CE6504- HIGHWAY ENGINEERING

VEL TECH HIGH TECH DR. RANGARAJAN DR.SAKUNTHALA ENGINEERING COLLEGE
AVADI, CHENNAI
DEPARTMENT OF CIVIL ENGINEERING

YEAR/SEM : III / V
SUBJECT CODE/TITLE : CE6504 / HIGHWAY ENGINEERING
FACULTY NAME : RAGHUL RAJ B

UNIT I
HIGHWAY PLANNING & ALIGNMNET

Significance of highway planning – Modal limitations towards sustainability - History of road development in India – Classification of highways – Locations and functions – Factors influencing highway alignment – Soil suitability analysis - Road ecology - Engineering surveys for alignment, objectives, conventional and modern methods

HIGHWAY PLANNING

Highway planning involves the planning, design, construction, operation, and maintenance of roads, bridges, and tunnels to ensure safe and effective transportation of people and goods.

SIGNIFICANCE OF HIGHWAY PLANNING

The significance are,

- ✓ To provide safe, efficient, economic, compartable and speedy moment of people and goods
- ✓ To plan for expected features development and social needs to fix update wise properties for development of each road link based on utility
- ✓ To optimise the usage of roads with available resources
- ✓ To work out financing system

Objectives of Highway Planning

- ✓ A highway should be safe and secure.
- ✓ The highway develop must be efficient, but at a minimum cost, especially in cases of developing and underdeveloped countries.

Objectives of Highway Research Board

- ✓ To collect and analyze results on research
- ✓ To coordinate and conduct the correlation services in transport research
- ✓ To evaluate the nature and extend of research required.
- ✓ To regulate the conductive services

Modes of Transportation

Railways

- ✓ Capital and initial investments are more.
- ✓ High material usage for the construction and even the fuel consumption

Roadways

- ✓ It mostly depends on climatic conditions.
- ✓ High cost for long distances.
- ✓ Productivity is low.

Airways

- ✓ Highest cost of transportation.
- ✓ Even adverse weather conditions effect the transportation.
- ✓ Material and fuel consumption is costly.

Waterways

- ✓ It is highly affected by the weather conditions.
- ✓ It requires large initial

HISTORY OF ROAD DEVELOPMENT OF HIGHWAYS IN INDIA (APRIL'15)

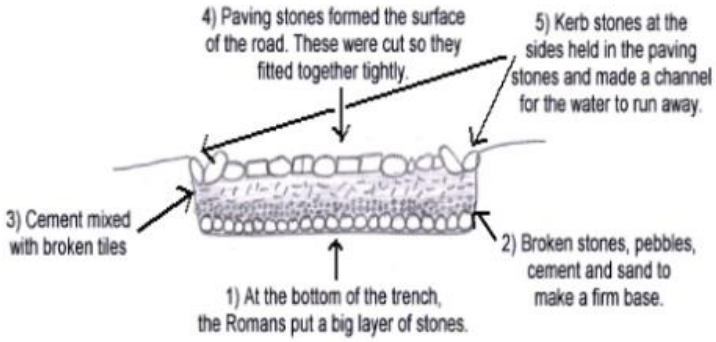
The excavation of the Mohn-Jodaro and Harappa civilization shows the traces of the roads in the ancient Indian times, in a period f 35th to 25th B.C.

The Aryan Period and Road Construction:

- ✓ "Arthashastra" written by Kautilya (Chanakya), the prime minister of the Chandra Gupta Mourya, discusses the depth of the road construction for different purposes in the **4th century.**
- ✓ **5th century A.D** - The emperor Ashoka has improved the quality of the roads in India for the travelers, in his ruling period.

Roman Roads:

- ✓ 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 0.75m to 1.2m.



Other oldest road transports are,

- ✓ Macadam construction
- ✓ Tresaguet construction
- ✓ Metcalf construction
- ✓ Telford construction

Mughal period and Road construction:

- ✓ The Mughal and Pathans improved the quality of the roads in India.
- ✓ Sher Shah Suri is still remembered for the construction of the Grand Trunk Road(GT Road) from Bangladesh-India to Kabul in Afghanistan.

19th Century and Road Construction in India:

- ✓ After the fall of the Mughal Empire in India in 19th century the Britishers participated in the road construction for the military and administrative purposes.
- ✓ The work was carried out by the British Military Engineers.
- ✓ Railway was introduced later but the existing roads were metaled and bridges were provided.

- ✓ The governor general of India i.e. Lord Dalhousie in the mid of 19th century introduced the PWD (Public works department), which still runs the various public works in India.

TRESAGUET CONSTRUCTION:

- ✓ Pierre Tresaguet (1716-1796) developed an improved method of construction in France by the year 1964.The main feature of his proposal was that the thickness of construction need be only in the order of 30 cm.
- ✓ Tresaguet was the inspector General of roads in France from 1775 to 1785.So his method of construction was implemented in that country in 1775.
- ✓ The typical cross section of tresaguets road construction and the construction steps may be enumerated as below.
  - The sub grade was prepared and layers of large foundation stones were laid on edge by hand. At the two edges of the pavement large stones were embedded edge wise to serve as submerged kerbs stones.
  - The corners of the heavy foundation stones were hammered and then the interstices filled with smaller stones.
  - The top-wearing course was made of smaller stones and compacted to a thickness of about 5 cm at the edges and gradually increased towards the center.
  - The shoulders were also provides cross slope to drain the surface water to the side drain.

MACADAM CONSTRUCTION:

- ✓ John Macadam put forward an entirely new method of road construction as
- ✓ Compared to all the previous methods. A typical cross section of Macadam construction:
  - The importance of sub grade drainage and compaction were recognized and the sub grade was compacted and was prepared with a cross slope of 1 in 36.
  - Macadam was the first person to suggest the heavy foundation stones are not at all necessary to be placed at the bottom layer of construction.
  - Though the total thickness of construction was less than previous methods. This technique could serve the purpose in a better way.
  - The size of broken stones for the top layer was decided based on the stability under animal drawn vehicles.

Jayakar Committee:

- ✓ It was formed by the both chambers of the Indian Legislature in the year 1927 to examine the roads in the India and ways of their development.
- ✓ The number of vehicles on the Indian roads increased after the First World War, so it was to develop a good network ofthe roads in India.
- ✓ **Indian Road development committee** was formed in the year **1927**, with M.R.Jayakar as its chairman. The committee **submitted** its report in the year **1928**,

The recommendations are,

1. An extra tax should be put on the petrol consumers to develop a road development fund, called the **Central Road Fund.**
2. A semi-official body should be formed to pool technical ideas, knowledge from the various parts of the country and to act as an advisory body on various aspects of roads.

3. A research organisation should be organised to carry out the research and development work.

Central Road Fund (1929):

- ✓ Central Road Fund was formed in the year **1929,** This fund was kept separate for the use in the road development in India.
- ✓ About 20% of the fund was kept to be used for the expenses of the administrative meetings and the research work of the highways of the national importance in the country.
- ✓ 80% of the funds were distributed for the road users and development of the roads by the state governments.

Indian Roads Congress (1934):

I Background:

The IRC was set up by the government of India in **December 1934** in consultation with state government as per **Jayakar** committee's recommendations. It is the premier body of highway engineer's in India.

A semi-government organization named, Indian Roads Congress was formed in the year December 1934, and was registered in the year 1937 under the registration act.

The main functions of IRC are,

- ✓ It provides a channel for expression of collective opinion of its members for all matters affecting the planning, construction and maintenance of roads in India.
- ✓ It promotes the use of the standard specification and to propose specification.

IRC is a registered society under the registration of societies act and is financed by contributions from central government and various state government.

II Committee and sub-committee:

The IRC has many Committees

- ✓ Bituminous
- ✓ Cement concrete
- ✓ Road transport development
- ✓ Transport operation cost
- ✓ Specifications and standards

The IRC has many sub Committees

- ✓ Cement concrete road surfacing
- ✓ Education of road engineers
- ✓ Prevention of ribbon development
- ✓ Soil research
- ✓ Traffic engineering

Motor vehicle act(1939):

- ✓ Increased numbers of vehicle on the Indian roads demanded for the rules and regulations.
- ✓ This Act was passed in 1939 - Rules for the road users and also for the identity of the vehicles.

NAGPUR ROAD PLAN (OR) FIRST 20-YEAR ROAD PLAN

The conference of civil engineer held at nagpur in 1943 finalized the first twenty year road development plan for India called Nagpur plan the period **1943-63**.The road network in the country was classified into five categories.

- ✓ National highway
- ✓ State highway
- ✓ Major district road
- ✓ Other district road
- ✓ Village road

Two-plan formulas were finalized at the Nagpur conference for deciding two categories of road length for the country as a whole as well as for individual areas. The two plan formula assumed the star and Grid pattern of road network. The total length of the first category or metalled roads for national and state Highways and major District Roads in km.

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

Where,
A=Agricultural area, km^2
B = Non-agricultural area, km^2
N=Number of towns and villages with population range 2001-5000
T= Number of towns and villages with population over 5000
D= Development allowance of 15 percent of road length calculated to be provided for agricultural and industrial development during the next 20 years.
R= Existing length of railway track, km.

The total length of second category roads for other District road and village Roads in km
ODR + VR (km) = [0.32 V + O.8 Q +1.6 P +3.2 S] +D
Where,
V = Number of villages with population 500 or less
Q = Number of villages with population range 501-1000
P = Number of villages with population range 1001-2000
S = Number of villages with population range 2001-5000
D = Development allowance of 15 % for next 20 years.
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Salient Features of Nagpur Road Plan:

- ✓ The responsibility of construction and maintenance of national highways was assigned to the central government.
- ✓ It was a 20-year plan intended for the period 1943-63 aiming to provide for about two-lakh km of surfaced roads and remaining unsurfaced roads.
- ✓ The formulae were based on star and grid pattern of road network. But the existing irregular pattern of roads and obligatory points not fitting in the geometric pattern were to be given due consideration.
- ✓ The second category roads are meant to provide internal road system linking small villages with first category roads.
- ✓ An allowance for agricultural and industrial development during the next 20 years was estimated as 15 percent and this allowance was to be provided while calculating the road length for both the categories of roads.

Classification of roads in Nagpur plan

- **National highways** which would pass through states, and places having national importance for strategic, administrative and other purposes.
- **State highways** which would be the other main roads of a state.
- **District roads** which would take traffic from the main roads to the interior of the district.
- **Village roads** which would link the villages to the road system.

Central Road Research Institute (1951):

- ✓ A series of laboratories, known as the Central Science and Industrial Research Center situated at Delhi.
- ✓ It contains the research center for the research work of the road construction in India.
- ✓ The main function of the CRRI
  - To do the research work for the road construction
  - To provide the consultation services for the state government.

