following requirements:-

1. The loading height should not exceed 1.5 m.
2. Vehicles should have tipping gear arrangement for fast & efficient unloading.
3. Vehicles should have covered body.
4. When fully loaded, they should be able to climb a gradient of upto 1:10.
5. Sufficient carriage capacity.
6. Reliable & economic.
7. Their bodies should have atleast two coats of anti corrosive paint of distinct color for easy identification.
8. The body should not have sharp corner where material accumulates & should facilitates easy cleansing.
9. Satisfy the prevailing motor vehicle rules.

Transport:-

The types of transportation vehicles:-

1. Animal cart
2. Tractor Trailer
3. 3 wheeled Auto Rickshaws
4. Trucks
5. Pedal Tricycle
6. Dumper Placer
7. Container Carriage System
8. Special Municipality Vehicles, etc.


54

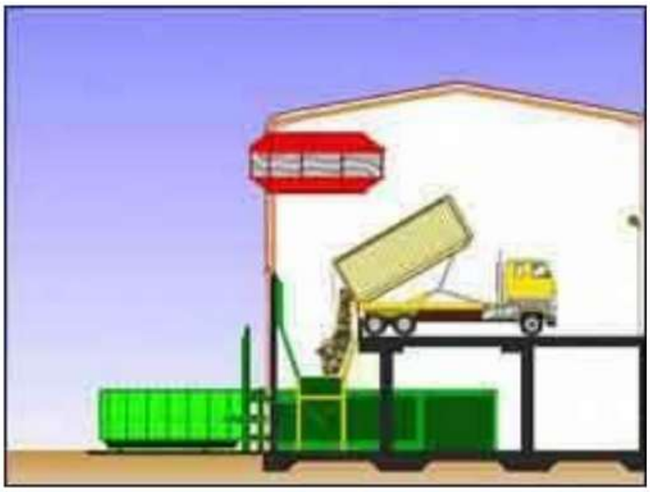

SML


NEW STRALIS HI-WAY
WORKING ON THE HI-WAY

Transfer Station:-

Transfer stations are of two types

1. Level site
2. Split level site




DEERE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Transfer Station:-

1. Built for transfer of slid waste from small short range transport vehicles to large long range vehicles.
2. Movement of solid waste from the transfer station is termed as secondary collection.
3. Large capacity vehicles then carry the refuse over a large distance to the processing or disposal site.
4. Transfer station is economical but adds an additional material handling step & construction of transfer station.
5. Therefore before deciding the use of bulk transportation to the final disposal site plus the cost of operating the transfer station should be compared with the cost of conveying the refuse directly to the disposal site by the primary collection vehicles.
6. Figure shows the economical use of transfer station.
7. It is economical if the transfer distance is more than critical point.

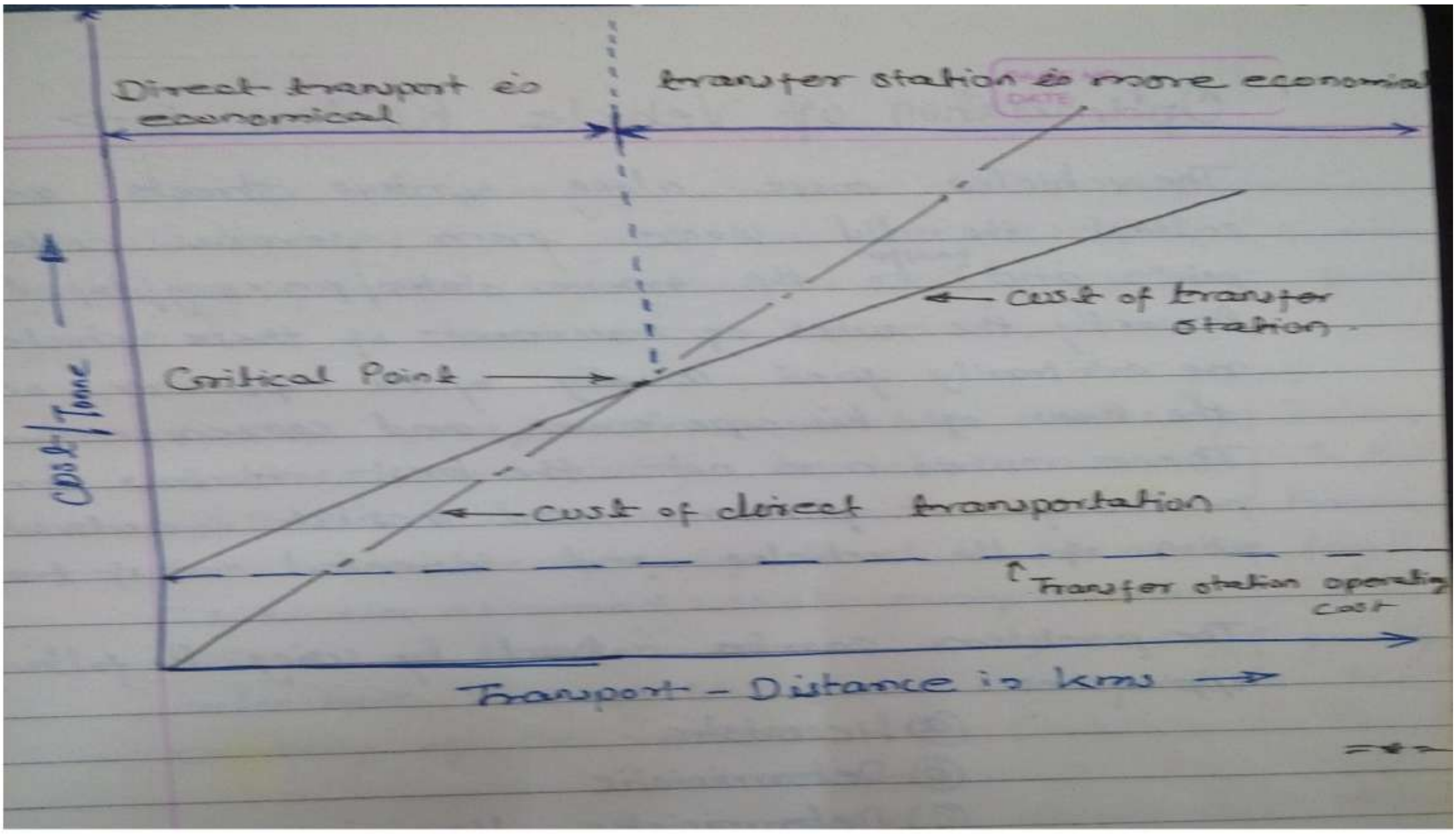

Figure shows the economical use of transfer station.

It is economical if the transfer distance is more than critical point.

Therefore before deciding the use of bulk transportation to the final disposal site plus the cost of operating the transfer station should be compared with the cost of conveying the refuse directly to the disposal site by the primary collection vehicles.

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Optimisation of vehicle Routes:-

- Vehicles move along the various streets & collect the solid waste from several collection points & transfer to the transfer station or processing site or disposal site.
- Presently routes of movements of these vehicles are arbitrarily fixed, usually by the supervisor on the basis of his experience and convenience.
- These best are not the best routes & certainly not optimum & result in under utilisation of vehicles & increases cost of transportation.
- The problem can be solved by using the following approaches:
  1. **Heuristics**
  2. **Deterministic**
  3. **Deterministic-Heuristic**
  4. **Modified Distribution (MODI).**

Heuristics Approach:-

- Uses a manual procedure by using certain guiding principles to arrive at a reasonable solution but not optimum.
- Good tool for use by experienced person.

Deterministic Approach:-

- Mathematical model is developed by providing all relevant input data & the model determines the optimum rotes.

Deterministic-Heuristic Approach:-

- A computer program is used to examine many possible alternatives, out of which the best possible is selected.

MODI Method:- Modified Distribution Method

1) NEERI prepared a suitable model MODI for Indian conditions for deciding the vehicle routes.

2) In this method it is assumed that the cost of transportation is directly proportional to the routes length.

3) Every community bin should be visited at least once in a day.

4) The quality collected in a routes should be equal to the capacity of the vehicles.

Six Functional Elements of Solid Waste Management:-

5) Processing:-

- It is the process to reduce its potential nuisance value (strength) and to recover usable material or energy from solid waste before its final disposal.

6) Disposal:-

- It is ultimate disposal of solid waste.
- After transportation or processing solid waste can be disposed on land or water logged areas for reclamation or low laying area or into sea etc.

Processing of Solid Waste:-

1) Perform a series of mechanical or chemical operations on (something) in **order to change it.**

1) It is the process **to reduce its potential nuisance value** (strength) and **to recover usable material or energy** from solid waste before its final disposal.

2) Solid waste contain various ingredients however these ingredients can be used as a raw material to produce some useful form of material or as **source of energy.**

3) Objective of a processing is **to utilize the recycling potential** of solid waste & simultaneously **reduce the load** on solid waste management system especially on the disposal.

Processing of Solid Waste:-

1) Physical Processing Technology

2) Biological Processing Technology

3) Thermal Processing Technology

➢ Composition of solid waste varies place to place & country to country. This aspect is important while selecting processing technology for above objectives.

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Physical Processing Technology:-

It involves altering the physical characteristics of a solid waste.

These solid waste may be shredded, separated & dried.

1) **Mechanical Separation**
2) **Densification**
3) **Size Reduction**
4) **RDF (Refused Derived Fuel)**

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Mechanical Separation:

- It is utilized for removing specific materials from solid waste.
- Mechanical separation is carried out before processing the waste by other methods.

TECHNOLOGY	MATERIALS TARGETED
Screening	Large: film plastics, large paper, cardboard, misc. Mid-sized: recyclables, organics, misc. Fines: organics, metal fragments, misc.
Hand Picking	Recyclables, inerts and chemical contaminants
Magnetic Separation	Ferrous plus contaminants associated with ferrous met
Eddy Current Separation	Non-ferrous metals
Air Classification	Lights: paper, plastic Heavies: metals, glass, organics
Wet Separation	Floats: organics, misc. Sinks: metals, glass, gravel, misc.
Ballistic Separation	Light: plastic, undecomposed paper Medium: compost Heavy: metals, glass, gravel, misc.

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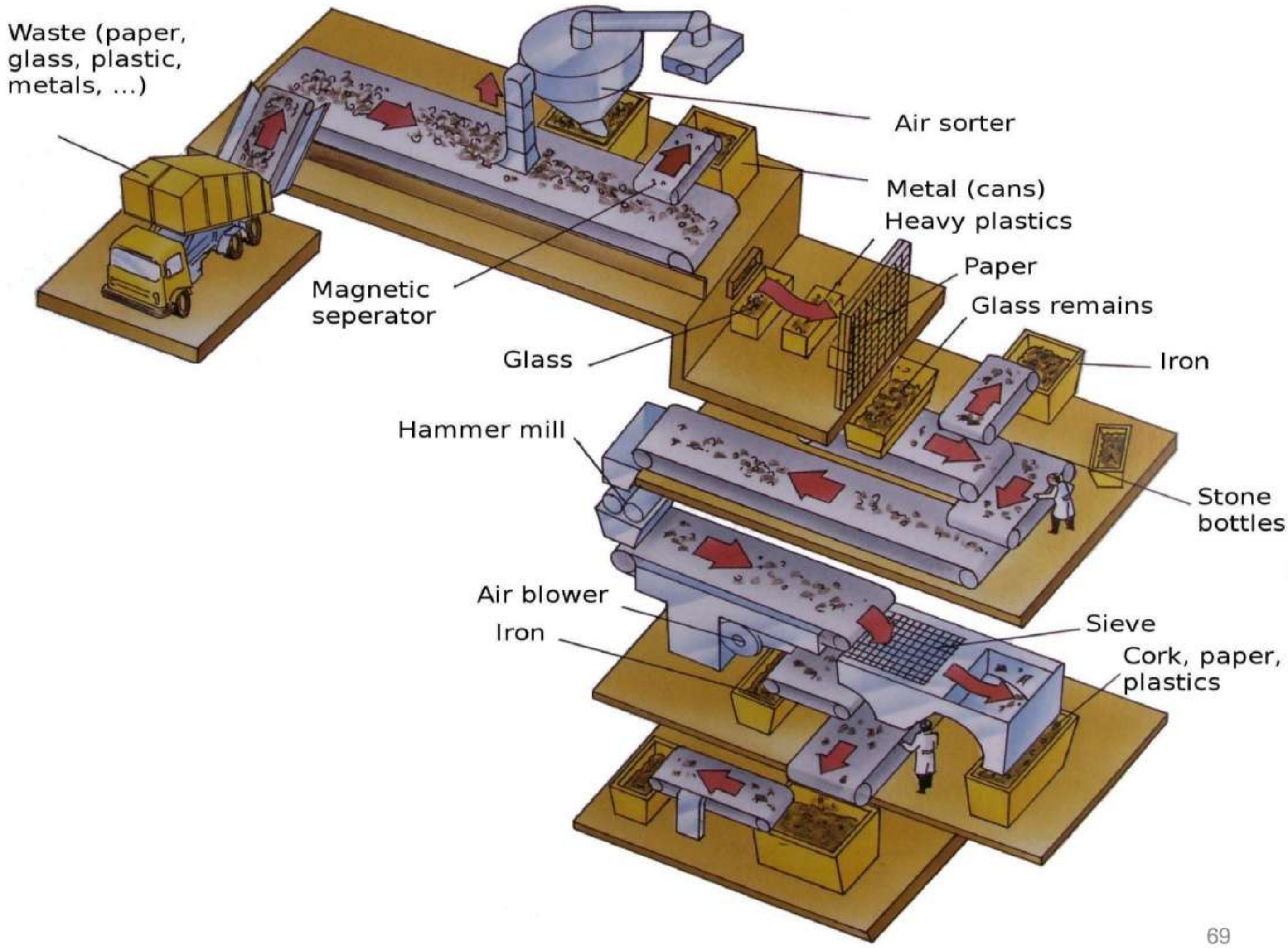
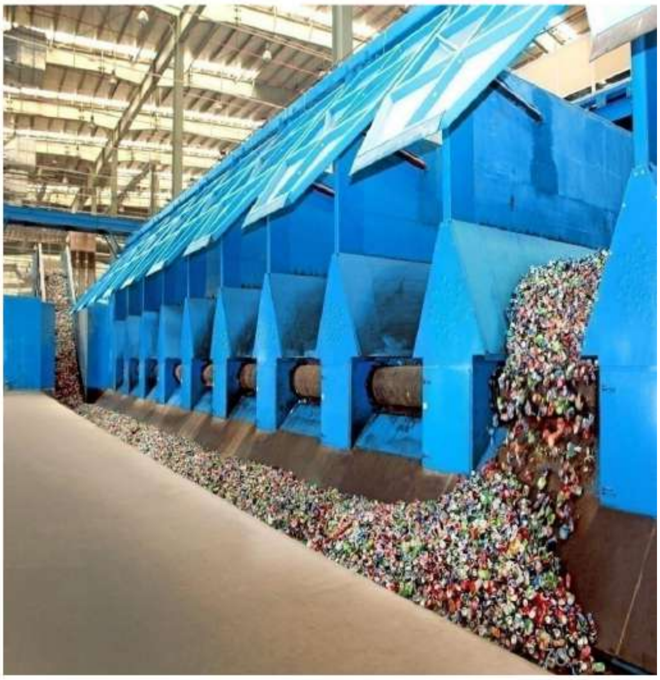

Waste (paper, glass, plastic, metals, ...)
Air sorter
Metal (cans)
Heavy plastics
Paper
Glass remains
Magnetic seperator
Glass
Iron
Hammer mill
Stone bottles
Air blower
Iron
Sieve
Cork, paper, plastics
69

Size Reduction:

- Size reduction is required to allow for efficient & easier handling of material.
- In order to reduce the size, mechanical equipment such as shredders is used. This allow for other process to work more efficiently.



RDF (Refuse Derived Fuel):

1) When solid waste contains large amount of combustible matter ex paper, etc it cab be used as a fuel.
2) The combustible portion is segmented from solid waste. The recovered combustible portion is commonly termed as a refuse derived fuel.
3) This is normally used as fuel in thermal power plant and for boilers in industries.
4) RDF is claimed to be coal substitute with a comparable calorific value of 3500 kcal/Kg.
5) Emission characteristics are claimed to be superior than coal & result in lesser emission of NOx, SOx, CO, CO2, & other GHGs.

Biological Processing Technology:-

- Biological processing operates at lower temperature and lower reaction rate.
- It can work with high moisture level but requires bio-degradable material.
- MSW contains large organic matter & natural phenomenon which can be profitably used to produce compost with or without biogas recovery.
- Biological processing methods are suitable for the waste generated & conditions existing in India.

1) Composting
   a) Aerobic Composting or Indore Method of Composting
   b) Anaerobic Composting or Bangalore Method of Composting
   c) Vermicomposting.
2) Anaerobic Digestion
3) Bioreactor landfilling

Composting:-

1) It is an organized method of producing manure by decomposition and stabilization of solid waste.

2) It is a natural microbiological process where bacteria break down organic fraction of solid waste under control condition to produce a pathogens free material called compost.

3) Compost is useful for the growth of plants which contains plants nutrients (NPK).

4) It can be carried out in a following ways:

    a) Aerobic Composting or Indore Method of Composting.

    b) Anaerobic Composting or Bangalore Method of Composting.

    c) Vermicomposting.

Aerobic Composting or Indore Method of Composting:-

1) During aerobic composting aerobic micro-organism oxidize organic compounds to CO_2, NO_2, & NO_3.
2) Carbon from organic compounds is used as source of energy while nitrogen is recycled.
3) Due to exothermic reaction, temp. of the mass rises.
4) Indore Method, conventionally carried out in pits.
5) Initially a layer of coarse solid waste is placed at the bottom of a pit to a depth of 15 to 25 cm & then night soil is put to a thickness of 5cm again layer of solid waste is placed over night soil.
6) In this way, a night soil is sandwiched between two layers of MSW.
7) Solid waste & night soils are place in alternate layers till it rises to a height of 30cm above the pit edge.
8) The final layer of solid waste is atleast 25 to 30 cm thick.
9) The top of deposited material is rounded off to avoid rain water entry into the mass or pit.

Anaerobic Composting or Bangalore Method of Composting:-

1) During anaerobic process, the anaerobic micro-organism, while metabolizing the nutrients break down the organic compounds through a process of reduction.

2) A very small amount of energy is released during the process and the temp. of composting mass does not rise much.

3) The gases evolved are mainly CH_4 & CO_2.

4) Anaerobic process is a reduction process & the final product is subjected to some minor oxidation when applied to the land.

Anaerobic Composting or Bangalore Method of Composting:-

1) In this method, pits are filled similar to Indore method except that it is covered at the top by soil layers to avoid rain water entering the pit.

2) Anaerobic condition is maintained in the pit.

3) After 4 to 6 months, decomposed and stabilized material is taken out and used as compost.

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Factors Affecting Composting Process:-

1) **Organism:** different micro-organism are known to play predominant role in the breakdown of solid waste

2) **Use of culture**: the required forms of micro-organisms are indigenous to solid waste

3) **Moisture:** 50-60%

4) **Temperature:** 30-60^{0}c

5) **C/N ratio:** 26 - 31

6) **Aeration:** 1-2 cum/day/kg of volatile solid

7) Addition of sludge or sewage:

8) Types of solid waste or composition of solid waste:

Vermi-composting:-

1) Organic solid waste is converted through earthworm consumption.
2) Decomposition of organic matter in the earthworm occurs in alimentary tract by micro-organism inhabiting the gut.
3) Ingested organic matter is first subjected to size reduction in anterior part of the worms, gut followed by decomposition.
4) These species survive in the temp. range of 20-40^{0}c & moisture range of 40-70.
5) They don't survive in pure organic substrate containing more than 40% fermentable organic substances. Hence, fresh waste is mixed with partially or fully stabilized waste before it can be vermi-composted.
6) Worms are adversely affected by high conce. Of heavy metals such as Cd, Cr, Pb, & Zn.
7) Vermi-compost has high nutrient content.
8) Generally Vermicompost is used for agricultural waste.
9) Houses & colonies often use this method for the organic household waste, however it has not yet been successfully used for MSW.

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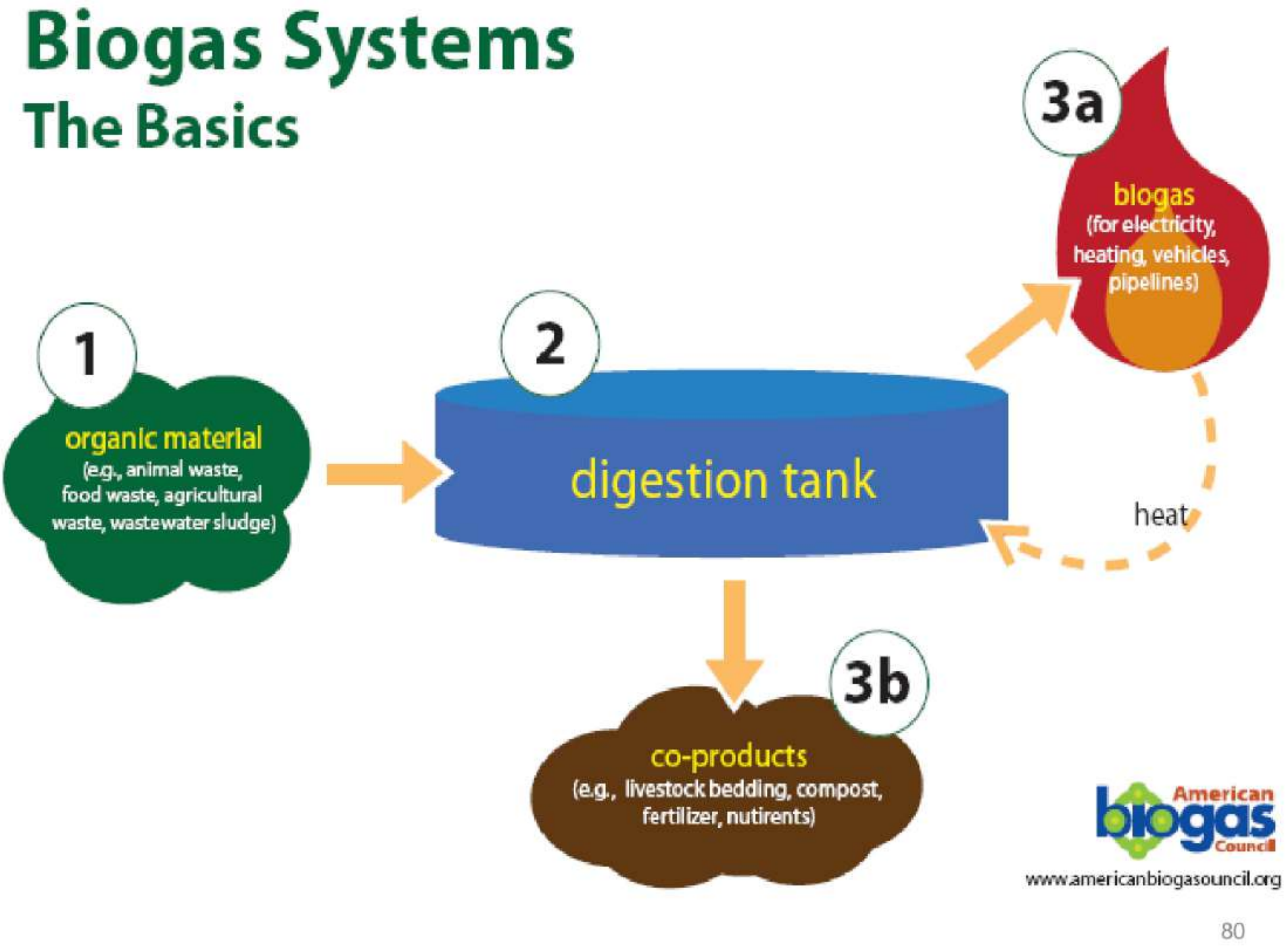
Biogas Systems
The Basics
1
organic material
(e.g., animal waste,
food waste, agricultural
waste, wastewater sludge)
2
digestion tank
3a
biogas
(for electricity,
heating, vehicles,
pipelines)
heat
3b
co-products
(e.g., livestock bedding, compost,
fertilizer, nutirents)
American
biogas
Council
www.americanbiogasouncil.org
80

Anaerobic Digestion:-

1) It is Composting : absence of oxygen, closed reactor system & high moisture.
2) Organics from MSW are first separated from the inorganic and then after size reduction are digested anaerobically in large size digesters.
3) The generated gas is either directly used as a source of energy or fed to dual fuel engines for generation of electricity.
4) The digested residue is commonly used as a manure.
5) In conventional anaerobic digestion, the solids concentration is kept at about 1%.
6) The pH is continuously monitored & maintained between 6.5 to 7.5.
7) The volatile acid conc. is not normally allowed to exceed 2000 mg/l.
8) The contents of the reactor are continuously stirred and the digested sludge is withdrawn from the bottom and put on drying beds.
9) The drainage liquid from the bottom of drying beds is again added to the plant influent.
10) The digester may have either a fixed dome or a floating dome for the collection of gas.