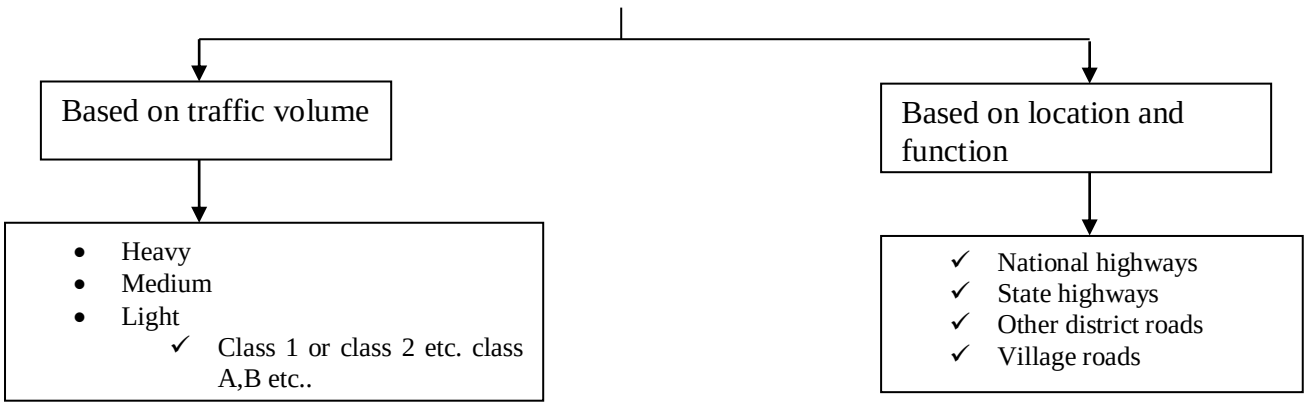
Bombay Road Congress 1961 ***(A.U MAY/JUNE 2016)***

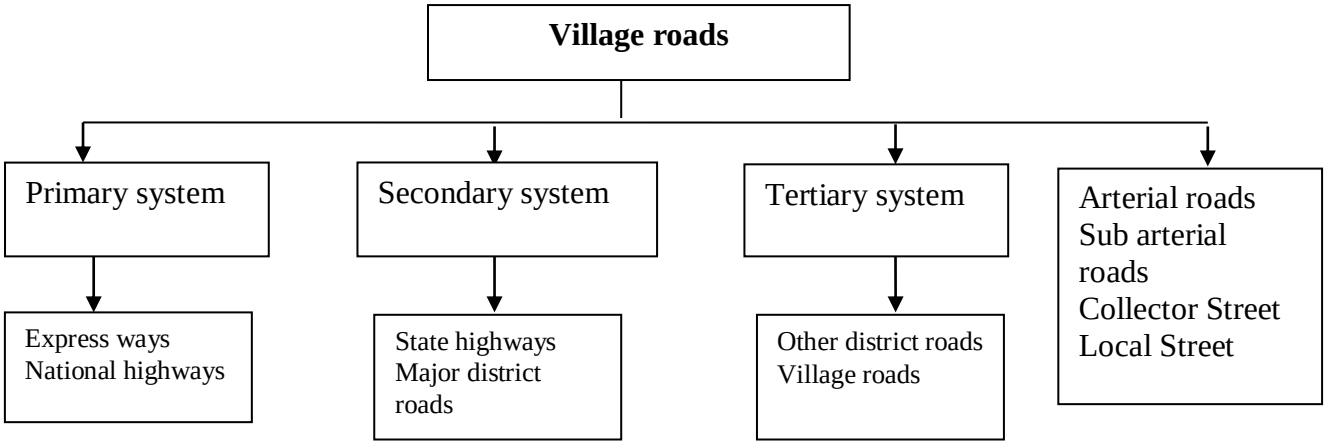
The length of roads envisaged under the Nagpur plan was achieved by the end of it, but the road system was deficient in many respects. The changed economic, industrial and agricultural conditions in the country warranted a review of the Nagpur plan. Accordingly a 20-year plan was drafted by the Roads wing of Government of India, which is popularly known as the Bombay plan.

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

CLASSIFICATION OF HIGHWAYS – LOCATION AND FUNCTION

CLASSIFICATION OF RURAL ROADS (A.U APRIL/ MAY 2017)





Expressways

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

National Highways

- ✓ India has a huge network of national highways.
- ✓ The national highways have a total length of **70,548 km**. Indian highways cover **2%** of the **total road network** of India and carry **40%** of the **total traffic**.
- ✓ The longest highway in India is **NH7** which stretches from **Varansi in Uttar Pradesh to Kanyakumari** in the southern most point of Indian mainland.
- ✓ The shortest highway is **NH47** A which stretches from **Ernakulam to Kochi** and covers total length of 4 Kms.

State Highways

- ✓ They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state.
- ✓ Total length of all SH in the country is **1,37,119Kms**.

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 **4,70,000kms** of MDR.

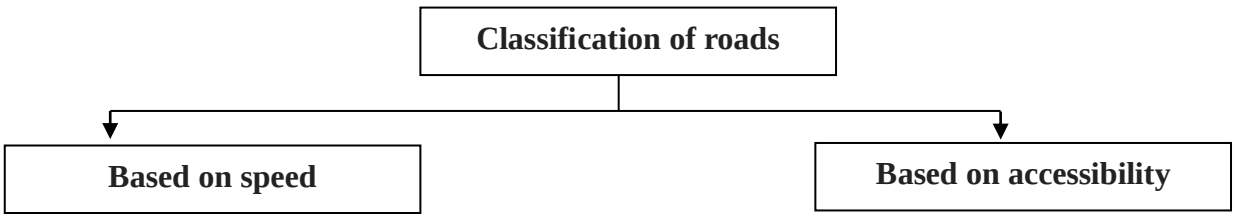
Other district roads

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

Village roads

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

CLASSIFICATION OF URBAN ROADS



Freeways:

- ✓ It is access-controlled divided highways.
- ✓ Freeways are 4 lanes and 2 lanes each direction.
- ✓ It depends upon the kind of intersecting road way (rural roads, another freeway etc.)

Expressways:

- ✓ It is designed for high speed (120 km/hr), high traffic volume and safety.
- ✓ Provided with grade separations at intersections.
- ✓ Not allowed for parking, loading and unloading of goods and pedestrian traffic.

Highways:

- ✓ It is divided into two types,
  Rural highways: passing through rural areas (villages)
  Urban highways: passing through large cities and towns.

Arterials:

- ✓ It is divided into fully or partially controlled access.
- ✓ Parking. Loading and unloading activities are regulated.
- ✓ Pedestrians are allowed to cross only at intersections/designated pedestrian crossings.
- ✓ No frontage access, no standing vehicle, very little cross traffic.
- ✓ Design Speed : 80km/hr
- ✓ Land width : 50 – 60m
- ✓ Spacing 1.5km in CBD & 8km or more in sparsely developed areas.
- ✓ Divided roads with full or partial parking
- ✓ Pedestrian allowed to walk only at intersection

Local streets:

- ✓ It is intended for access to residence, business or abutting property.

Collector streets:

- ✓ It is intended for collecting and distributing traffic to and from local streets.
- ✓ Providing access to arterial streets.

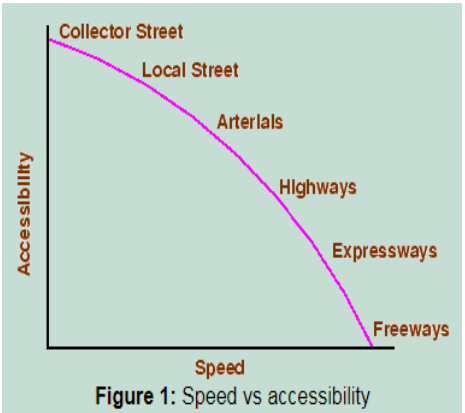


Figure 1: Speed vs accessibility

- ✓ Full access is provided on these streets.

Sub-arterial

- ✓ Bus stops but no standing vehicle.
- ✓ Less mobility than arterial.
- ✓ Spacing for CBD : 0.5km
  Sub-urban fringes: 3.5km

Design speed : 60 km/hr
Land width: 30 – 40 m

Collector Street

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

Local Street

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

Cul-De-Sac

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

FACTORS INFLUENCING HIGHWAY ALIGNMENT

Highway alignment:

The position or layout of centre line of the highway on the ground is called the alignment. It includes straight path, horizontal deviation and curves.

The various factors that control the alignment are as follows:

Obligatory points:

- ✓ These are the control points governing the highway alignment. These points are classified into twocategories. Points through which it should pass and points through which it should not pass.

Examples are,

Bridge site:

- ✓ It can be located only where the river has straight and permanent path and also where theabutment and pier can be strongly founded.

- ✓ It should not be curved and skew crossing should be avoided as possible.
- ✓ To locate a bridge the highway alignment may be changed.

Mountain:

- ✓ While the alignment passes through a mountain, the various alternatives are to either construct a tunnel orto go round the hills.
- ✓ It depends on factors like topography, site conditions and construction and operation cost.

Intermediate town:

- ✓ The alignment may be slightly deviated to connect an intermediate town or village nearby.
- ✓ To avoid obstructions such as places of cemeteries, archeological, historical monument, public facilities like schools and hospitals, utility services.

Geometric design features

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

Topographical control points

The alignment, where possible should avoid passing through

- ✓ Marshy and low lying land with poor drainage
- ✓ Flood prone areas
- ✓ Unstable hilly features
- ✓ Avalanche prone areas
  - ➢ Flat terrain-below 3%
  - ➢ Rolling terrain -3 to 25%
  - ➢ Mountainous terrain–above 25%
  - ➢ A location on high ground should be preferred rather than valley to avoid cross drainage works

Economics

The total cost Construction cost+ maintenance cost+ operation cost) should be kept minimum.

- ✓ Initial cost-by avoiding high embankments and deep cutting
- ✓ Maintenance cost-by avoiding unsuitable land
- ✓ Operation cost- by avoiding steep gradient and curves

Other considerations

- ✓ Environmental considerations
- ✓ Engineering feasibility
- ✓ Social considerations
- ✓ Drainage and Hydrological factors
- ✓ Political considerations- avoiding into foreign territory
- ✓ Monotony- long stretch of straight road leads to driving discomfort.

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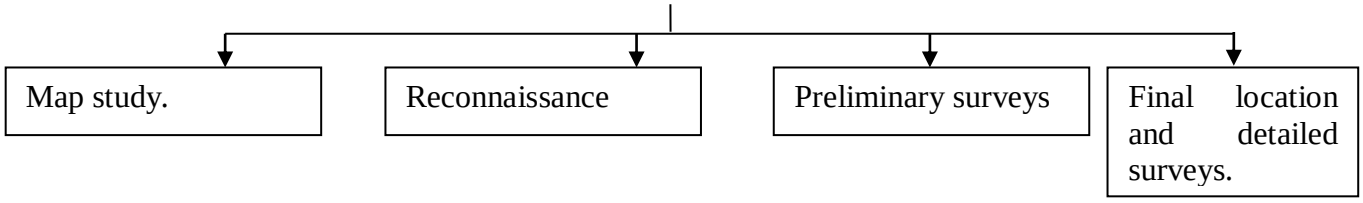
ENGINEERING SURVEYS FOR ALIGNMENT

Stages of the Engineering Surveys



Map study: -

The probable alignment can be located on the map from the following details available on the map.

- ✓ Alignment avoiding valleys, ponds or lakes.
- ✓ When the road has to cross a row of hills, possibility crossing through a mountain pass.
- ✓ a road is to be connected between two stations one of the top and the other on the foot of the hill thenalternate routes can be suggested keeping in view the permissible alignment.

Reconnaissance Survey:-

To examine the general character of the area for deciding the most feasible routes for detailed studies. The details to be collected are given below:

- ✓ Valleys, ponds, lakes, marshy, land, ridge, hills, permanent structures and other obstructions along the route, which are not available in the map alignments.
- ✓ Number and types of cross drainage structures maximum flood level and natural groundwater level along the probable routes.
- ✓ Soil type along the routes from field identification tests and observation of geological features.
- ✓ Source of construction materials water and location of stone quarries.
- ✓ When the road passes through hilly or mountainous terrain, additional data regarding the geological formation types of rocks, dip of strata, seepage flow etc.

Salient features:

- ✓ Map updating – to confirm features indicated on map.
- ✓ Checking for:
  - Number of cross drainage structures.
  - High Flood Level (HFL)
  - Confirming Length and value of gradient to IRC standards.
  - Soil Characteristics and Geological features.
  - Proximity to source of construction materials- quarries, water sources.
  - Prepare a report on merits and demerits and profile map of scale 1:50,000.

Preliminary survey: -

The main objectives of the preliminary surveys are:

- ✓ To survey the various alternate alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil.
- ✓ To compare the different proposals in view of the requirements of a good alignment.
- ✓ To estimate quantity of earthwork materials and other construction aspects and to work out the cost of alternate proposals.

- ✓ To finalize the best alignment from all considerations.

The procedure of the conventional methods of preliminary surveys the given steps:

- ✓ **Primary survey: -**

For alternate alignments either secondary traverses (or) independent primary traverses may be necessary.

- ✓ **Topographical features: -**

All geographical and other man made features along the traverse and for a certain width on either side surveyed and plotted.

- ✓ **Leveling work: -**

Levelling work is also carried out side by side to give the centerline profiles and typical cross sections. The leveling work in the preliminary survey is kept to a minimum just sufficient to obtain the approximate earthwork in the alternate alignments.

- ✓ **Drainage studies: -**

Drainage investigations and hydrological data are collected so as to estimate the type, number and approximate size of cross and drainage structures.

- ✓ **Soil survey: -**

The soil survey conducted at this stage helps to working out details of earthwork, slopes, suitability of materials, subsoil and surface drainage requirements and pavement type and the approximate thickness requirements.

- ✓ **Material survey: -**

The survey for naturally occurring materials like stone aggregates, soft aggregates etc and identification of suitable quarries should be made.

- ✓ **Traffic survey: -**

Traffic surveys conducted in the region from basis for deciding the number of traffic lanes and roadway width, pavement design and economic analysis of highway project.

Final location and detailed survey: -

The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centerline. The detailed survey should be carried out for collecting the information technology for the preparation of plans and construction details.

Location: -

- ✓ The centerline of the road finalized in the drawings to be translated on the ground during the location survey.
- ✓ Major and minor control points are established on the ground and center pegs are driven, checking the geometric design, requirements.

Detailed survey: -

- ✓ Levels along his final centerline should be taken at all staked points.

Levelling work is to great importance as the vertical alignment.

- ✓ A detailed soil survey is carried out to enable drawing of the soil profile.
- ✓ The data during the detailed survey should be elaborate and complete for preparing detailed plans, design and estimates of the project

ROAD ECOLOGY (NOV'15)

Road ecology is the study of the ecological impacts (both positive and negative) of roads and highways (public roads). It include local effects, such as on noise, water pollution, habitat destruction/disturbance and local air quality; and wider effects such as habitat fragmentation, ecosystem degradation, and climatechange from vehicle emissions.

- ✓ The design, construction and management of roads, parking and other related facilities as well as the design and regulation of vehicles can change the impacts to varying degrees.
- ✓ Roads are known to cause significant damage toforests, prairies, streams and wetlands.
- ✓ Roads are a form of linear infrastructure intrusion that has some effects similar to infrastructure such as railroads, power lines, and canals, particularly in tropical forests.

Negative Impacts

- ✓ Air pollution from fossil (and some biofuel) powered vehicles can occur wherever vehicles are used and are of particular concern in congested city street conditions and other low speed circumstances.
- ✓ Emissions include particulate emissions from diesel engines, NO*x*, volatile organic compounds, CO and various other hazardous air pollutants including benzene.
- ✓ Concentrations of air pollutants and adverse respiratory health effects are greater near the road than at some distance away from the road.
- ✓ Road dust kicked up by vehicles may trigger allergic reactions.
- ✓ $CO_2$is non-toxic to humans but is a major greenhouse gas and motor vehicle emissions are an important contributor to the growth of CO2 concentrations in the atmosphere and therefore to globalwarming.

Positive Impacts

- ✓ The construction of new roads which divert traffic from built-up areas can deliver improved air quality to the areas relieved of a significant amount of traffic.
- ✓ The *Environmental and Social Impact Assessment Study* carried out for the development of the Tirana Outer Ring Road estimated that it would result in improved air quality in Tirana city center.
- ✓ A new section of road being built near Hindhead, UK, to replace a four-mile section of the A3 road, and which includes the new Hindhead Tunnel, is expected by the government to deliver huge environmental benefits to the area including the removal of daily congestion, the elimination of air pollution in Hindhead caused by the congestion, and the removal of an existing road which crosses the environmentally sensitive Devil's Punchbowl area of outstanding natural beauty.

CONVENTIONAL AND MODERN METHODS

The conventional and modern methods are,

1. Primary traverse
2. Topographical features
3. Levelling work
4. Drainage studies

5. Soil survey
6. Material survey
7. Traffic survey
8. Determination of final centre line

UNIT II
GEOMETRIC DESIGN OF HIGHWAYS

Typical cross sections of Urban and Rural roads — Cross sectional elements - Sight distances – Horizontal curves, Super elevation, transition curves, widening at curves – Vertical curves -Gradients, Special consideration for hill roads - Hairpin bends – Lateral and vertical clearance at underpasses.

TYPICAL CROSS SECTIONS OF URBAN AND RURAL ROADS

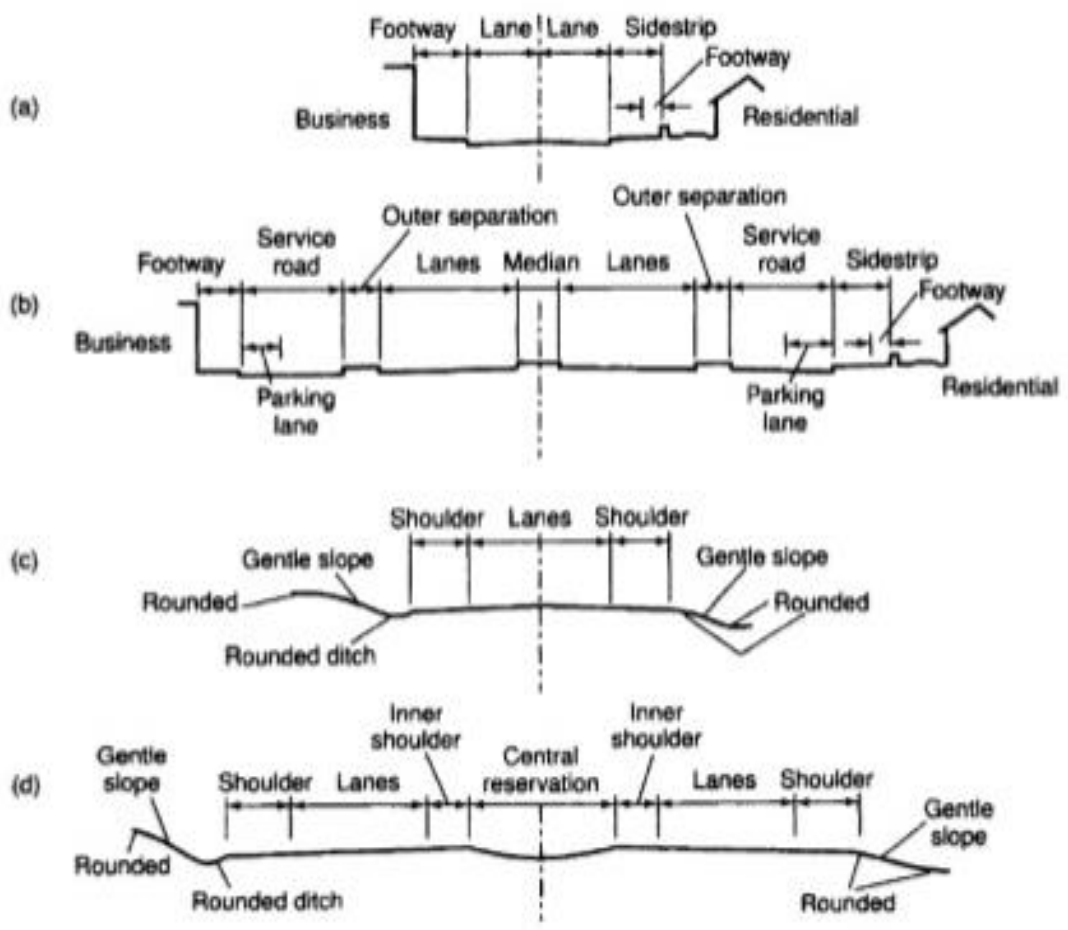


Fig. 19.10 Simplified road cross-sections: (a) 2-lane street, (b) urban motorway, (c) 2- or 3-lane rural highway, and (d) rural motorway

CROSS SECTIONAL ELEMENTS

The cross section elements involved in highway geometric design,l

- ✓ Kerbs
- ✓ Shoulders
- ✓ Parking

- ✓ lanes
- ✓ Right of way
- ✓ Service roads
- ✓ Drainage and Footpath

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface.

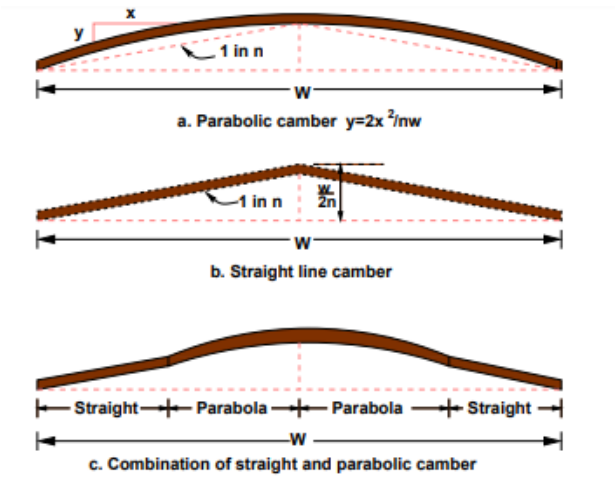
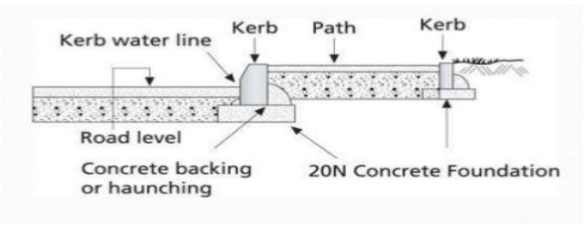
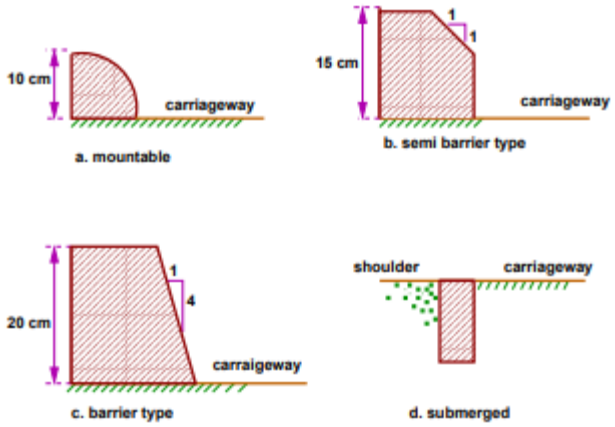


Figure 12:1: Different types of camber

Kerbs: The boundaries between pavement and shoulders or footpath are known as kerbs.





Types of kerbs:

1. Mountable
2. Semi-barrier
3. Barrier
4. submerged

Shoulders : Shoulders are provided along the road edge and are intended for accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses. The shoulder should be strong enough to bear the weight of a fully loaded truck even in wet conditions. The shoulder width should be adequate for giving working space around a stopped vehicle. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane highways in India.

Cycle track :Cycle tracks are provided in urban areas when the volume of cycle traffic is high Minimum width of 2 meter is required, which may be increased by 1 meter for every additional track.

FACTORS AFFECTING GEOMETRIC DESIGN (A.U APRIL/MAY 2017)

Design speed

Definition: Design speed is defined as the highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are conducive.

Topography

- ✓ The factor of affecting the geometric design is the topography. It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multiform with the gradient and the terrain.
- ✓ **Geometric design standards** are **different for different terrain**.
- ✓ It is characterized by **sharper curves** and **steeper gradients**.

Other factors

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

Vehicle:

- ✓ The dimensions, weight of the axle and operating characteristics of a vehicle influence the design aspects such as width of the pavement, radii of the curve, clearances, parking geometrics etc.
- ✓ A *design vehicle* which has standard weight, dimensions and operating characteristics are used to establish highway design controls to accommodate vehicles of a designated type.

Human:

- ✓ The important human factors that influence geometric design are the physical, mental and psychological characteristics of the driver and pedestrians like the reaction time.

Traffic:

- ✓ Uneconomical to design the road for peak traffic flow.
- ✓ The geometric design is based on this design volume, capacity etc.

Environmental:

- ✓ Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.

Economy:

- ✓ The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.

Others: Geometric design should be such that the aesthetics of the region is not affected.

PIEV theory

According to this theory the total reaction time of the driver is split into four parts:

- ✓ Perception: Seeing the object along with other objects
- ✓ Identification: Identification and understanding the stimuli
- ✓ Emotion/Judgment: Deciding the course of action
- ✓ Volition: Execution of the decision.

SIGHT DISTANCE

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead.

Factors affecting sight distance (A.U MAY/JUNE 2016)

Reaction time of the driver

- ✓ It is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied.
- ✓ Total reaction time may be split up into **four components** based on **PIEV theory.**
- ✓ In practice, all these times are usually combined into a total perception-reaction time suitable for design purposes as well as for easy measurement.
- ✓ The drivers require about 1.5 to 2 secs under normal conditions.

Speed of the vehicle

- ✓ Affects the sight distance.
- ✓ Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

Efficiency of brakes

- ✓ It depends upon the age of the vehicle, vehicle characteristics etc.
- ✓ If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied.
- ✓ But practically, not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes is less.