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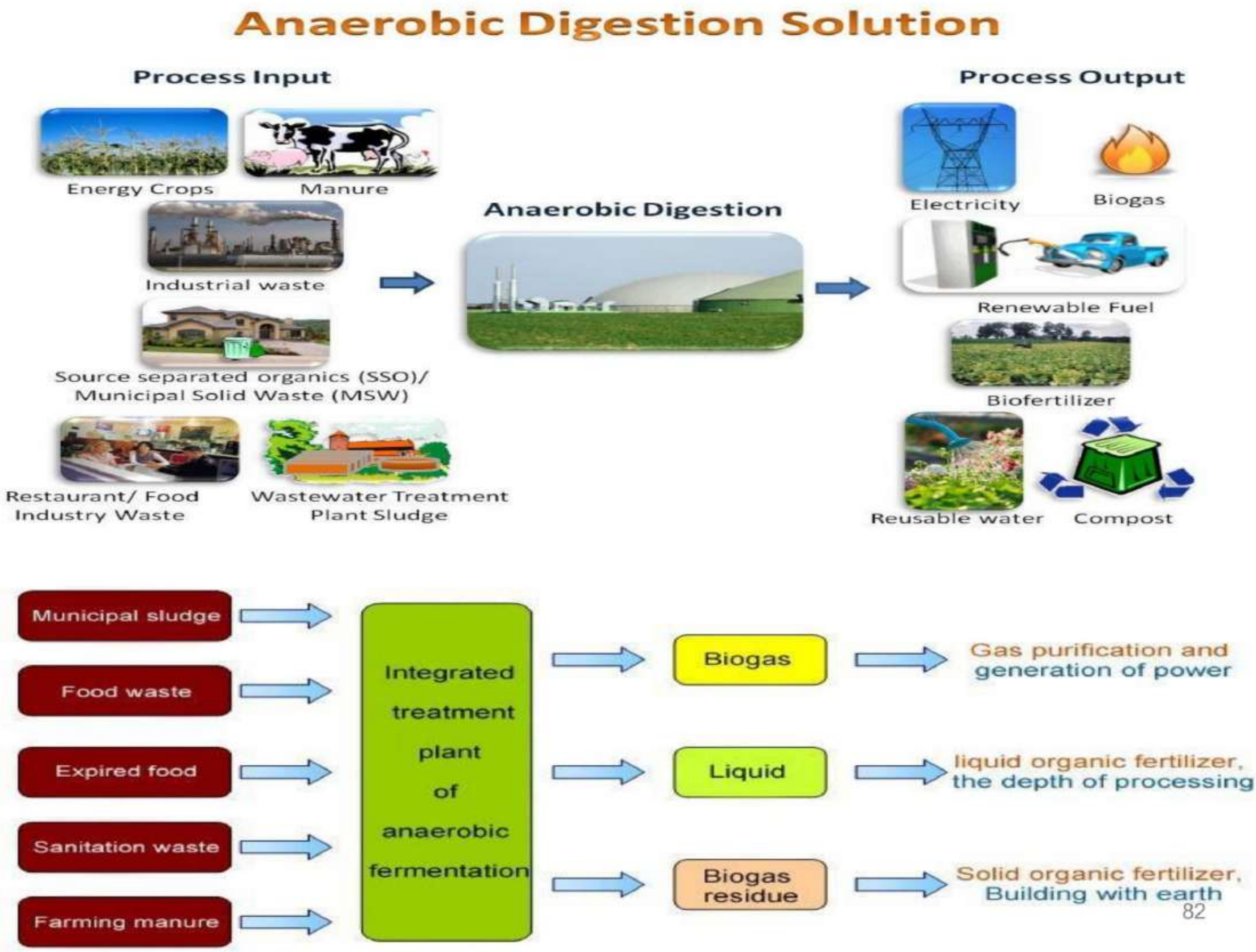
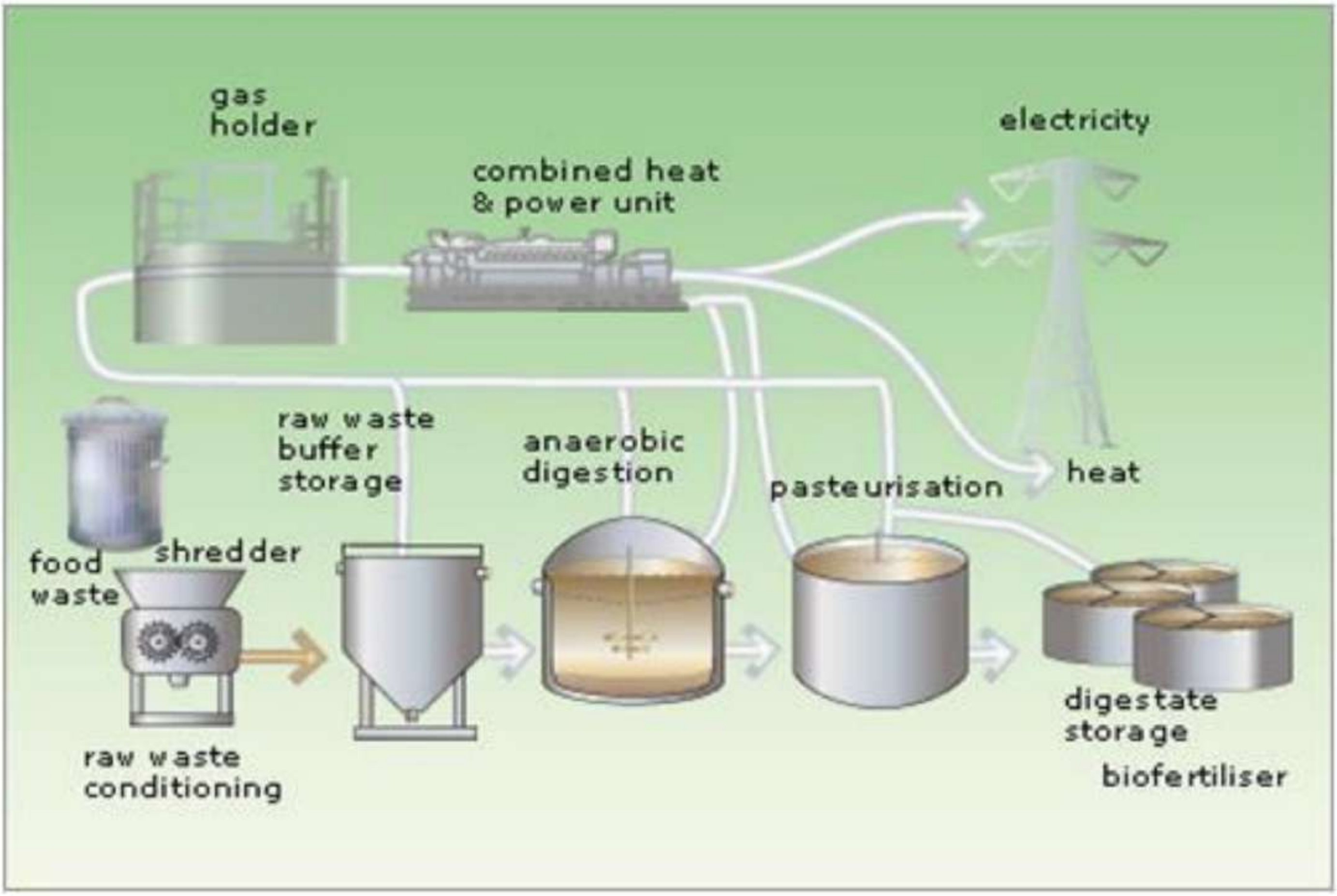

Anaerobic Digestion Solution
Process Input
Energy Crops
Manure
Industrial waste
Source separated organics (SSO)/
Municipal Solid Waste (MSW)
Restaurant/ Food
Industry Waste
Wastewater Treatment
Plant Sludge
Anaerobic Digestion
Process Output
Electricity
Biogas
Renewable Fuel
Biofertilizer
Reusable water
Compost
Municipal sludge
Food waste
Expired food
Sanitation waste
Farming manure
Integrated treatment plant of anaerobic fermentation
Biogas
Liquid
Biogas residue
Gas purification and generation of power
liquid organic fertilizer, the depth of processing
Solid organic fertilizer, Building with earth
82


gas
holder
combined heat
& power unit
electricity
raw waste
buffer
storage
anaerobic
digestion
pasteurisation
heat
food
waste
shredder
digestate
storage
raw waste
conditioning
biofertiliser

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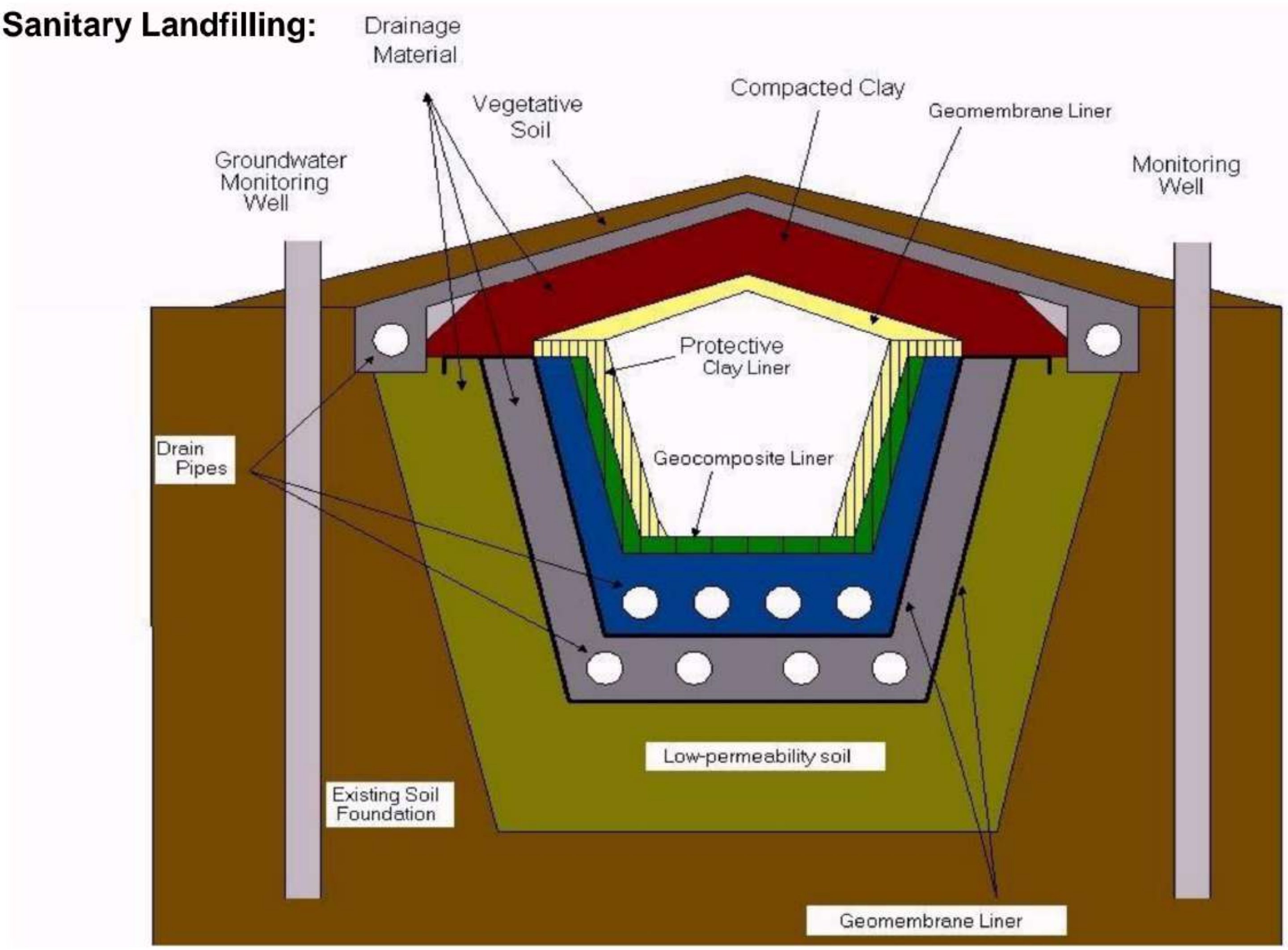
Sanitary Landfilling:



Points to be Considered while Selecting the Site for Sanitary land filling:-

1) **Approach:** site should have easy access for vehicles through out the year.

2) **Haul Distance**: site should be as near as possible to the city (Transport cost).

3) Cover Material: If the required soil cover is available at the site itself, no additional expenditure needed on transporting it to the site.

4) **Hydro-geological Data:** the rain water percolating through the solid waste tends to carry large amount of pollutants to the ground water if the underlying strata is previous.

5) **Flow of surface water:** water courses flowing across the site should be diverted.

6) **Future Expansion**: site should be compatible with future requirements and plans.

7) **Quantity of waste & area available.**

8) **Planted Trees** along the periphery of the site, it will serve as a barrier against the noise & odor from the plant.