Frictional resistance between the tyre and the road

- ✓ It plays an important role to bring the vehicle to stop.
- ✓ When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less. No separate provision for brake efficiency is provided while computing the sight distance.
- ✓ IRC has specified the value of longitudinal friction in between 0.35 to 0.4.

Gradient of the road

- ✓ It affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less.
- ✓ While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case

Types of sight distances

- ✓ Stopping sight distance / absolute minimum sight distance
- ✓ Intermediate sight distance – twice SSD
- ✓ Overtaking sight distance- for safe overtaking operation
- ✓ Head light sight distance
- ✓ Safe sight distance

Stopping sight distance

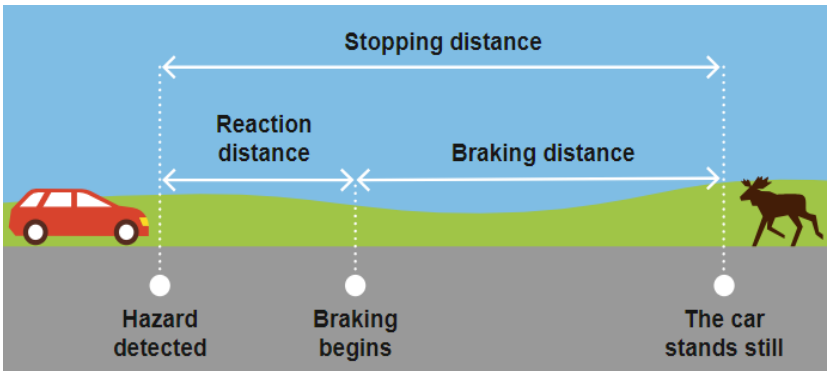
SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle travelling at design speed,safely without collision with any other obstruction.

Overtaking sight distance

Overtaking zones are provided when OSD cannot be provided throughout the length of the highway. These are zones dedicated for overtaking operation, marked with wide roads. The desirable length of overtaking zones is 5 times OSD and the minimum is three times OSD.

Intermediate sag distance

A distance equivalent to twice the stopping sight distance, a distance where overtaking could be attempted with reasonable safety.ISD is usually twice the stopping sight distance.



PROBLEM BASED ON SIGHT DISTANCE

1. The speed of the overtaking and overtaken vehicles is 80 and 50 kmph respectively. On a two way traffic load, the acceleration of overtaking vehicles is 0.99m/sec^2. Calculate OSD, mention the minimum length of overtaking zone and draw the sketch of the overtaking zone with details. (A.U APRIL-MAY 2017)

Data:

Speed of the overtaking ,V = 80 kmph, v = 80/3.6 = 22.2

Speed of the overtaken vehicles,V_b = 50 kmph, v_b = 50/3.6 = 13.8

Acceleration = 0.99m/sec^2

Solution:

a) **OSD for two way traffic = d1+d2+d3 = $v_bt + v_bT + 2s + vT$**

Reaction time for overtaking, t = 2s

d1 = v_bt

= 13.8x2 = 27.6m

d1 = 27.6m

d2 = v_bT (since $T = \sqrt{4s/a}$; $s = 0.7v_b + 6 = 15.66$)

= 13.8x 7.95

d2 = 109.71m

d3 = vT

= 22.2x 7.95 = 176.49m

d3 = 176.49m

Therefore, OSD = d1+d2+d3

= 27.6+109.71+ 176.49 = 313.8m = 314m

b) **Minimum length of overtaking zone= 3 x OSD**

= 942 m

c) **Desirable length of overtaking zone= 5 x OSD**

= 1570m

2. Calculate the safe stopping distance while travelling a speed of 100 kmph on a level road. Assume all other data. (A.U NOV-DEC 2015) (A.U NOV-DEC 2017)

Data:

Design Speed, V = 100 kmph

Solution:

OSD for 1- way traffic = d1+d2 = $0.278v_bt + 0.278v_bT + 2s$

Assume V_b is 16 km/h lesser than that of V

V_b = 100-16 = 84 km/h

Acceleration = 2.5 km/h/sec

Acceleration of overtaking vehicle = $2.5 \times (\frac{10000}{60x60}) = 0.694$ m/sec^2

Reaction time for overtaking, t = 2s

d1 = $0.278v_bt$

= $0.278 \times 84 \times 2 = 46.7$m

d1 = 46.7m

d2 = $0.278\ v_bT + 2s$

(since $T = \sqrt{4s/a} = \sqrt{4x22.8/0.694}$ = 11.49m ;$s = 0.2v_b + 6 = 22.80$m)

Sub d and T value in d2 eq.

d2 = $(13.8x \times 84 \times 11.49) + (2 \times 22.8)$

d2 = 313.91m

Therefore, OSD = d1+d2

= **46.7** +**313.91** = 360.61 m = 361m

OSD for 1- way traffic = 361m

HORIZONTAL CURVES

The presence of horizontal curve imparts centrifugal force which is a reactive force acting outward on a vehicle negotiating it.

Centrifugal force depends on speed and radius of the horizontal curve and is counteracted to a certain extent by transverse friction between the tyre and pavement surface.

On a curved road, this force tends to cause the vehicle to overrun or to slide outward from the centre of road curvature. For proper design of the curve, an understanding of the forces acting on a vehicle taking a horizontal curve is necessary.

The centrifugal force P in kg/m^2

$$P=Wv^2/gR$$

Where W is the weight of the vehicle in kg, v is the speed of the vehicle in m/sec, g is the acceleration due to gravity in m/sec^2 and R is the radius of the curve in m.

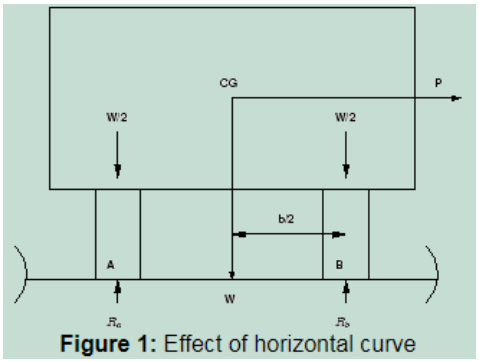


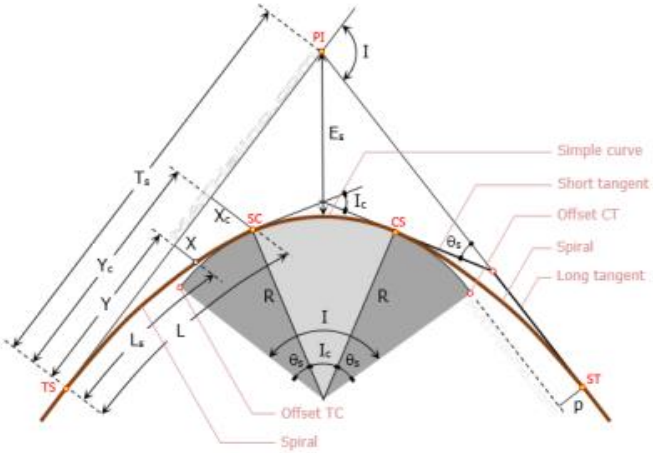
Figure 1: Effect of horizontal curve

Two effects of horizontal curve,

1. Overturning effect
2. Skidding effect

TRANSITION CURVE

A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve. The rate of change of the radius of the transition curve will depend on the equation of the curve or its slope.



Thus the functions of transition curves in the horizontal alignment of highway may be summed up into the following points.

- ✓ To introduce gradually, the centrifugal force between the tangent point and the circular curve.
    1. To enable the driver turn the steering gradually for his own comfort and security.
    2. To improve the aesthetic appearance of the road.

Different types of transition curves:

1. Spiral
2. Lemniscate
3. Cublic parabola.

EXTRA WIDENING AT CURVES

Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment.

- ✓ Additional width required for a vehicle taking a horizontal curve.
- ✓ Due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.

SUPER ELEVATION

Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counteracting the effect of centrifugal force.

Maximum and Minimum Super Elevation (A.U APRIL/MAY 2017)

Depends on

1. Slow moving vehicle
2. Heavy loaded trucks with high CG.

IRC specifies a **maximum super-elevation**- 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent. The **minimum super elevation** is 2-4 percent for drainage purpose, especially for large radius of the horizontal curve.

Design of super elevation:

There are four steps involved in the design of super elevation.

Step 1:

Calculate the super elevation necessary for 75% design speed and assume No lateral friction is developed

That is $f = 0$

$$V = 75\%\ (V) = 0.75V$$

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

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

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

If e value is less than e_{max} = 0.07, provide calculated e value. Otherwise proceed to next step

Step 2:

When $e_{cal} > e_{max}$

Provide $e = e_{max} = 0.07$ in this step and go to next step.

Step 3:

From the above step we have the value of e. so, check for lateral friction factor is applied in this step for the known value of e.

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

$$f_{cal} = \frac{V^2}{127R} - 0.07$$

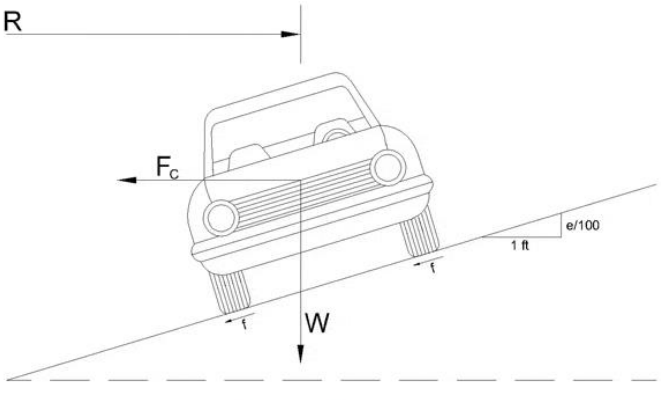
If $f_{cal} < f_{max}$ (0.15)

Then e = 0.07 is safe.

But if $f_{cal} > 0.15$

Then restrict the values to f = 0.15, e = 0.07

And go to last step.



Step 4:

In this step we will find out the value of restricted speed.

Let V = Va

$$e + f = \frac{(Va)^2}{127R}$$

$$0.07 + 0.15 = \frac{(Va)^2}{127R}$$

$$V_a = \sqrt{127R(0.22)}$$

If Va > V, then e = 0.07, f= 0.15

If Va < V , then also e = 0.07, f = 0.15

PROBLEM BASED ON SUPER ELEVATION:

A road has a total width of 7.5m including extra widening on curve and design speed of 60kmph. Calculate the length of transition curve and its shift on the curve of 200m radius. Allowable super elevation 1 in 150 and the pavement is rotated About centre lines. (A.U NOV-DEC 2016) (A.U NOV-DEC 2017)
Or
Calculate the safe OSD for a design speed of 90kmph. Take reaction time of driver as 2.5 seconds and acceleration of overtaking vehicle as 2.5 kmph/sec. draw OSD.

Data:
Road width = 7.5m
Allowable super elevation = 1 in 150
Radius = 200m
design speed = 60kmph
Solution:
a) Length of transition curve as per allowable rate of centrifugal acceleration:

$$C = \frac{80}{75+V}$$

$$= \frac{80}{75+60}$$

$$= 0.59 \text{ m/sec}^3$$

As per IRC, the value of C = 0.5 to 0.8. therefore the value of 0.59 is acceptable.

$$L_s = 0.0215 \frac{V^3}{CR}$$

$$= 0.0215 \times \frac{60^3}{0.59 \times 200}$$

$$\mathbf{L_s` = 39.35m}$$

b) Length of transition curve as per allowable rate of introduction of super elevation:

$$\text{Superelevation, } e = \frac{V^2}{225R}$$

$$= \frac{60^2}{225 \times 200}$$

$$e = 0.08$$

This value is greater than the maximum allowable rate of 0.07. Therefore the limit the value of **e = 0.07.**

Check the safety against traverse skidding,

$$f = \frac{V^2}{127R} - e$$
$$= \frac{60^2}{127x\ 200} - 0.07$$
$$= 0.07$$

Total raise of outer edge of pavement with reference to the centre line

$$\frac{E}{2} = \frac{eB}{2}$$
$$= \frac{0.07\ x\ 7.5}{2} = \mathbf{0.26m} = \frac{\boldsymbol{E}}{\mathbf{2}}$$
$$L_S = \frac{EN}{2}$$
$$= 0.26 \text{ x } 150 = 39\text{m}$$
$$\mathbf{L_s = 39m}$$

c) Minimum value of L_s as per IRC = $2.7\frac{V^2}{R}$

$$\mathbf{L_s} = 2.7 \text{ x } \frac{60^2}{200}$$
$$\mathbf{L_s = 49m}$$

Shift, $$S = \frac{Ls^2}{24R}$$
$$= \frac{49^2}{24\ X\ 200}$$
$$\mathbf{S = 0.50m}$$

VERTICAL CURVES

I Summit Curve / Crest curve

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

a. When a positive gradient meets another positive gradient.
b. When positive gradient meets a flat gradient.
c. When an ascending gradient meets a descending gradient.
d. When a descending gradient meets another descending gradient.

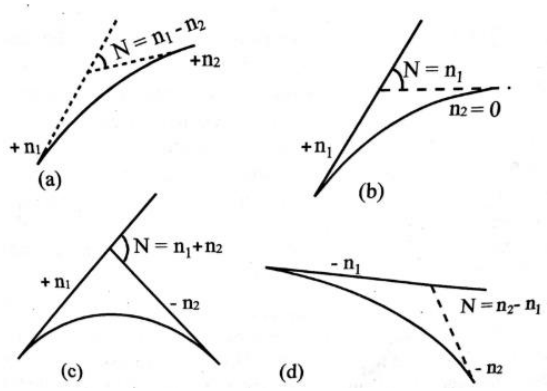
Type of Summit Curve

- ✓ Mostly use **parabolic curves** in summit curves.
- ✓ This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another.
- ✓ **Circular curve** offers equal sight distance at every point on the curve, for very small deviation angles a circular curve and parabolic curves are almost congruent.
- ✓ Furthermore, the use of parabolic curves was found to give excellent riding comfort.

II Valley (Sag) curve:

- ✓ When two grades meet at the valley (sag) and the curve will have convexity downwards, the curve is simply referred as the valley (sag) curve.

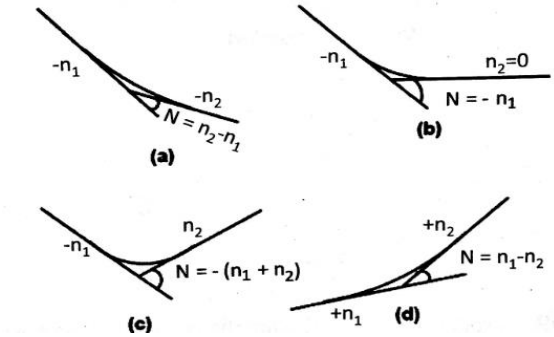
- ✓ The centrifugal force at these curves acts downwards along the weight of the vehicle. This add to the pressure on the springs and the suspension of the vehicle.
- ✓ Hence the rate of change of centrifugal acceleration should govern the design of valley curves.



Summit Curve

For determining the minimum length of the curves:

- ✓ The vehicle headlight sight distance
- ✓ Motorists comfort
- ✓ Drainage control
- ✓ General aesthetic considerations.



Valley Curve

GRADIENT

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided for designing the vertical curve

TYPES OF GRADIENT (A.U NOV-DEC 2016)

Ruling gradient /design gradient:

- ✓ It is the maximum gradient and to design the vertical profile of the road.
- ✓ It depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve.
- ✓ In flatter terrain- to provide flat gradients,
- ✓ in hilly terrain it is not economical and sometimes not possible also.
- ✓ This gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions.

Limiting gradient

- ✓ High cost of construction.
- ✓ On rolling terrain and hilly terrain – To adopt limiting gradient.
- ✓ But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

Exceptional gradient

- ✓ This gradient is very steeper gradients given at unavoidable situations.
- ✓ For short stretches not exceeding about 100 meters at a stretch.
- ✓ In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient.
- ✓ At hairpin bends, the gradient is restricted to 2.5%.

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. It depends on the size, power, load, grad-ability of the truck, initial speed, final desirable minimum speed

Minimum gradient

- ✓ Camber will take care of the lateral drainage.
- ✓ But the longitudinal drainage along the side drains requires 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 gradient of 1 in 500 for concrete drain and 1 in 200 for open soil drains.

SPECIAL CONSIDERATION OF HILLY AREAS

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

Stability of the slopes: for hilly areas, the road should be aligned through the side of the hill that is stable. The common problem with hilly areas is that of landslides. Excessive cutting and filling for road constructions give way to steepening of slopes which in turn will affect the stability.

Hill side drainage: Adequate drainage facility should be provided across the road. Attempts should be made to align the roads in such a way where the number of cross drainage structures required are minimum. This will reduce the construction cost.

Special geometric standards: The geometric standards followed in hilly areas are different from those in flat terrain. The alignment chosen should enable the ruling gradient to be attained in minimum of the length, minimizing steep gradient, hairpin bends and needless rise and fall.

Ineffective rise and fall : Efforts should be made to keep the ineffective rise and excessive fall minimum.

HAIR-PIN CURVES

The curve in a hill road which changes its direction through an angle of 180 degree or so, downthe hill on the same side is known as hair-pin curve.

This curve is so called because it conforms to the shape of a **hair-pin**. The bend so formed at the **hair-pin**curve in a hill road is known as **hair-pin bend**. This type of curve should be located on a hill side having the minimum slope and maximum stability. It must also be safe from view point of land slides and ground water.

Hair-pin bends with long arms and farther spacing are always preferred. They reduce construction problems and expensive protective works. **Hair-pin** curves or bends of serpentine nature are difficult to negotiate and should, therefore, be avoided as far as possible.

Hairpin bend curves

LATERAL AND VERTICAL CLEARANCE ON UNDERPASS

Lateral clearance is the distance between the extreme edge of the carriageway to the face of the nearest support whether it ios a solid abutment,pier or column.

Vertical clearance stands for the height above the highest point of the travelled way

- ✓ Minimum width clearance of 5m should be ensure over the full width of roadway.
- ✓ The vertical clearance should be measured with regard to the highest point of carriageway.
- ✓ Allowance for any future raising of pavement is also be made.

Underpass:

It implies a short passage beneath a grade separated structure to carry one or more streams of traffic.

UNIT –III
DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

Design principles – pavement components and their role - Design practice for flexible and rigid Pavements (IRC methods only) – Embankments

Highway pavement:

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution.

Need of highway pavement

- ✓ Road surface should be stable and un-yielding.
- ✓ Uneven and undulating, vehicle operating cost, road user cost, time cost and accident cost will increase.
- ✓ Earthen roads yield and are unstable under adverse weather condition and wheel loads.

Basic requirements of quality pavement

1. Perfect compaction
2. Optimum Moisture Content
3. Maximum Dry Density

Types of highway pavement

1. **Flexible pavements** - flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure. The Typical layers of a flexible pavement are,

Seal Coat:

- ✓ It is a thin surface treatment used to water-proof the surface.
- ✓ To provide skid resistance.

Tack Coat:

- ✓ It is a very light application of asphalt, usually asphalt emulsion diluted with water.
- ✓ Provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat:

- ✓ It is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed.
- ✓ Provides bonding between two layers.

2. **Rigid pavements** - Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area.
3. **Semi-rigid pavements**

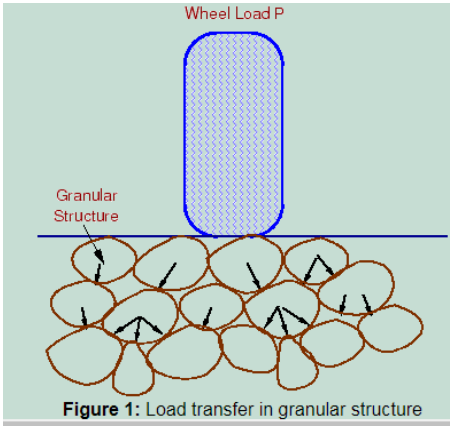
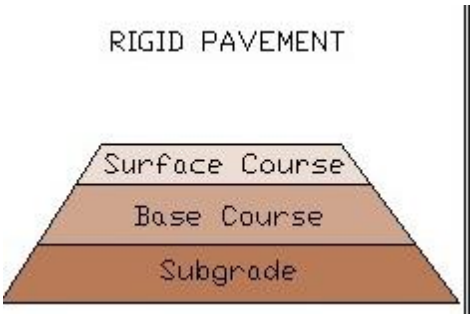


Figure 1: Load transfer in granular structure

Rigid pavements



Types of rigid pavement (A.U APRIL/MAY 2017)

Rigid pavements can be classified into four types:

- ✓ Jointed plain concrete pavement (JPCP)
- ✓ Jointed reinforced concrete pavement (JRCP)
- ✓ Continuous reinforced concrete pavement (CRCP) and
- ✓ Pre-stressed concrete pavement (PCP)

Critical load positions (A.U APRIL/MAY 2016)

- ✓ Since the pavement slab has finite length and width, either the character or the intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface. There are three typical locations are *interior, edge* and *corner*. These locations are termed as critical load positions

DESIGN PRINCIPLES

Flexible pavement:

- ✓ A load of magnitude may be dissipated by carrying it deep into ground through layers of granular materials.
- ✓ The intensity of load diminishes in geometric proportions as it is transmitted downwards from the surface by virtue of spreading it over an increasing larger area.
- ✓ Strength of each layer could be reduced with increased depth.

Rigid pavement:

- ✓ Design is based on providing flexural strength in a structural slab to resist destructive action of wheel loads.
- ✓ A rigid pavement because of its rigidity and high modulus of elasticity tends to distribute the load over a relatively wider area of soil.

Difference between rigid and flexible pavements

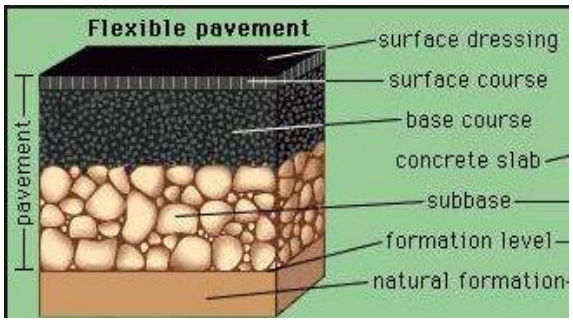
Issues	Flexible	Rigid
Flexural Strength	Low or negligible	Very high
Design principle	Layering system concept	Slab action
stress	Compressive stress	Tensile and temperature stress
Transfer of stress	Grain to grain transfer and	No such transfer and deformation,

	deformation on top is reflected on the bottom layer	if any is not reflected on lower surface.

FUNCTIONS OF PAVEMENT COMPONENTS

The functions are:

Soil sub grade and its evaluation:



- ✓ The soil sub grade is a layer of natural soil prepared to receive the layers of pavement materials placed over it. It is essential that at no time the soil sub grade is overstressed, it means that the pressure transmitted on the top of the sub grade is within the allowable limit.
- ✓ Many tests are known for measuring the strength properties of the sub grades. Some of the tests have been standardized for the use. The common strength test for the evaluation of soil subgrade is:
    1. California bearing ratio test.
    2. California resistance value test.
    3. Triaxial compression test
    4. Plate bearing test.

California bearing ratio (CBR) test:

It is evolved for the empirical method of flexible pavement design. The CBR test is carried out either in the laboratory on prepared specimens or in the field by taking in situ measurements.

California resistance value:

It is found by using hveem stabliometer. This test is used in an empirical method of flexible pavement design based on soil strength.

Triaxial test:

It is the most important soil strength, but still the test is not very commonly used in structural design of pavements.

Plate bearing test:

- ✓ It is carried out using a relatively large diameter plate to evaluate the load supporting capacity of supporting power of the pavement layers. The results are plate bearing tests are used in flexible pavement design method like McLeod method on based on layer system analysis by brumister.

Sub base and base courses and their evaluation:

- ✓ There layers are made of broken stones, bound or unbound aggreagate,some times in sub base course a layer of stabilized soil.(or) Selected granular soil is also used.
- ✓ however at the sub base course it is desirable to use smaller size graded aggregates. When the sub grade consists of fine grained soil and when the pavement carries heavy wheel loads.