Sanitary landfilling:-

1) It is method of disposing of waste on land without creating nuisance or hazards to public health or environment.
2) This method utilizes the principles of engineering to confine the solid waste to the smallest practical area.
3) To reduce it to the smallest practical volume & to cover it with a layer of earth at the end of each days operations or at more frequent intervals.
4) Sanitary Landfilling can be done by following three ways:
    1) **Trench Methods**
    2) **Area Methods**
    3) **Ramp Methods**

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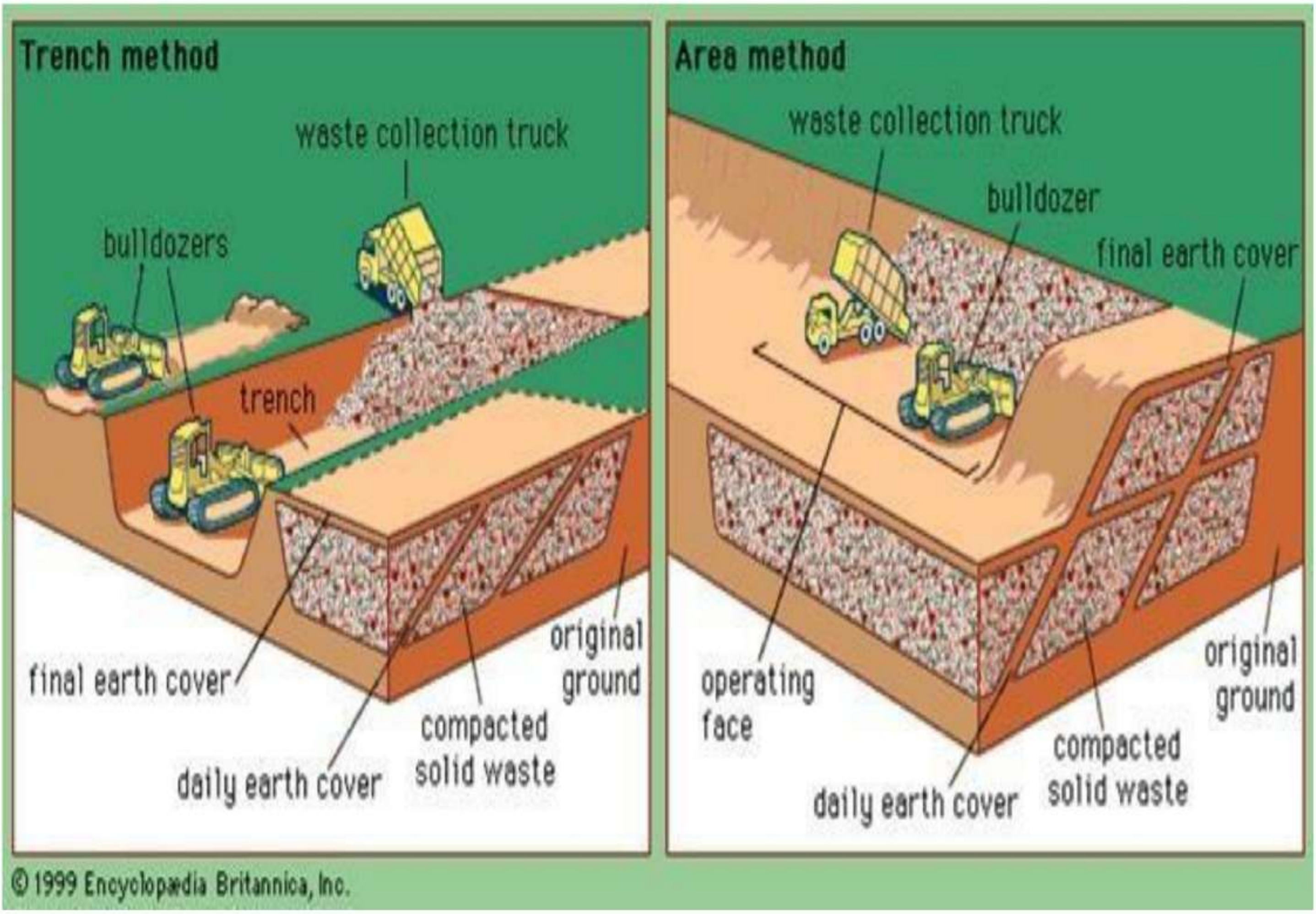
Trench Method of Sanitary Landfilling:-

1) Best suited for flat land where excavation can be carried out easily and where the ground water table is sufficiently low.
2) A trench 2m deep, 2-5 m wide is cut & The length of the trench depends upon the site conditions.
3) The excavated soil is placed on the sides of the trench and after the solid waste has been put in layers are compacted & trench filled.

Area Methods of Sanitary Landfilling:-

1) Best used in areas where natural depressions exists like valleys.
2) The waste is put in the natural depression & compacted.
3) A layers of earth is given on the top & compacted.
4) The process is repeated till the depression is filled up.
5) The earth cover has to be excavated at the site itself or imported from elsewhere.


Trench method
waste collection truck
bulldozers
trench
final earth cover
daily earth cover
compacted solid waste
original ground
Area method
waste collection truck
bulldozer
final earth cover
operating face
daily earth cover
compacted solid waste
original ground
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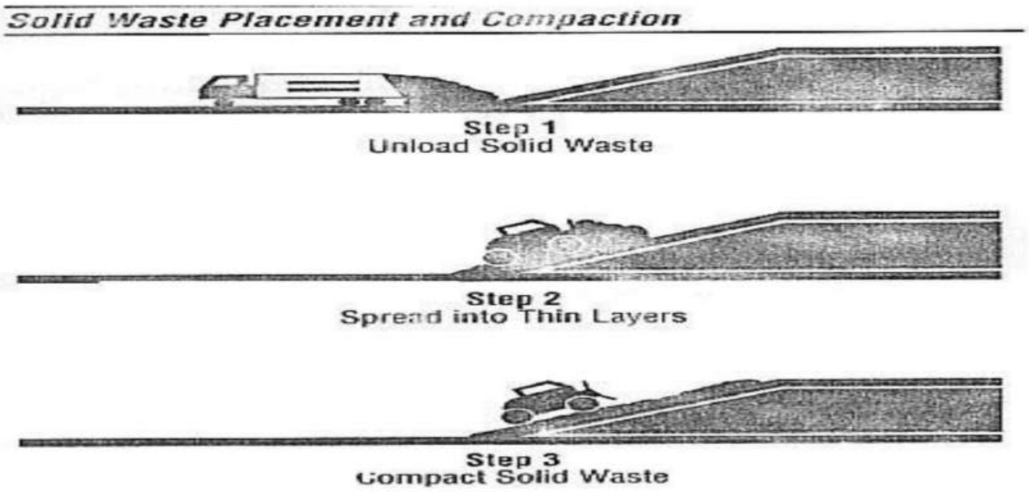
Ramp Method of Sanitary Landfilling:-

1) Modified form of area & trench method and used in flat as well as gently rolling areas.
2) A ramp about 15m wide, 30m long and of a suitable height is created.
3) A valley like trench is cut so that the tractor come to the top of the ramp and discharge the contents inside the trench.
4) At the end of day (operation), the refuse is compacted by the tractor which also pushes earth on it and compacts it.
5) Thus it becomes a part of ramp on the top of which vehicles can be operated on the next day.



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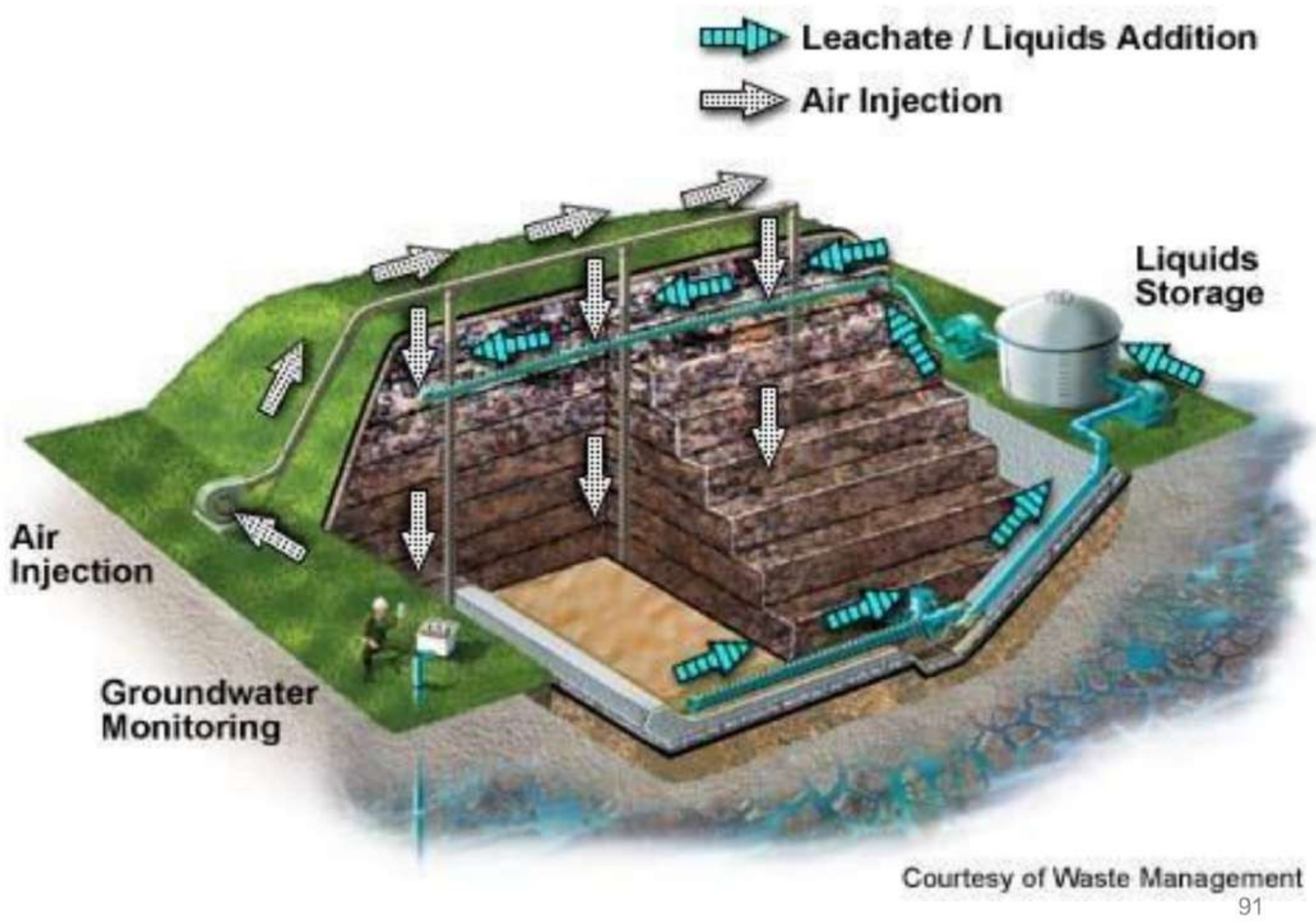
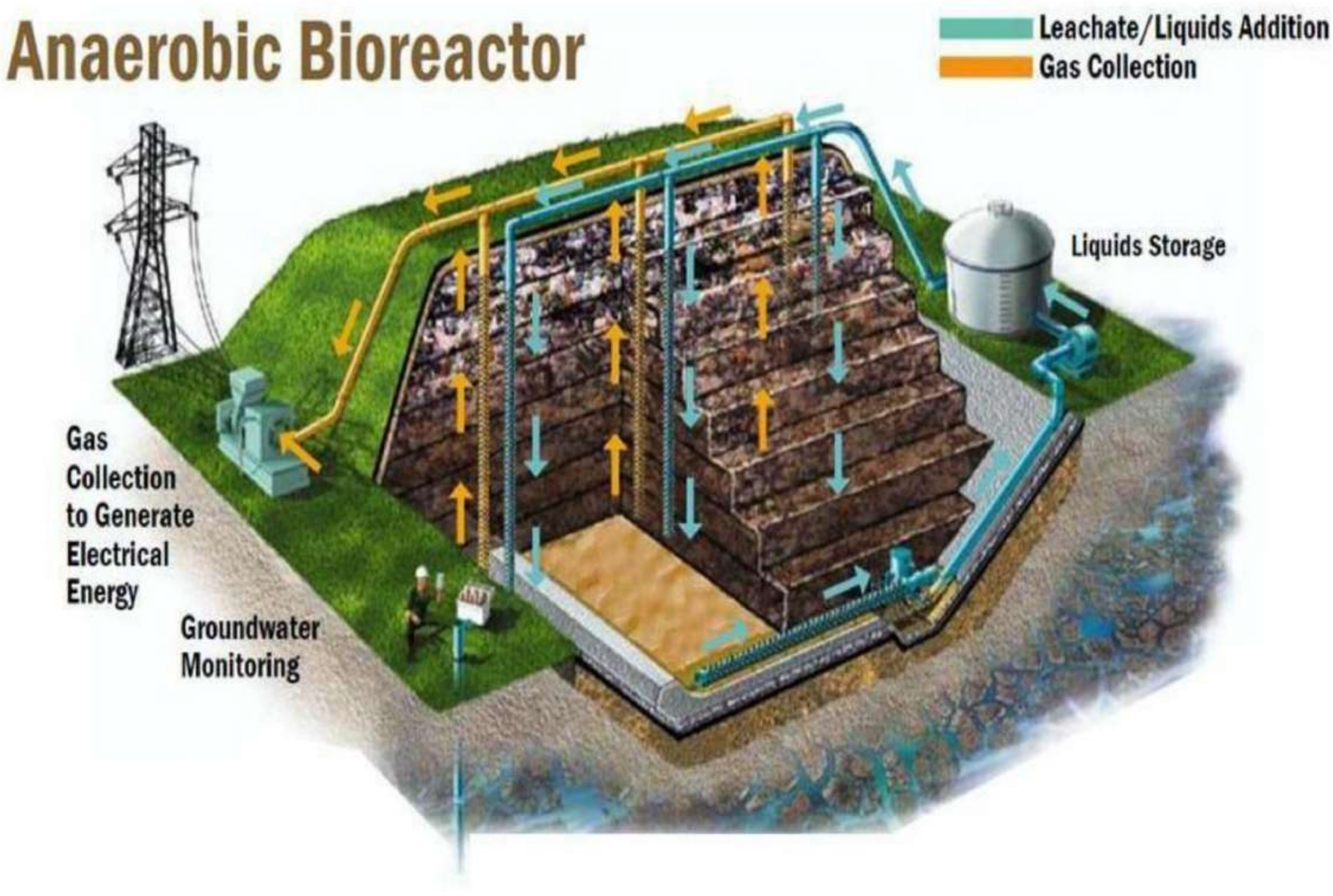
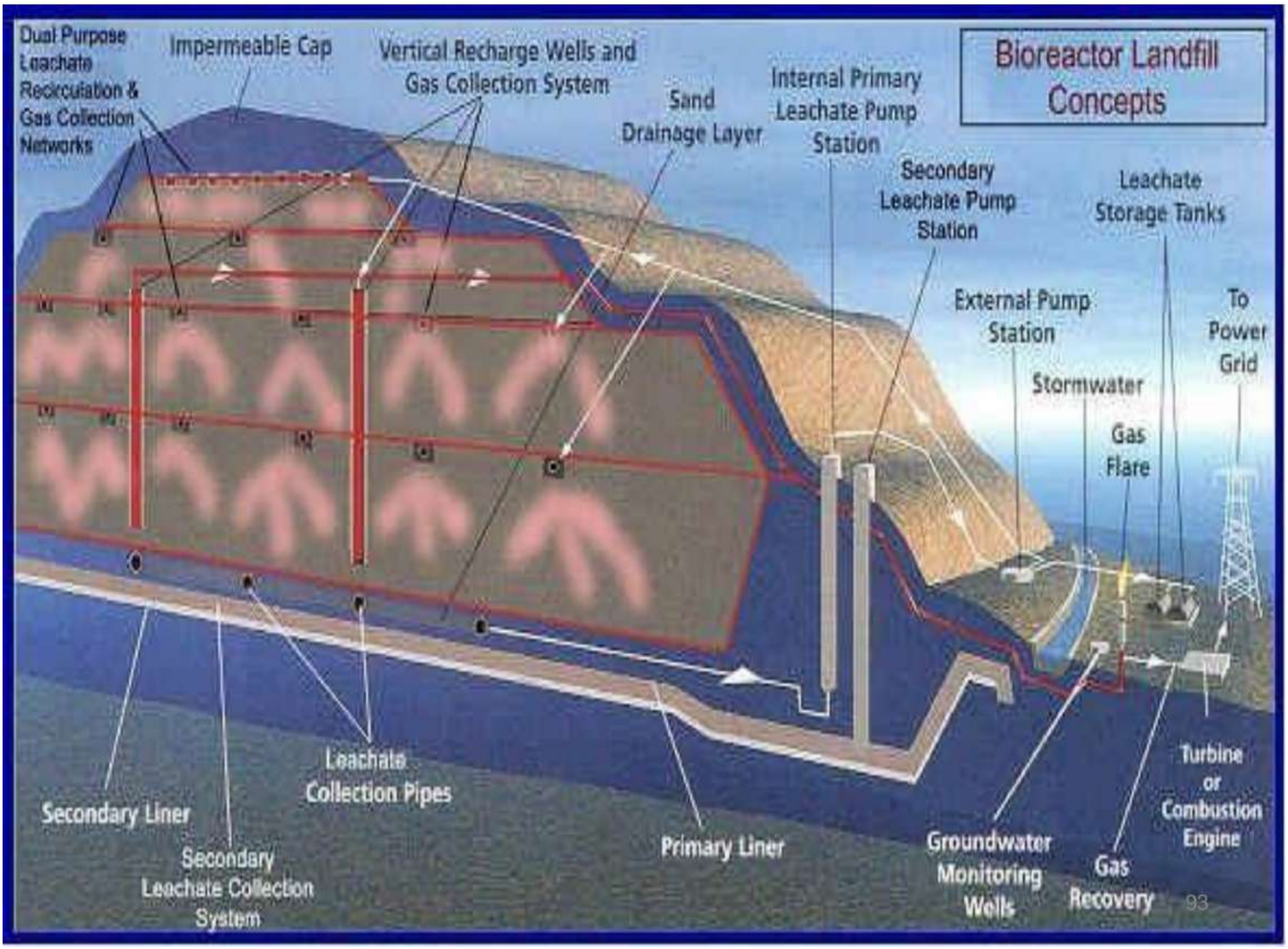
Bioreactor landfilling