- ✓ Sub base course primarily has the similar function as of the base course and is provided with inferior materials than of base course. Base courses are used, under rigid pavement for
    1. Preventing pumping
    2. Protecting the sub grade against frost action.
- ✓ Thus the fundamental purpose of abase course and sub base course is to provide a stress transmitting medium to spread the surface wheel loads in such manner.
- ✓ The sub base and base course layers may be evaluated by suitable strength or stability test like plate bearing CBR test.

The function of wearing course

- ✓ To provide a smooth riding surface
- ✓ To resist pressures exerted by tyres.
- ✓ To take up wear and tear
- ✓ To prevent infiltration of rainwater into the pavement and subgrade

DESIGN FACTORS

Various factor considered for the design of pavements (A.U APRIL/MAY2017)

a. Pavement design consists of two parts
    - ✓ Mix design of materials
    - ✓ Thickness design of pavement and component layers.

b. Factors for the design of pavement
    - ✓ Design wheel load
    - ✓ Subgrade soil
    - ✓ Climatic factors
    - ✓ Pavement component materials
    - ✓ Environmental factors.

Design wheel load:

The various wheel load factors to be considered in pavement design are:

1. Maximum wheel load
2. Contact pressure
3. Dual or multiple wheel loads
4. Repetition of loads.

Maximum wheel load:

- ✓ The wheel load configurations are important to know the way in which the loads of agiven vehicle are applied on the pavement surface.
- ✓ For highways the maximum legal axle load as specified by Indian road congress is 8170 kg with a maximum equivalent single wheel load of 4085 kg.
- ✓ The evaluation for vertical stress computations under a uniformly distribute of circular load based on Boussineq's theory is given by:

$$\sigma_z = p\left[1-\frac{z^3}{\left(a^2+z^2\right)^{\frac{3}{2}}}\right]$$

σ_z = vertical stress at depth z
P= surface pressure

Z=depth at which σ_z computed.
A=radius of loaded area.

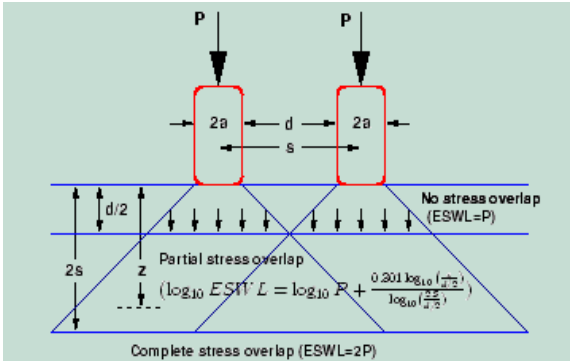
Contact pressure:

- ✓ Generally the wheel load is assumed to be distributed over a circular area. But by measurement of the imprints of tyers with different load and inflation pressures. Three terms in use with reference to tyre pressure are:
  1. Tyre pressure
  2. Inflation pressure
  3. Contact pressure

$$\text{Contact pressure} = \frac{load\ on\ wheel}{contact\ area}$$

The ratio of contact pressure to type pressure is defined as **rigidity factor**. Thus value of rigidity factor is 1.0 for an average tyre pressure of 7 Kg/cm2.This value is higher than unity for lower type pressures and less than unity for tyre pressures higher than 7 kg/cm2.

ESWL:



- ✓ ESWL is the single wheel load having the same contact pressures, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth. The procedure of finding the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method.
- ✓ ESWL may be determined based on either equivalent deflection or equivalent stress criterian. Multiple wheel loads are convert to ESWL and this value is used in pavement design. The ESWL is usually determined by the equivalent stress criterion using a simple graphical method.
- ✓ A straight line relationship is assumed between ESWL and depth on log scales.

Repetition of loads:

- ✓ The deformation of load pavement (or) sub grade due to a single application of wheel load may be small. It required carrying out traffic surveys for accounting the factor of repetitions for wheel loads in the design of pavement.
- ✓ Data collected are converted to some constant equivalent wheel loads. Equivalent wheel load is a single load equivalent to the repeated applications of any particular wheel load on a pavement which requires the same thickness and strength of pavements.
- ✓ McLeod has given a procedure for evolving equivalent load factors for designing flexible pavements.

Design Procedure of Rigid Pavements As Per IRC 58 (A.U APRIL/MAY2017)

Salient features of IRC-58-2002:

- ✓ Computation of flexural stress due to the placement of single and tandem axle loads along the edge.
- ✓ Introduction of the cumulative fatigue damage approach in the design.
- ✓ Revision of criteria for design of dowel base.
- ✓ Design of tie bars.

Factors:

Temperature

- ✓ The effect of temperature on asphalt pavements is different from that of concrete pavements.
- ✓ Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab.
- ✓ In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed.
- ✓ In flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness.

Precipitation

- ✓ The precipitation from rain and snow affects the quantity of surface water in filtrating into the sub grade and the depth of ground water table.
- ✓ Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

Traffic and Loading

- ✓ Three different approaches for considering vehicular and traffic characteristics, which affects pavement design.

Fixed traffic

- ✓ Thickness of pavement is governed by single load and number of load repetitions is not considered.
- ✓ The heaviest wheel load anticipated is used for design purpose.
- ✓ This is an old method and is rarely used today for pavement design.

Fixed vehicle

- ✓ The thickness is governed by the number of repetitions of a standard axle load.
- ✓ The axle load is not a standard one, and then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor.

Variable traffic and vehicle:

- ✓ In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load.
- ✓ The loads can be divided into a number of groups and the stresses, strains, and deflections under each load group can be determined separately; and used for design purposes.
- ✓ The traffic and loading factors to be considered include axle loads, load repetitions, and tyre contact area.

Contact pressure:

- ✓ The tyre pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface.

- ✓ The shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

Wheel load:

- ✓ To determines the depth of the pavement required to ensure that the subgrade soil is not failed.
- ✓ Wheel configuration affects the stress distribution and deflection within a pavemnet.
- ✓ Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits.
- ✓ The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

Axle configuration:

The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

Design of Flexible Pavement- C.B.R METHOD (IRC:37-2001)

The flexible pavement is built with number of layers. In the design process it is to be ensured that under the application of load none of the layers is overstressed.

- ✓ The maximum intensity of stresses occurs in the top layer of the pavement .The magnitude of load stresses reduces at lower layers.
- ✓ In the design of flexible pavements, it has yet not been possible to have a rational design method wherein design process and service behavior of the pavement can be expressed by mathematical laws.

Flexible pavement design methods are accordingly either empirical or semi empirical. In these methods, the knowledge and experience gained on the behavior of the pavements in the past are usefully utilized.

Flexible Pavement Design Method:

California bearing ratio method:

- ✓ California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.porter.
- ✓ One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including subgrade, subbase and base course.
- ✓ Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.
- ✓ A higher load needs a thicker pavement layer to protect the subgrade.Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.
- ✓ It is possible to extend the CBR design curves for various loading conditions,using the expression:

$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{\frac{1}{2}}$$

$$t = \left[\frac{1.75p}{CBR} - \frac{A}{\pi}\right]^{\frac{1}{2}}$$

Hence,

T = pavement thickness, cm
P = Wheel load, kg
CBR = California bearing ratio, percent
P = tyre pressure, kg/cm^2
A = area of contact.cm^2

IRC Recommendations:

- ✓ The CBR tests should be performed on remoulded soils in the laboratory. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction.
- ✓ For the design of new roads, the sub grade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment.
- ✓ The CBR test samples may be soaked in water for four days period before testing .the annual rainfall is less than 50 cm and the water table is too deep to affect the sub grade and imperable surfacing is provided to carrying out CBR test.
  If the maximum variations in CBR value of the three specimens exceed the specified limits, the design CBR should be average of at least six samples.
- ✓ The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.
- ✓ An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.
- ✓ The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G.The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500 kg.
- ✓ When subbase course materials contain substantial proportion of aggregates of size above 20mm, the CBR value of these materials would not be valid for the design of subsequent layers above them.

The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

Recommended method of design (IRC 37-2001):

1. Context
2. Design Approach and Criteria
3. Estimation of design traffic
4. Data requirements
   - ✓ No. of vehicle commercial per day
   - ✓ Traffic growth rate during design life
   - ✓ Design life in number of years
   - ✓ Vehicle damage factors: VDF is the number of standard axles per truck. So determination of VDF can be made through the determination of the load

equivalency factor (LEF) for each axle of the truck and then taking the sum total of the equivalent standard axles for all the axles in the truck.

- ✓ Distribution of commercial traffic over a carriageway

5. Computations of design traffic
6. Sub grade
   - ✓ Compaction requirements for different class of roads
   - ✓ Dry density and moisture content

PAVEMENT DESIGN:

1.A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design. (8 mark)

(i) Two lane carriage way

1. Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)
2. Traffic growth rate = 7.5 %
3. Design life = 15 years
4. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial.

(ii) Distribution factor = 0.75

Total pavement thickness for CBR 6% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm

Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

(a) Bituminous surfacing = 20 mm PC + 50 mm BM
(b) Road-base = 250 mm Granular base
(c) sub-base = 280 mm granular material.

(iii) Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations.

It must be noted that the performance of PMB and CRMB is dependent on strict control on temperature during construction.

Advantages of using modified bitumen are:

- ✓ Lower susceptibility to daily and seasonal temperature variations
- ✓ Higher resistance to deformation at high pavement temperature Better age resistance properties
- ✓ Higher fatigue life for mixes
- ✓ Better adhesion between aggregates and binder Prevention of cracking and reflective cracking

2. Design the pavement for construction of a new bypass with the following data: Two lane carriage way, Initial traffic in the year of completion of construction = 400 CVPD

(sum of both directions), Traffic growth rate = 7.5 %. Design life = 15 years, Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial vehicle and Design CBR of subgrade soil = 4%. (8 marks) (A.U APRIL/MAY 2016) (A.U NOV/DEC 2016) (A.U APRIL/MAY 2017)

Two lane carriage way
Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)
Traffic growth rate = 7.5 %
Design life = 15 years
Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial
Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

1. Bituminous surfacing = 25 mm SDBC + 70 mm DBM
2. Road-base = 250 mm WBM
3. sub-base = 315 mm granular material of CBR not less than 30 %

Design procedure for rigid pavements. (NOV'16)

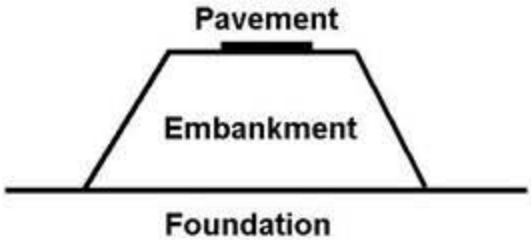
Design procedure
Step 1: Find the length of the dowel bar embedded in slab by equating Eq.

Step 2: Find the load transfer capacities ,and of single dowel bar with the
Step 3: Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as
Step 4: Spacing of the dowel bars.

- ✓ Effective distance upto which effective load transfer take place is given by , where is the radius of relative stiffness.
- ✓ Assume a linear variation of capacity factor of 1.0 under load to 0 at .
- ✓ Assume dowel spacing and find the capacity factor of the above spacing.
- ✓ Actual capacity factor should be greater than the required capacity factor.
- ✓ If not, do one more iteration with new spacing.

EMBANKMENTS

- ✓ An Embankment is an artificial barrier that typically is used to hold back water or to support a roadway, railway or canal.
- ✓ It is a ridge to prevent water from passing beyond desirable limits.
- ✓ These man-made mounds mainly consist of stones, rocks and earth.
- ✓ Most have sloping slides, much like small hills. Generally, embankments are longer than they are in height.



UNIT-IV
HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE

Highway construction materials, properties, testing methods – CBR Test for subgrade - tests on aggregate & bitumen – Construction practice including modern materials and methods, Bituminous and Concrete road construction, Polymer modified bitumen, Recycling, Different materials – Glass, Fiber, Plastic, Geo-Textiles, Geo-Membrane (problem not included) – Quality control measures - Highway drainage — Construction machineries.

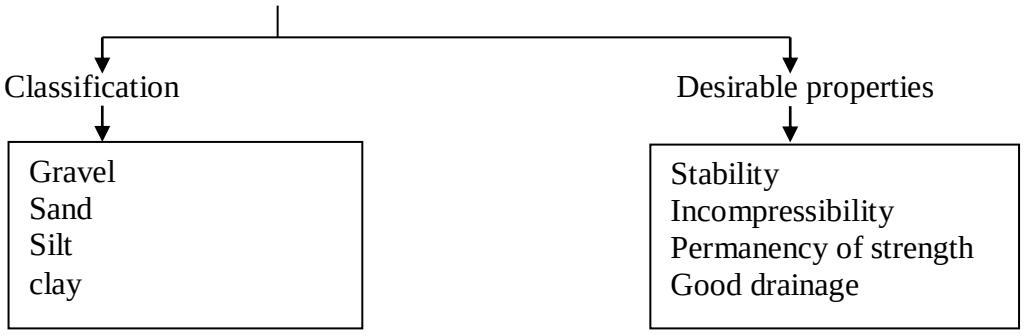
HIGHWAY CONSTRUCTION MATERIALS, PROPERTIES, TESTING METHODS

Good quality construction material makes superior pavements. Thickness, performance and efficiency of pavements depend upon quality of highway materials. Highway materials include:

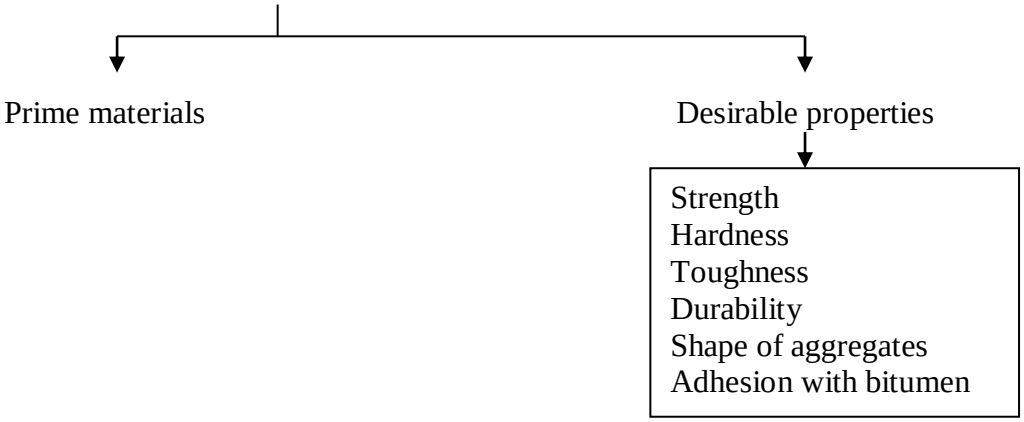
1. Sub-grade soil
2. Stone aggregates
3. Bituminous materials
4. Cement and cement concrete

Classification, characteristics and desirable properties:

1. Sub-grade soil



2. Stone aggregates



Desirable Properties of Aggregates **(A.U APRIL/MAY 2016)**

1. Strength
2. Hardness
3. Toughness

4. Durability
5. Shape of aggregates
6. Adhesion with bitumen

1. Strength

- ✓ The aggregates to be used in road construction, particularly the aggregates used in the wearing course of the pavement should be sufficiently strong/ resistant to crushing to withstand the high stresses induced due to heavy traffic wheel loads.

2. Hardness

- ✓ The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic.
- ✓ Abrasive action may be increased due to the presence of abrasing material like sand between the tyre of vehicle and the aggregates exposed to the top surface.
- ✓ It should be hard enough to resist the wear due to abrasive action of traffic.

3. Toughness

- ✓ Aggregates in the pavement are also subjected to impact due to moving wheel loads.
- ✓ The magnitude of impact increase with roughness of road and speed of vehicle. Severe impact is common when heavily loaded steel tyre vehicles move on WBM.
- ✓ The resistance to impact or toughness is thus another desirable property of aggregates.

4. Durability

- ✓ The aggregates are subjected to physical and chemical actions of rains and ground water, the impurities in them and that of atmosphere.
- ✓ The road stones used in the construction should be sound enough to withstand the weathering action. The property of aggregates to withstand the adverse actions of weather may be called soundness.

3. Types of bituminous material:

- ✓ Asphalt
- ✓ Bitumen
- ✓ Cutback bitumen
- ✓ Bitumen emulsion
- ✓ tar

CBR TEST FOR SUBGRADE

Apparatus for CBR Test (A.U NOV/DEC 2016) (A.U APRIL/MAY 2017)

Loading machine-any compression machine can operate at constant rate of 1.25mm per minute can be used. Cylindrical moulds- moulds of 150mm diameter and 175mm height provided with a collar of about 50mm length and detachable perforated base.

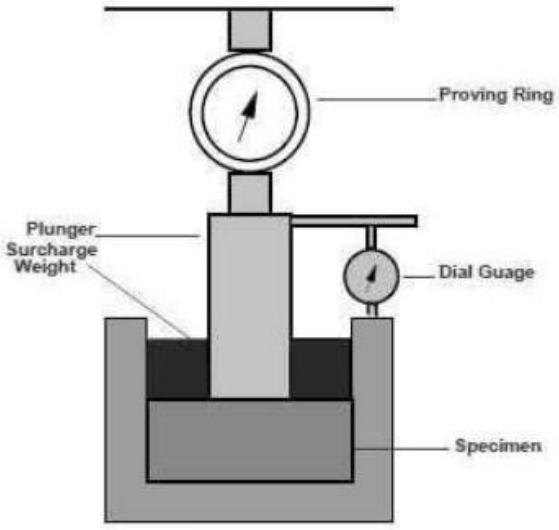
Compaction rammer, surcharge weight-annular weights each of 2.5kg and 147mm diameter. IS sieve 20mm, Coarse filter paper, balance etc.

California Bearing Ratio (CBR) test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements.

- ✓ CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus.
- ✓ CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions.
- ✓ The test procedure should be strictly adhered if high degree of reproducibility is desired. The CBR test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

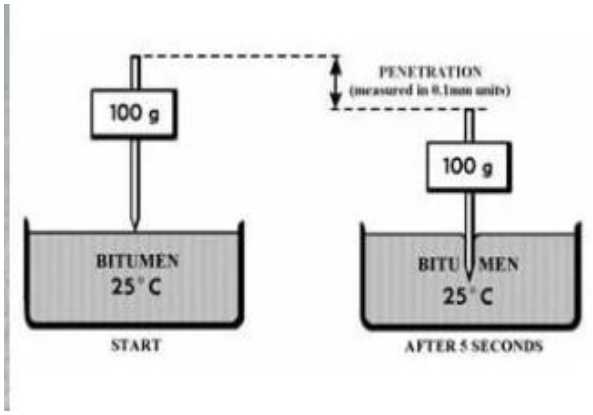
Test Procedure

- ✓ The laboratory CBR apparatus consists of a mould 150 mm diameter with a base plate and a collar, a loading frame and dial gauges for measuring the penetration values and the expansion on soaking.
- ✓ The specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame.
- ✓ Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25mm/min. A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively.
- ✓ CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore, Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking.
- ✓ If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.



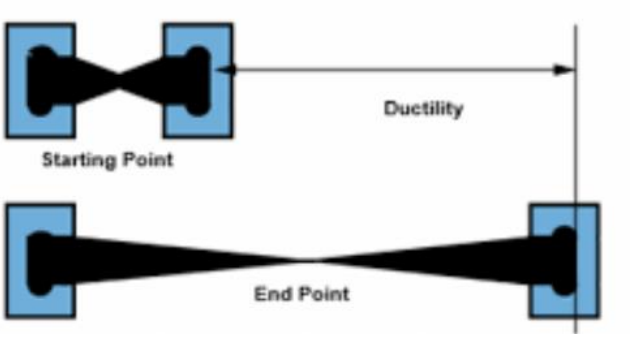
TEST FOR BITUMEN

Penetration Test:



- ✓ The penetration test determines the hardness or softness of bitumen by measuring the depth of a millimeter to which a standard loaded needle will penetrate vertically in five seconds.
- ✓ The sample is maintained at temperature of 25^{0}C for one hour. The dial is set to zero
  or the initial reading is taken and the needle is released for 5 seconds. The final reading is taken on dial gauge on dial gauge.
- ✓ After each test the needle is designed and wiped with benzene and dired.the depth of penetration is repeated in one tenth millimeter units.
- ✓ The value is influenced by any inaccuracy as regards pouring temperature size of needle, weight placed on the needle and the test temperature.
- ✓ The bitumen grade is specified in terms of penetration value. The penetration test is applied almost exclusively to bitumen. As road tars are soft, the penetration test cannot be carried out on these materials.
- ✓ The penetration values of various types of bitumen used in pavement construction in this country range between **20 and 2254, 30/40 and 80/1000 grade bitumen** are more commonly used, depending on construction type and climatic conditions.

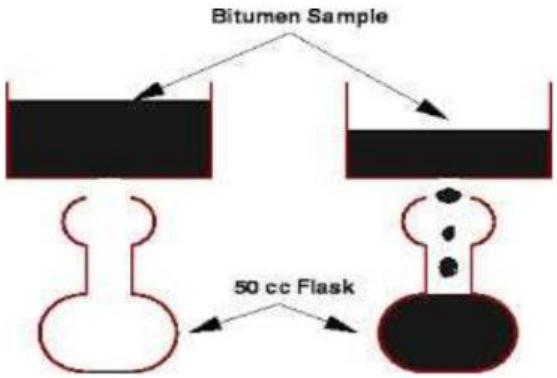
Ductility test: (A.U APRIL/MAY 2016)



- ✓ In the flexible pavement constructions where bitumen binders are used, it is important that the binders form ductile thin films around the aggregates.
- ✓ This serves as a satisfactory binder in improving the physical interlocking of the aggregate bitumen mixes. Under traffic loads the bituminous pavement layer is subjected to repeated deformation and recoveries.
- ✓ It is carried out on bitumen to test this property of the binder. The test is believed to measure the adhesive property of bitumen and its ability to stretch.
- ✓ Bitumen paving engineer would however want that both test requirements are satisfied in the field jobs.
- ✓ It is expressed as the distance in **centimeters** to which standard briquette bitumen can be stretched before the thread breaks. The test is conducted at 27^{0}C and at a rate of pull of **50 mm per minute.**

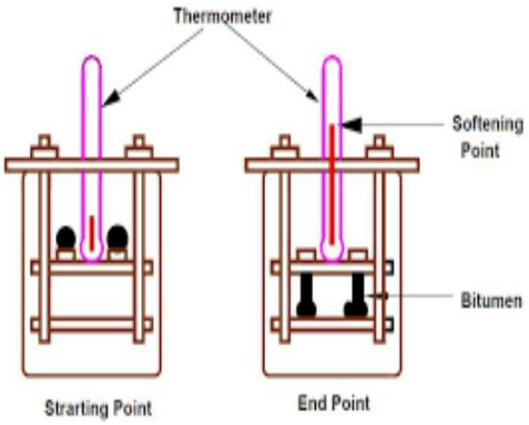
- ✓ The ductility machine functions as a constant temperature water bath with a pulling device at a pre calibrated rate. The **ductility values of bitumen** vary from **5 to over 100** for different bitumen grades.

Viscosity test:



- ✓ Viscosity is defined **as inverse of fluidity**. Viscosity thus defines the fluid property of bituminous material. Viscosity is the general term for consistency and it is measure of resistance to flow. Many researchers believe that grading of bitumen should be by absolute viscosity units of the conventional penetration units.
- ✓ The degree of fluidity of the binder at the application temperature greatly influences the strength characteristics of the resulting paving mixes.
- ✓ The bituminous binder simply lubricates the agg regate particles instead of providing a uniform film for binding action.similiarly high viscosity also resists the comp active effort and the resulting mix is heterogeneous in character exhibiting low stability values.
- ✓ The viscosity of tar is determined as the time taken in seconds for 50 ml of the sample to flow through 10mm orifice of the standard tar viscometer at the specified temperature of 35,40,45 or 550°C.
- ✓ The viscosity of cutback bitumen is determined as the time taken in seconds for 50 ml of the sample to flow through either 4.0mm orifice at **250°C or 10mm orifice at 25 or 400°C**.

Softening point test: **(A.U APRIL/MAY 2016)**



- ✓ The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test.
- ✓ It is determined by ring and Ball test.
- ✓ Generally higher softening point indicates lower temperature susceptibility and is preferred in warm climates .A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature.
- ✓ A steel ball is placed upon the bitumen sample and the liquid is then heated at a rate of 5°C per minute. The temperature at which the softened bitumen touches the metal placed at a specified distance below the ring is recorded a point of bitumen.