Bioreactor landfilling




Bioreactor Landfill Concepts
Dual Purpose Leachate Recirculation & Gas Collection Networks
Impermeable Cap
Vertical Recharge Wells and Gas Collection System
Sand Drainage Layer
Internal Primary Leachate Pump Station
Secondary Leachate Pump Station
Leachate Storage Tanks
External Pump Station
To Power Grid
Stormwater
Gas Flare
Leachate Collection Pipes
Secondary Liner
Secondary Leachate Collection System
Primary Liner
Groundwater Monitoring Wells
Gas Recovery
Turbine or Combustion Engine
93

Thermal Processing Technology:-

a) The various constituents of solid waste give it a good thermal value, when solid waste is completely or partially burnt, heat energy is released.

b) The residue after combustion requires less volume and is hygienic to handle.

c) It is that process which generates energy in the form of electricity, fuel or heat from thermo-chemical process such as combustion or gasification of solid waste.

d) Solid waste Thermal Technology is also referred to as waste to energy transformation.

e) There are following thermal processing technologies:-

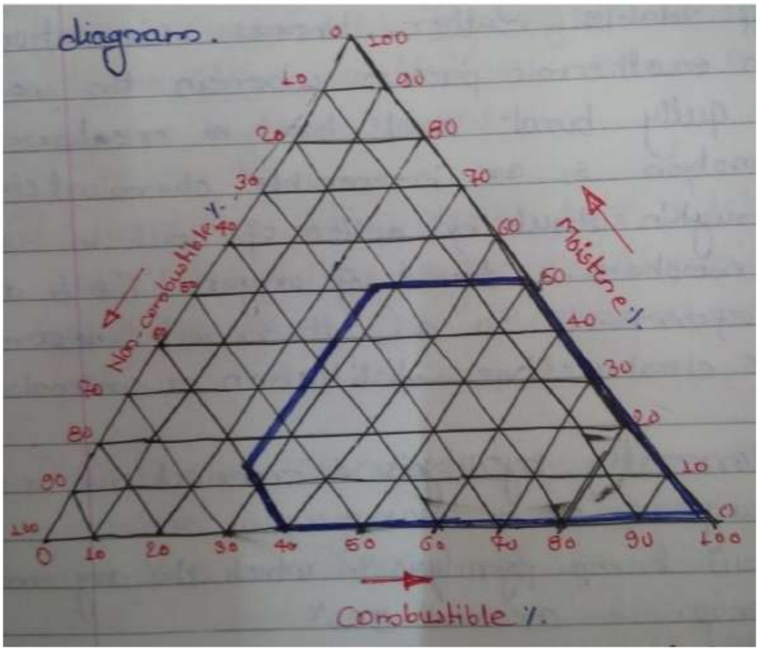
1) **Incineration**
2) **Pyrolysis**
3) **Gasification**
4) **Plasma Arc Gasification (Plasma Pyrolysis)**

Incineration:-

1) It involves controlled combustion of the waste with specific amount of air to ensure that complete combustion occurs in a specific range of temperature is an enclosed space.
2) During the process of incineration the combustible portion is burnt to final residue and ash, which is comparatively less in volume (10-20% of original).
3) Residue can be used for landfilling or some other suitable purpose.
4) Incineration plant requires much less space as compared to other disposal facilities.
5) The plant can be located in the city area itself, so that the cost of transportation is reduced.
6) Large amount of heat can be made available from incineration.
7) Incineration is not commonly used due to various reason mainly due to low calorific value and high operation & maintenance.
8) Types of incineration according to purpose:
   - Domestic (low capacity upto 50 kg/hr)
   - Commercial (capacity between 50 to 500 kg/hr)
   - Municipal (above 500 kg/hr)

Feasibility of Incineration:-

➢ The feasibility of incineration can be tested with the help of **Three Component Diagram**.



Feasibility of Incineration

by

3 Component Diagram.

➢ The moisture%, combustible% & non-combustible% values are plotted in the above three component diagram. If the point lies in the indicated zone, the reaction is self sustaining. However this is a approximation to assess the feasibility of incineration.

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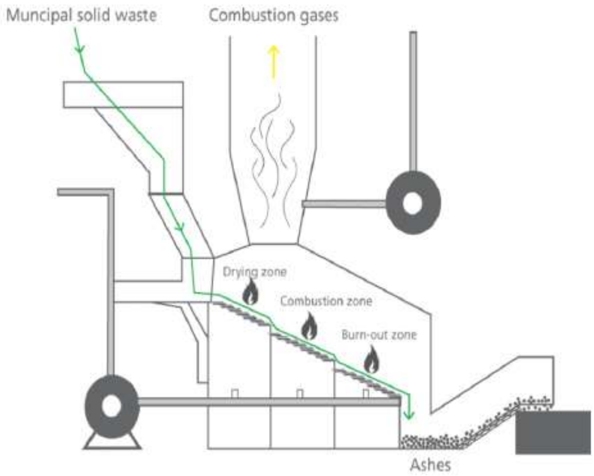
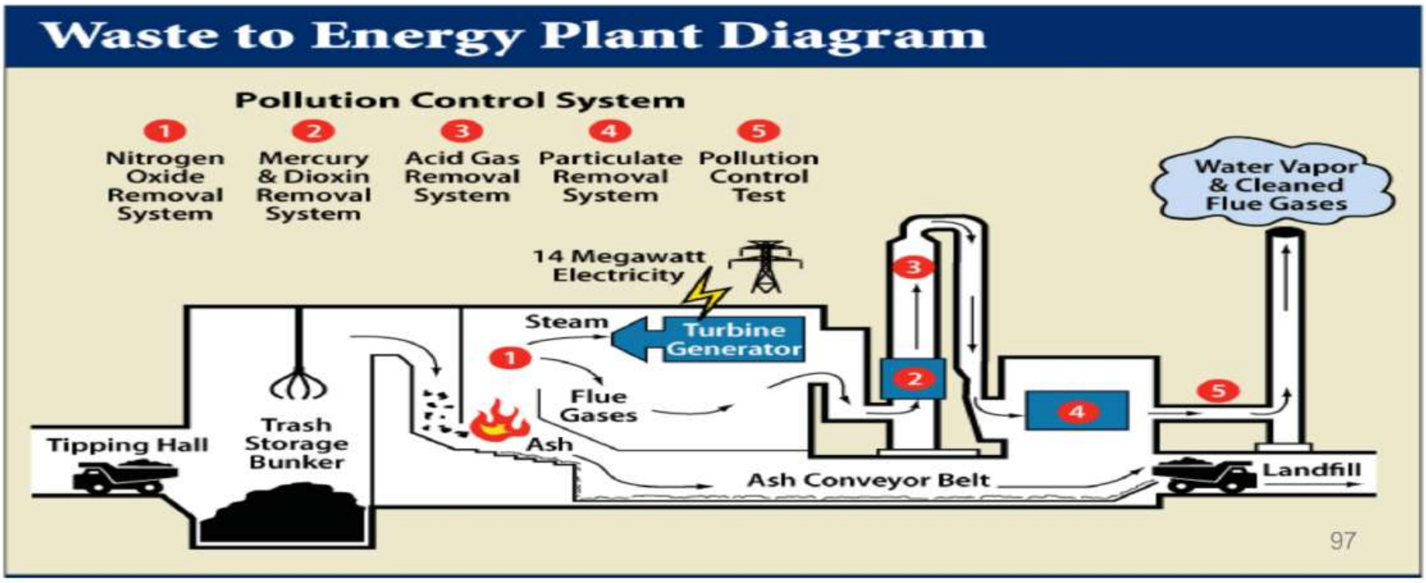
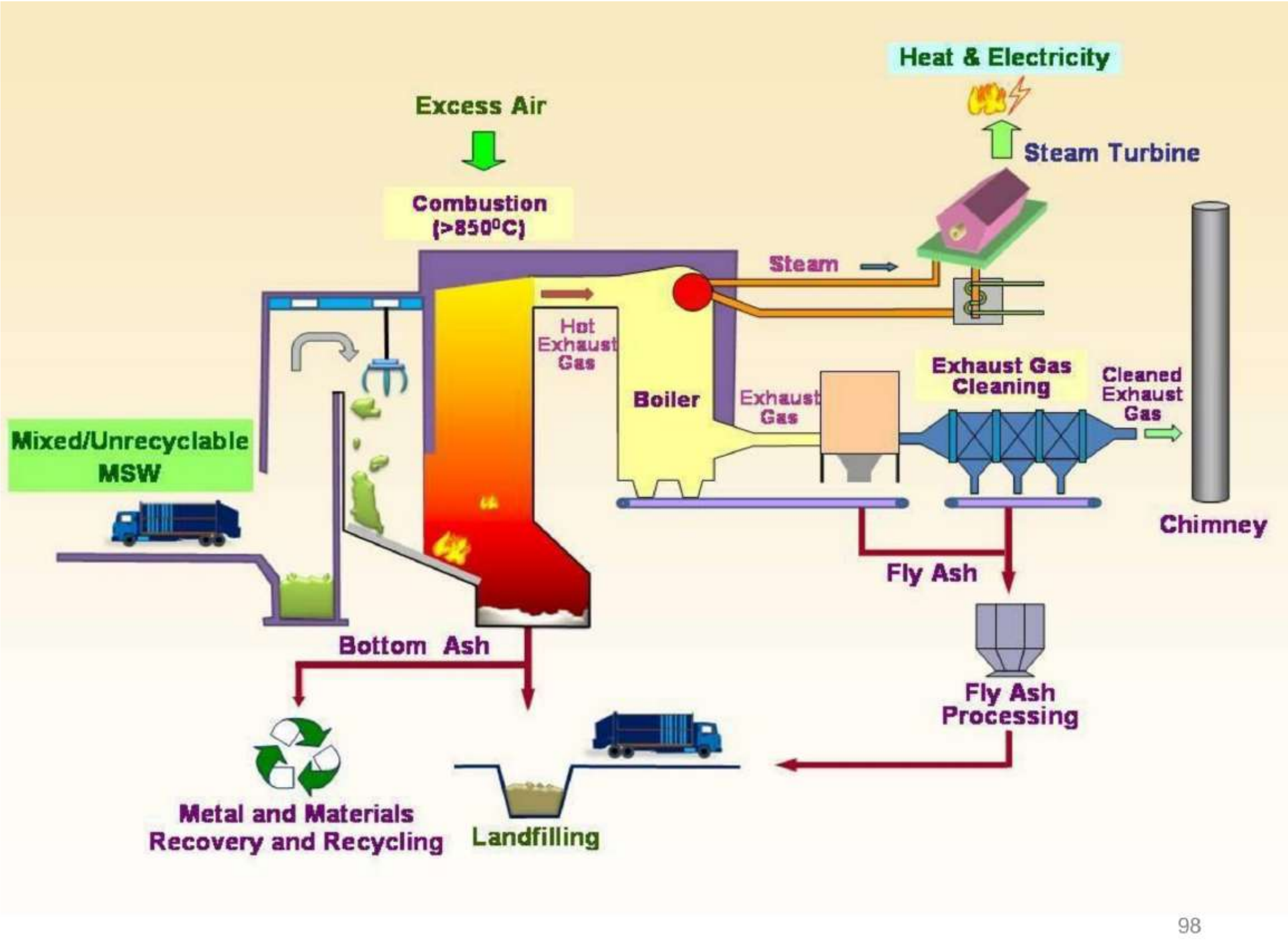

Muncipal solid waste
Combustion gases
Drying zone
Combustion zone
Burn-out zone
Ashes


Waste to Energy Plant Diagram
Pollution Control System
1 Nitrogen Oxide Removal System
2 Mercury & Dioxin Removal System
3 Acid Gas Removal System
4 Particulate Removal System
5 Pollution Control Test
Water Vapor & Cleaned Flue Gases
14 Megawatt Electricity
Steam
Turbine Generator
Flue Gases
Tipping Hall
Trash Storage Bunker
Ash
Ash Conveyor Belt
Landfill
97


Heat & Electricity
Excess Air
Steam Turbine
Combustion
(>850⁰C)
Steam
Hot
Exhaust
Gas
Boiler
Exhaust
Gas
Exhaust Gas
Cleaning
Cleaned
Exhaust
Gas
Mixed/Unrecyclable
MSW
Chimney
Fly Ash
Bottom Ash
Fly Ash
Processing
Metal and Materials
Recovery and Recycling
Landfilling
98

Pyrolysis:-

1) It is an endothermic reaction and heat must be supplied to the waste to distill off volatile matter.
2) Whereas incineration is an exothermic process wherein the waste is fully burnt and heat is released.
3) Pyrolysis is an irreversible chemical change brought by action of heat in an atmosphere devoid of oxygen.
4) This is also referred to as thermal decomposition or destructive distillation or carbonization.
5) 500 – 900 ^{0}C.
6) Normally pyrolysis is carried out in two ranges: low temp. in which avg. reaction temp. is around 500 ^{0}C & high temp in which the avg. temp. is around 900 ^{0}C.
7) Pyrolysis of solid waste produces three types of products.
    1) Gas
    2) Liquid
    3) Char
8) According to the temp. at which the solid waste are pyrolysed, the % of these products vary.

Pyrolysis:-

- Pyrolysis of solid waste produces three types of products.

    1) **Gas** : mixture of gases such as hydrogen, carbon monoxide, methane, carbon dioxide & other hydrocarbons

    2) **Liquid :** contains tar, pitch, light oil, low organic chemicals like acetic acid, acetone, methanol, etc.

    3) **Char :** consist of elemental carbon along with the inert material in the waste feed.

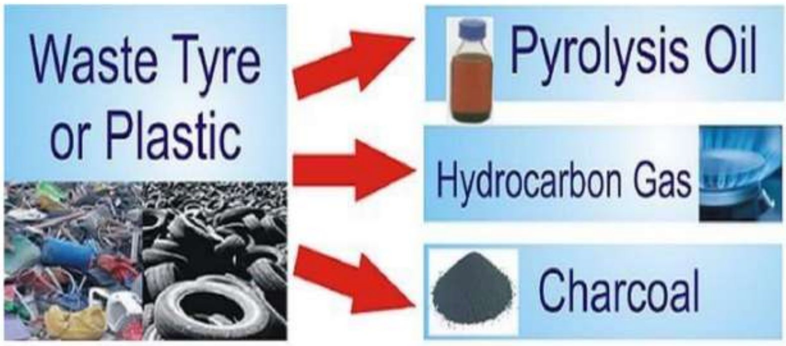
    All the three component have **high calorific values** & can be used as fuels after making necessary modification in the design of burning equipment.

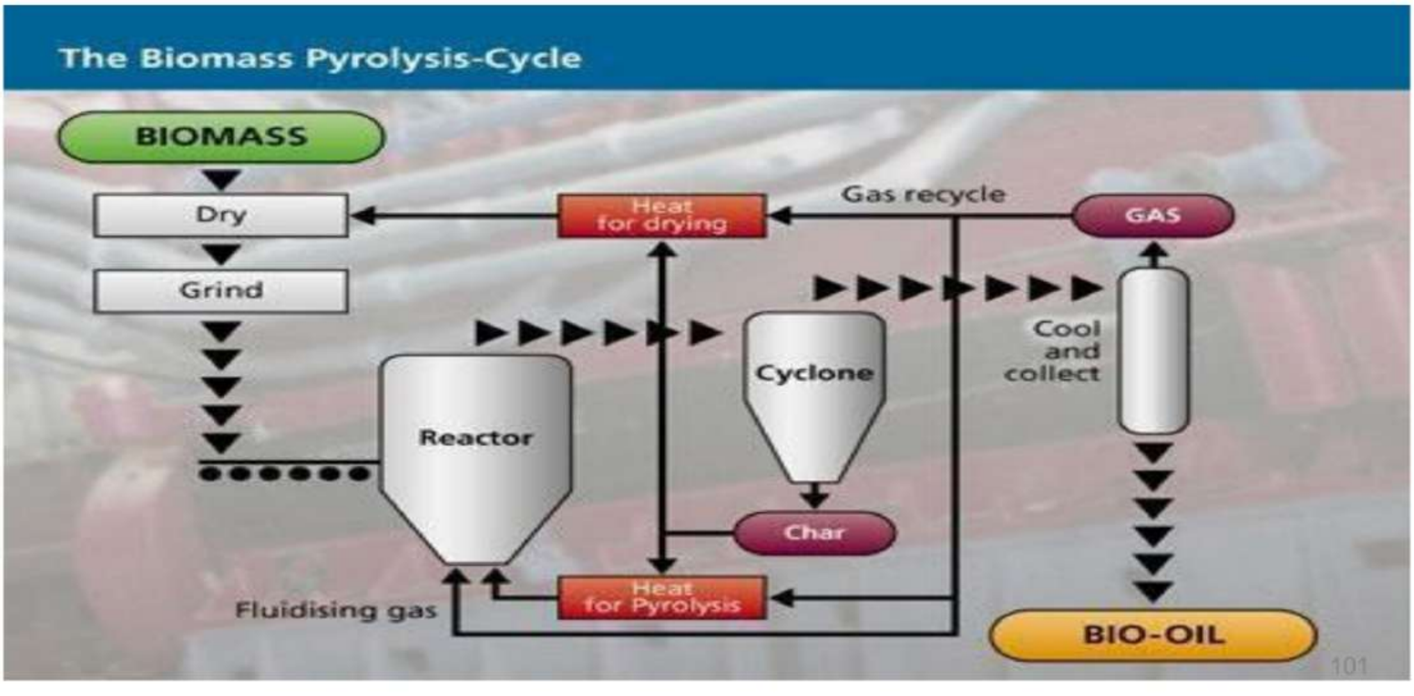
- **Different Pyrolysis Methods Recently Developed** :

    1) Destrugs system

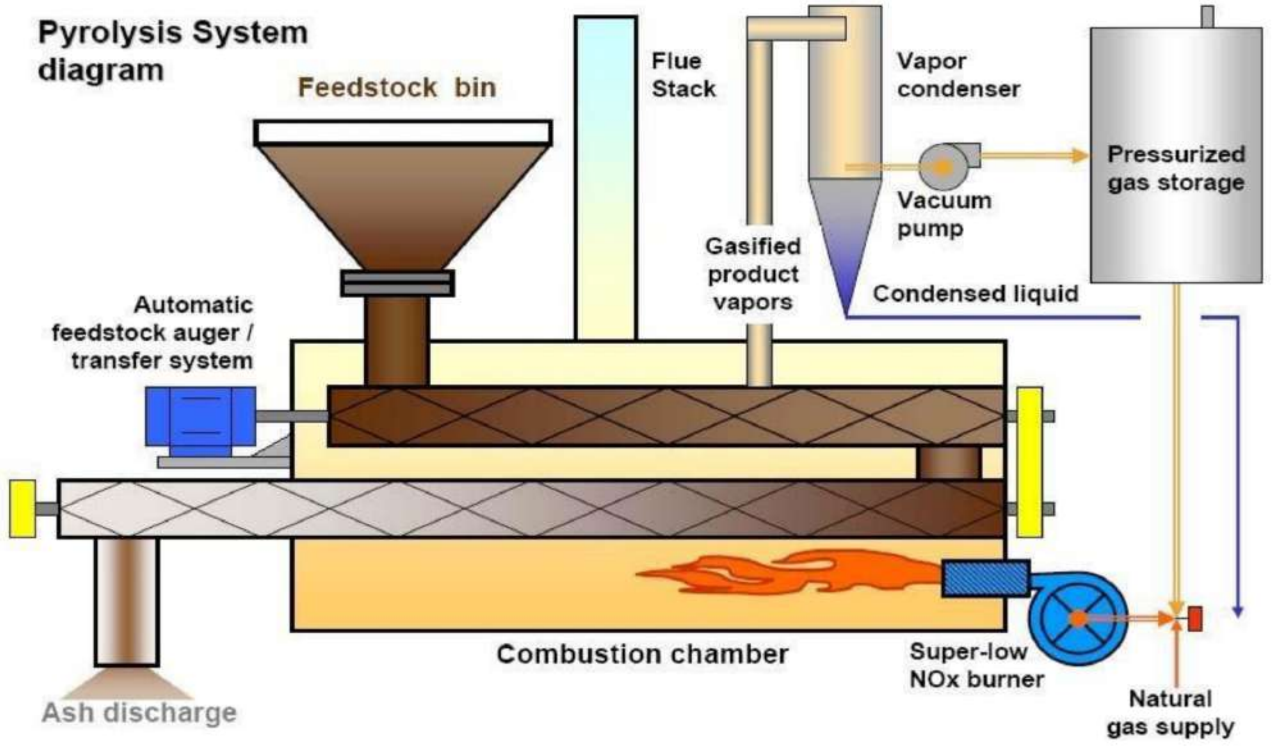
    2) Garetts Flash Pyrolysis Process

    3) Process Developed by Energy Research Center of Bureau of Mines.


Waste Tyre or Plastic
Pyrolysis Oil
Hydrocarbon Gas
Charcoal


The Biomass Pyrolysis-Cycle
BIOMASS
Dry
Grind
Heat for drying
Gas recycle
GAS
Cool and collect
Cyclone
Reactor
Char
Heat for Pyrolysis
Fluidising gas
BIO-OIL
101

Pyrolysis Process



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Gasification:-

1) It is a important technology for renewable energy. > 700 ^{0}C
2) Now days, gasification is main technology for solid waste conversion to energy & effective alternative for incineration.
3) It is achieved by reacting the material at high temp.
4) Limited amount of air is introduced to allow some organic waste to be burned to produce energy which drives a second reaction.
5) This process is largely exothermic but some heat may be required to initialize & sustain the gasification process.
6) It is a method for extracting energy from different types of organic materials.
7) The resulting gas mixture is called syngas or producer gas & itself as fuel.
8) Syngas can be valuable commercial product such as transportation fuel, chemicals & fertilizers instead of making just heat & electricity.
9) The main products are CO, CH4, H2, etc.

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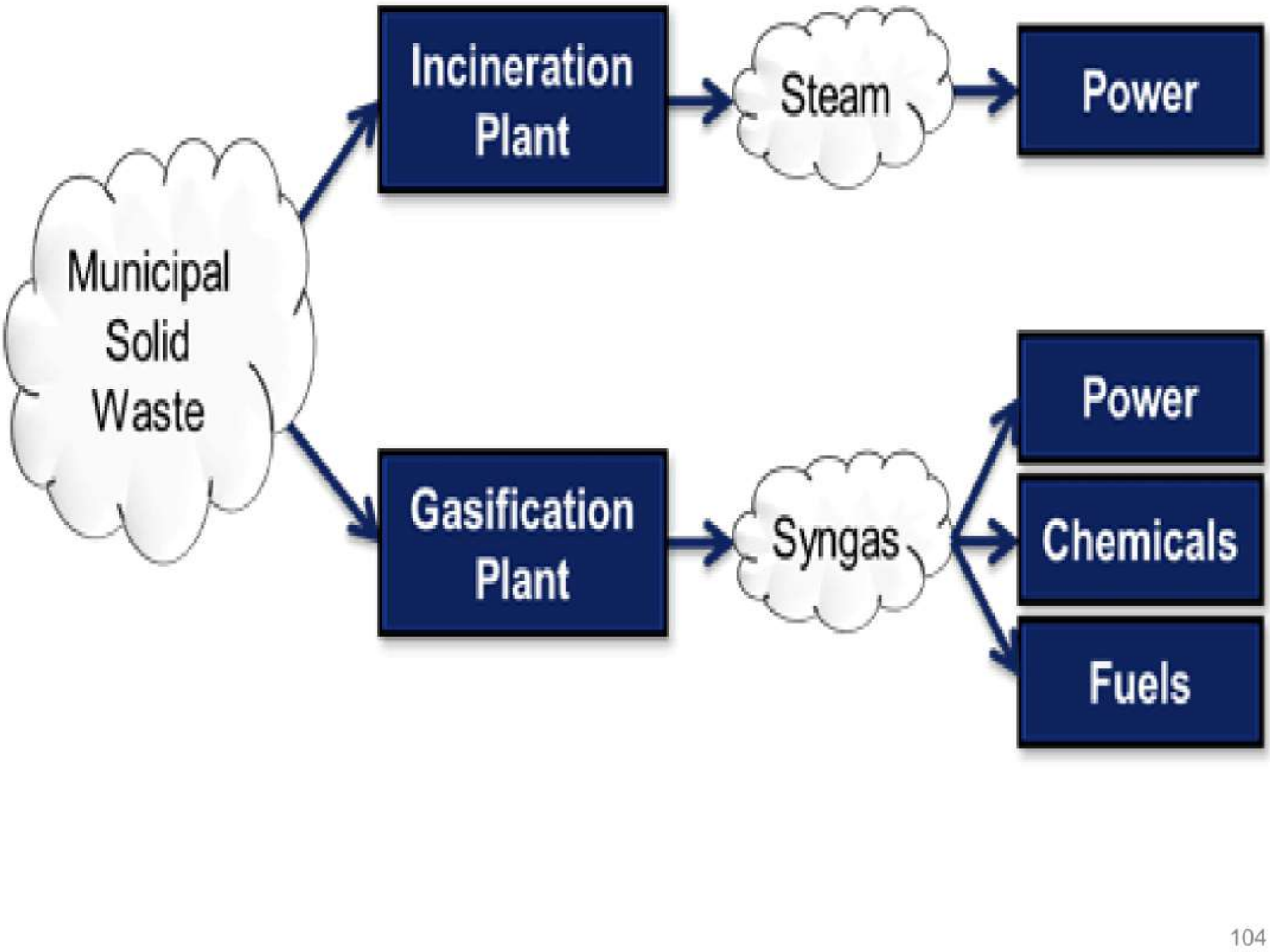
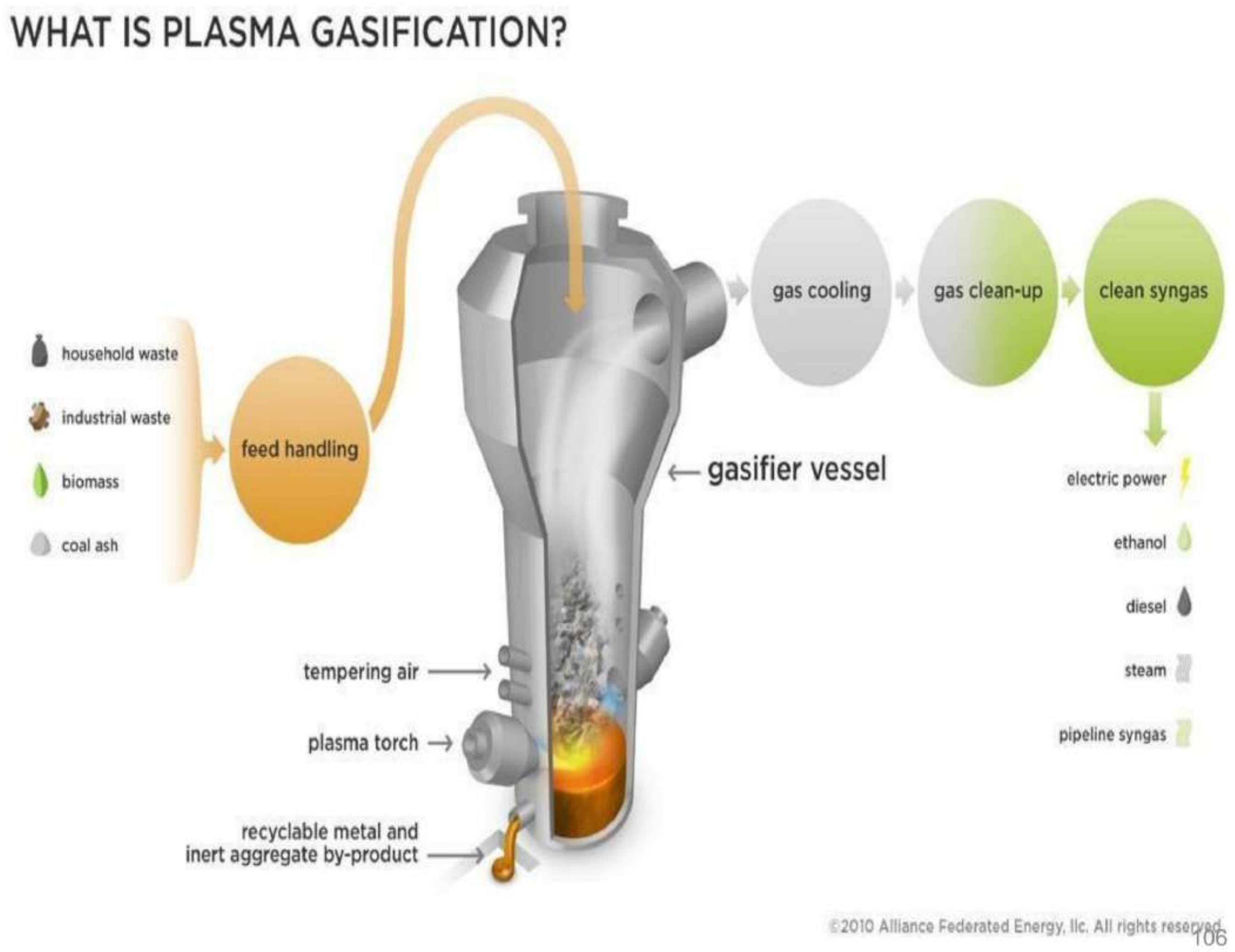

Municipal Solid Waste
Incineration Plant
Steam
Power
Gasification Plant
Syngas
Power
Chemicals
Fuels
104

Plasma Arc Gasification:-

1) Hazardous & toxic compounds broken down to elemental constituents by high temp (4000 to 7000 ^{0}C)
2) Organic matter will be gasified / melted and converted to fuel gases.
3) Process which converts organic waste into synthetic gas, electricity & slag using plasma.
4) Synthesis gas is created in an oxygen deficient atmosphere.
5) The high temp. of this process is created by an electric arc in a torch where a gas is converted into plasma.
6) The process containing a reactor with plasma torch processing of solid waste is called plasma arc gasification.
7) Plasma is called 4^{th} state of matter as it is different from solid, liquid & gaseous state.


WHAT IS PLASMA GASIFICATION?
household waste
industrial waste
biomass
coal ash
feed handling
gasifier vessel
gas cooling
gas clean-up
clean syngas
electric power
ethanol
diesel
steam
pipeline syngas
tempering air
plasma torch
recyclable metal and
inert aggregate by-product
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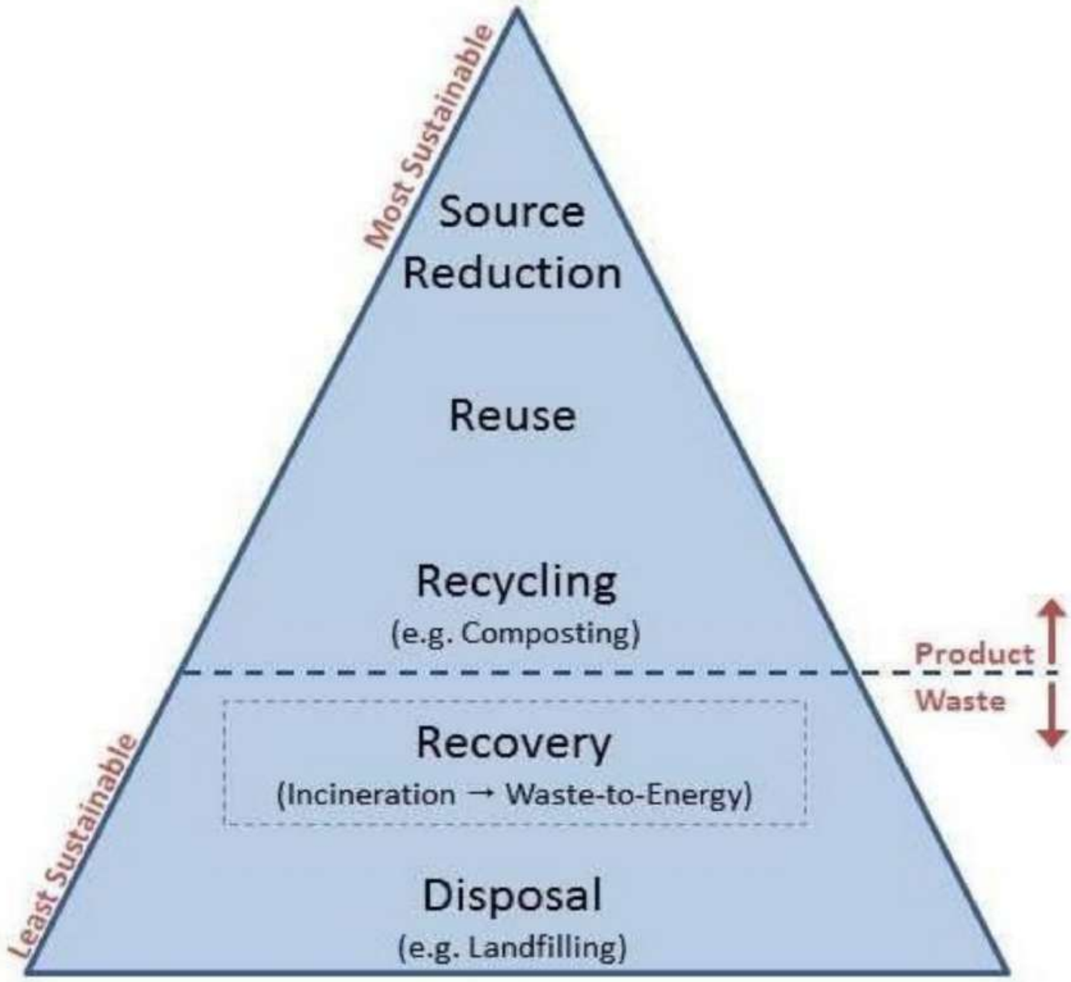
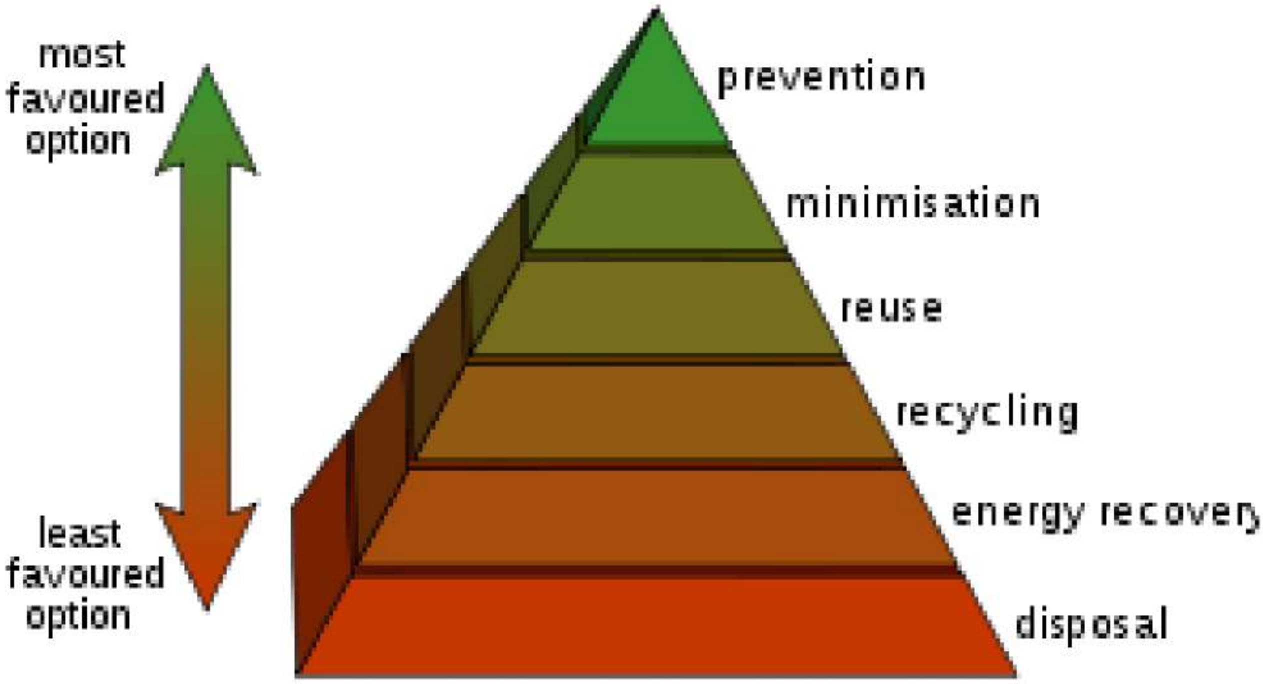

Most Sustainable
Source
Reduction
Reuse
Recycling
(e.g. Composting)
Product
Waste
Recovery
(Incineration → Waste-to-Energy)
Disposal
(e.g. Landfilling)
Least Sustainable

Waste hierarchy

Waste hierarchy refers to 3 Rs
Reduce, Reuse, Recycle



❖ The three **R's - reduce, reuse and recycle** - all help to cut down on the amount of waste.

❖ They conserve natural resources, landfill space and energy.

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REDUCE

1) The best way to manage waste is to not produce it. This can be done by shopping carefully and being aware of a few guidelines:
2) Buy products in bulk. Larger, economy-size products or ones in concentrated form use less packaging and usually cost less per ounce.
3) Avoid over-packaged goods, especially ones packed with several materials such as foil, paper, and plastic. They are difficult to recycle, plus you pay more for the package.
4) Avoid disposable goods, such as paper plates, cups, napkins, razors, and lighters. Throwaways contribute to the problem, and cost more because they must be replaced again and again.
5) Buy durable goods - ones that are well-built or that carry good warranties. They will last longer, save money in the long run and save landfill space.
6) At work, make two-sided copies when ever possible.
7) Maintain central files rather than using several files for individuals.
8) Use electronic mail or main bulletin board.
9) Use cloth napkins instead of paper napkins.
10) Use a dish cloth instead of paper towels.

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REUSE

It makes economic and environmental sense to reuse products. Sometimes it takes creativity:

1) Reuse products for the same purpose. Save paper and plastic bags, and repair broken appliances, furniture and toys.
2) Reuse products in different ways. Use a coffee can to pack a lunch; use plastic microwave dinner trays as picnic dishes.
3) Sell old clothes, appliances, toys, and furniture in garage sales or ads, or donate them to charities.
4) Use re-sealable containers rather than plastic wrap.
5) Use a ceramic coffee mug instead of paper cups.
6) Reuse grocery bags or bring your own cloth bags to the store. Do not take a bag from the store unless you need one.

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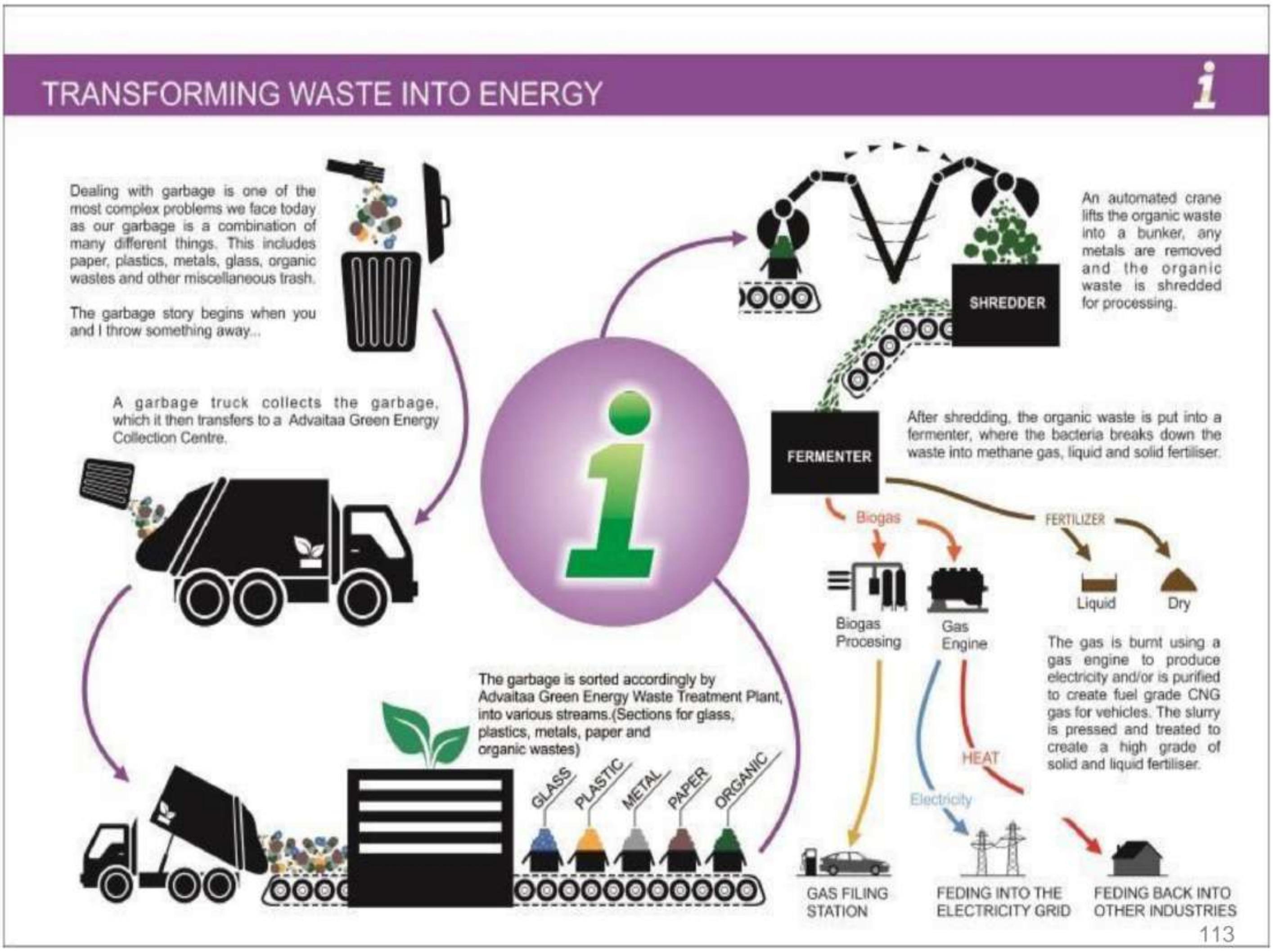
RECYCLE

Recycling is a series of steps that takes a used material and processes, remanufactures, and sells it as a new product. Begin recycling at home and at work:

1) Buy products made from recycled material. Look for the recycling symbol or ask store managers or salesmen. The recycling symbol means one of two things - either the product is made of recycled material, or the item can be recycled. For instance, many plastic containers have a recycling symbol with a numbered code the identifies what type of plastic resin it is made from. However, just because the container has this code does not mean it can be easily recycled locally.
2) Check collection centers and curbside pickup services to see what they accept, and begin collecting those materials. These can include metal cans, newspapers, paper products, glass, plastics and oil.
3) Consider purchasing recycled materials at work when purchasing material for office supply, office equipment or manufacturing.
4) Speak to store managers and ask for products and packaging that help cut down on waste, such as recycled products and products that are not over packaged.
5) Buy products made from material that is collected for recycling in your community.

6) Use recycled paper for letterhead, copier paper and newsletters.


TRANSFORMING WASTE INTO ENERGY
Dealing with garbage is one of the most complex problems we face today as our garbage is a combination of many different things. This includes paper, plastics, metals, glass, organic wastes and other miscellaneous trash.
The garbage story begins when you and I throw something away...
A garbage truck collects the garbage, which it then transfers to a Advaitaa Green Energy Collection Centre.
The garbage is sorted accordingly by Advaitaa Green Energy Waste Treatment Plant, into various streams.(Sections for glass, plastics, metals, paper and organic wastes)
GLASS
PLASTIC
METAL
PAPER
ORGANIC
An automated crane lifts the organic waste into a bunker, any metals are removed and the organic waste is shredded for processing.
SHREDDER
FERMENTER
After shredding, the organic waste is put into a fermenter, where the bacteria breaks down the waste into methane gas, liquid and solid fertiliser.
Biogas
FERTILIZER
Biogas Procesing
Gas Engine
Liquid
Dry
The gas is burnt using a gas engine to produce electricity and/or is purified to create fuel grade CNG gas for vehicles. The slurry is pressed and treated to create a high grade of solid and liquid fertiliser.
HEAT
Electricity
GAS FILING STATION
FEDING INTO THE ELECTRICITY GRID
FEDING BACK INTO OTHER INDUSTRIES
113

TYPICAL QUESTIONS

1) Define solid waste and classify the solid waste with their sources of generation?
2) What are the various sources of generation of SWM?
3) How do you find per capita generation of solid waste?
4) Explain the various factors affecting the per capita generation of solid waste?
5) What are the things to be kept in mind while sampling?
6) Explain physical and chemical characteristics of MSW?
7) Explain various compositions of solid waste by giving its value for Indian refuse?
8) Explain the procedure adopted for finding out the various characteristics of solid waste?
9) What is material balance analysis? How is it performed?
10) What do you understand by SWM? Why is it necessary? Explain?
11) Explain the elements of solid waste management?
12) With a neat flow diagram show the interrelationship between the functional elements of solids waste management system?
13) Write a short note on:- Characteristics of solid waste, Composition of solid waste, Classification of solid waste with their source, Sources of generation of solid waste.

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1) Solid Waste Management in Developing Countries, A. D. Bhide & B. B. Sundrsan.
2) Solid Waste Management, D. Joshep Hangertey & Joseph L. Pavoni.
3) Integrated Solid Waste Management, George Techobanoglous, McGraw- Hill Publication, 1993.
4) Solid Waste Engineering, William A Warrell, Cenage Learning Publication, 2012.
5) Manual on Solid Waste Management, CPHEEO, India.
6) MSW Management Rules, CPCB, Govt. of India. (website)

1) How many elements are there in an integrated solid waste management system?

a. 4

b. 5

c. 6

d. 3

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1) How many elements are there in an integrated solid waste management system?

a. 4

b. 5

c. 6

d. 3

2) What are the major composition of landfill gas?

a. Methane and carbon dioxide

b. carbon dioxide and carbon monoxide

c. Argon and hydrogen

d. Methane and ethane

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1) How many elements are there in an integrated solid waste management system?

a. 4

b. 5

c. 6

d. 3

2) What are the major composition of landfill gas?

a. Methane and carbon dioxide

b. carbon dioxide and carbon monoxide

c. Argon and hydrogen

d. Methane and ethane

3) Liquid waste that that drains from a landfill is termed as:

a. Wastewater

b. Sewage water

c. Polluted water

d. Leachate

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4) What is the order of waste management hierarchy, from least to most favored?

a. Reuse- Disposal- Prevention- Recycle

b. Disposal-Recycle- Prevention-Reuse

c. Recycle- Prevention-Disposal -Reuse

d. Disposal- Recycle- Reuse- Prevention

4) What is the order of waste management hierarchy, from least to most favored?

a. Reuse- Disposal- Prevention- Recycle

b. Disposal-Recycle- Prevention-Reuse

c. Recycle- Prevention-Disposal -Reuse

d. Disposal- Recycle- Reuse- Prevention

5) Which gas produced from landfill can be used as a renewable energy?

a. Methane

b. Carbon dioxide

c. Oxygen

d. None of the above

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4) What is the order of waste management hierarchy, from least to most favored?

a. Reuse- Disposal- Prevention- Recycle

b. Disposal-Recycle- Prevention-Reuse

c. Recycle- Prevention-Disposal -Reuse

d. Disposal- Recycle- Reuse- Prevention

5) Which gas produced from landfill can be used as a renewable energy?

a. Methane

b. Carbon dioxide

c. Oxygen

d. None of the above

6) What is solid waste management?

a. Compressive program of waste prevention, recycling, composting and disposal

b. Compressive program of waste disposal only

c. Compressive program of waste recycling only

d. None of the above

7) What are the characteristics of hazardous waste?

a. Ignitability and Corrosivity

b. Reactivity

c. Toxicity

d. All of the above

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a. Ignitability and Corrosivity

b. Reactivity

c. Toxicity

d. All of the above

Which of the following waste is not compostable?

a. Food waste
b. Paper
c. Dry leaves
d. Ashes

7) What are the characteristics of hazardous waste?

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b. Reactivity

c. Toxicity

d. All of the above

Which of the following waste is not compostable?

a. Food waste
b. Paper
c. Dry leaves
d. Ashes

Which of the following movement was carried out for the management of municipal solid waste?

a. Forest movement
b. Swachh Bharat mission
c. Tehri Andolan
d. Chipko Andolan

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1) Solid Waste Management by **A. D. Bhide & Sunderson**.

2) Solid Waste Engineering, 2nd Edition (SI Edition) **William A Worrell and P. Aarne Veslind** Cengage Learning, 2012.

3) Integrated Solid Waste management, **George Tchobanoglous, Hilary Theisen and Samuel A Vigil**, Tata McGraw Hill.

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