MODERN CONSTRUCTION MATERIALS USED FOR THE CONSTRUCTION OF PAVEMENTS (A.U APRIL/MAY 2016)

Steel slag aggregate is a good example of synthetic aggregates obtained from by-products of industrial processes. It has good binding properties with bitumen due to its high calcium oxide content (NatSteel 1993).

The angular shape of the aggregates helps to form strong interlocking structure. Road paving with steel slag aggregate show good skid resistance
mechanical strength able to withstand heavy traffic and surface wearing. Also, many industrial and other waste products like fly-ash, cement kiln dust, incenerated refuse etc. have been successfully used to produce synthetic aggregates.

Mixing bitumen with rubber (natural or crumb form) sometimes poses difficulty. As an alternative approach, tiny crumb rubber pieces can be mixed with aggregates - known as dry-process, this process does not require any modification to the existing batch mixing plant.

Polymer modified bitumen is emerging as one of the important construction materials for flexible pavements. Use of plastic waste in the construction of flexible pavement is gaining importance because of the several reasons.

- ✓ The polymer modified bitumen show better properties for road construction & plastics waste, otherwise considered to be a pollution menace, can find its use in this process and this can help solving the problem of pollution because most of the plastic waste is polymers.
- ✓ In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate.
- ✓ It also helps to improve the strength of the road. But its resistance towards water is poor. Antistripping agents are being used. A common method to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with organic synthetic polymers like rubber and plastics.

Geo- textile is any permeable textile material used with foundation, soil, rock, earth, etc. that is an integral part of a constructed project, structure or system.

- ✓ It may be made of synthetic or natural fibers. In contrast; a geo-membrane is a continuous membrane-type liner or barrier. It must have sufficiently low permeability to control migration of fluid in a constructed project, structure or system.
- ✓ A geo-textile is designed to be permeable to allow the flow of fluids through it or in it, and a geomembrane is designed to restrict the fluid flow.

Separation

In this function, the geo-textile serves to separate two dissimilar materials, eg, two different soils, landfill material and the native soil, stone material and sub-grade soil, old and new pavement, foundation soils and various types of walls, or one of many other similar situations. In some instances, it is difficult to distinguish between the separation and stabilization functions because in both situationsthe geo-textile is serving as a separator. However, in stabilization some additional phenomena occur.

Stabilization

In this application, the natural soil on which the geo-textile is placed is usually a wet, soft, compressible material, exhibiting very little strength. By acting as a separator, the geo-textile allows water from the soft natural soil to pass from this soil into a free-draining construction soil, which in turn allows consolidation of the natural soil to take place. As a result of the consolidation process, there is a strength gain in the natural soil, which then provides an adequate foundation for construction to take place.

Reinforcement

- ✓ The key difference between stabilization and reinforcement is that stabilization is accomplished by providing for drainage of water from the unstable soil, while in reinforcement the strength characteristics (stress–strain) of the geo-textile provide added strength to the whole system.
- ✓ Another difference is that in stabilization the geo-textile is placed on or around the area being stabilized and thereby also acts as a separator, whereas in the reinforcement application the geotextile is placed within the material being reinforced. This is in line with reinforcement concepts in concrete and other materials.

Filtration

- ✓ Here the prime function is to retain soil or other fine materials, while allowing water to pass through. Again, it is seen that more than one function is being performed.
- ✓ If there were no drainage of water taking place, movement, and therefore retention of the soil, would not be of concern. Part of the mechanism by which filtration occurs is through the development of a soil filter behind the geo-textile.
- ✓ As the water passes through, soil is filtered out and collects behind the geo-textile. As buildup takes place, a natural soil filter is developed.

Drainage

- ✓ Drainage parallel to the plane of the geo-textile is described. The property called transmissivity is defined as flow parallel to the plane of the geotextile.
- ✓ This type of flow can occur to some extent in all geo-textiles, but is best achieved in needle-punched non-woven materials.
- ✓ This class of geo-textiles can be manufactured in a range of thicknesses such that this characteristic is optimized.

Moisture Barrier

- ✓ When impregnated with an asphaltic emulsion, geo-textiles become impermeable and can then be used as moisture barriers. The primary application for this type of geo-textile is in pavement rehabilitation.

Fiber reinforced bituminous mix

Addition of various kinds of fibers to the binder and aggregates during mix preparation process results in fiber reinforced bituminous mix (FRBM). Fibers are generally blended with bitumen binder before mixing it with the aggregates to achieve complete coating and even distribution throughout the mix.

BITUMINOUS RECYCLING

In recycling method, bitumen and aggregates are separated out (partly or fully) and used again. The specific benefits of recycling of bituminous pavement can be summarized as:

- ✓ Conservation of energy and construction material.
- ✓ Prevention of undesirable rise in height of finished surface and preservation of the existing road geometrics.
- ✓ Reuse of deteriorated road materials which in turn solves the disposal problem.
- ✓ Solution to the problem of scarcity of good quality material.
- ✓ Preservation of the environment.
- ✓ Reduction in susceptibility to reflection cracking.

Bitumen ages due to oxidation with atmospheric oxygen as a result of which resins get converted into asphaltenes (Petersen, 1984). By this process bitumen loses its ductility and becomes more brittle. Recycling is based on the fact that bitumen obtained from old deteriorated bituminous pavement, may still has its residual properties and recycling helps in restoring those residual properties of the bitumen.

To judge the suitability for use as a recycled material, aggregates are tested for their gradation and bitumen is tested for its engineering properties. The optimum quantity of reclaimed material to be mixed with fresh material is generally determined from mix design process. Fresh thin (soft grade) bitumen having low viscosity can be used to replenish the aged bitumen. Rejuvenators (like road oils and flux oils) are sometimes added for improvement in properties of reclaimed bitumen.

There are four major technologies exist for bituminous pavement recycling :
(i) Hot mix recycling
Here recycled asphalt pavement (RAP) is combined with fresh aggregate and bituminous binder or recycling agent in a hot mix plant. Mix is transported to paving site, placed, and compacted.

(ii) Cold in-place recycling
In this the existing pavement is milled up to a depth of 75 to 100mm, RAP, if necessary and recycling agent in emulsion form is introduced, then compacted.

(iii) Hot in-place recycling

In hot in-place recycling method the existing asphalt surface is heated, scarified to a depth from 20 to 40 mm, scarified material combined with aggregate and/or bituminous binder and/or recycling agent and compacted. New overlay may or may not be provided.

(iv) Full depth reclamation
Here all the bituminous layers and predetermined thickness of underlying material is pulverized, stabilized with additives, and compacted. A surface course is applied over it.

HIGHWAY DRAINAGE

Highway drainage may be defined as the process of interception and removal of water from over, under and the vicinity of the road surface. Road drainage is very important for safe and efficient design of the road way and hence is an essential part of highway design and construction

Effects of Improper Drainage

One of the major causes of road failure is its improper drainage. Improper drainage of the road causes destruction in the following ways:

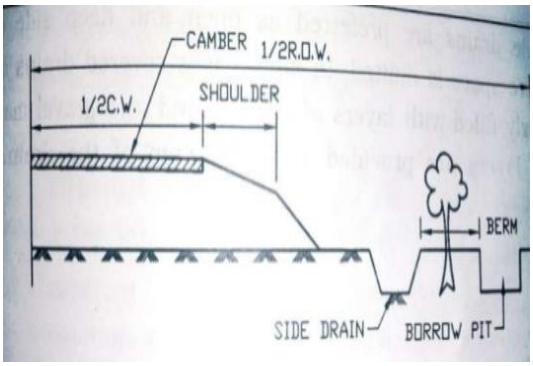
- ✓ Road surface if made of soil, gravel or water bound macadam, it will becomes soft and losses strength
- ✓ .The road sub-grade may be softened and its bearing capacity reduced.
- ✓ Variation in moisture content in expensive soils, causes variation in the volume of sub-grade and thus causes failure of roads.
- ✓ Failure of formation slopes is also attributed to poor drainage.

Highway Drainage Requirements

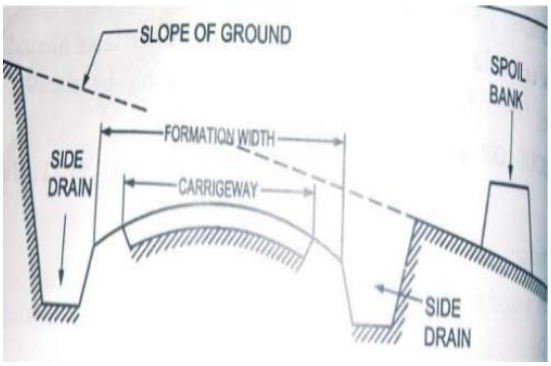
- ✓ Surface water should not be allowed to remain standing on the road pavement and shoulders. Measures should be taken to drains off this water, immediately.
- ✓ The surface rain water from the adjoining area, should not be allowed to come towards the road surface. For this, general slope of the ground adjoining road, should be made slopping away from the road. This objective can be achieved by aligning road on ridge.

Surface drainage:

- ✓ The problem of surface drainage is first tackled at the location survey stage. An ideal location for a highway from drainage point of view is along the divides between large drainage areas. All the streams would then flow away from the highway and the drainage problem would be reduced to tackling the water that falls within the roadway boundary only.



Side rain for roads in embankment



Side rain for roads in cutting

CONSTRUCTION MACHINERIES

Equipments refer to apparatus and machineries required for construction and maintenance roads. Durability, dust free riding quality and skid resistance depends up on the superiority and efficiency of equipments. The following are some important equipment required for road construction and maintenance.

1. Mechanical brooms
2. Bitumen distributors
3. Aggregate chip spreaders
4. Rollers
5. Pavers

Mechanical brooms:

- ✓ The mechanical broom may be either towed or powered. It ensures clean pavement surface prior to spreading. It is made of fibers, steel or nylon. In modern broom sweepers are constructed from a pressed steel shell. It gives an excellent strength to weight ratio.
- ✓ It is traction mount equipment and is designed for use with almost any tractor fitted with hydraulic lift. The equipment can be fitted or detached in less than five minutes. Castor wheels fitted to the rear enable the sweeper to follow road undulations. The sweeper may be used to sweep straight ahead and in two angled positions either side. The equipment has collection box and water spray equipment.

Technical specifications:

1. Overall length= 2500mm
2. Overall width= 1500mm
3. Overall height= =1000
4. Sweeping width= 2200mm
5. Brush outer diameter=500mm
6. Dust collecting capacity=0.2cum

Salient features:

1. Five different angle positions
2. Rigid pressed steel shell
3. Optional water tank and sprinkler and collection box of attachment
4. Steel wire brush section.

Binder distributor:

The riding quality depends on uniform application of the binder at the prescribed rate of spread and temperature. The requirements of binder distributor is to,

1. Spread binder uniformly
2. Spread binder at a pre-determined rate
3. Spray an area matching the output of chip spreader on a working day.

The distributor may be either a self propelled unit or a towed unit.

Types of binder distributor:

1. Pressurized tank type
2. Constant rate of spread type
3. Constant volume type
4. Constant pressure type

Aggregate chip spreader:

It is constructed from pressed steel with square and rectangular section.
It is a truck mounted one. It is driven from pneumatic tyred wheels, which tranmits the drive from the road surface to a dog clutch mounted on a lay shaft.
The drive transmitted to the feed roller through chain and sprocket mechanism.

It can be fitted to any standard tipper truck. It has a maximum spreading width of 2.5m. its function is to apply a uniform aggregate over the freshle spread bitumen film on the pavement surface.

Types of Aggregate chip spreader:

1. Tail gate spreader
2. Truck attached spreader
3. Self propelled spreader

Rollers:

- ✓ Rolling is a vital to ensure retention of aggregates with initial orientation and embedding in the binder. Mostly used steel wheeled rollers.
- ✓ However, pneumatic tyred rollers with smooth road are preferable. Kneading action of resilient tyres force aggregates family into the binder without splitting or crushing.
- ✓ Nowadays vibratory rollers with rubber- coated drums are used.
- ✓ These achieve better compaction as well as better embedment of aggregates.

Technical specifications:

1. Un ballasted weight = 8000 to 10000kg.
2. Length = 5000mm, width=2000mm, height=3000mm
3. Dia. Of rear wheel= 1400mm
4. Dia. Of front tolls= 1000mm
5. Line pressure: front rolls: 30 to 50 kg/cm
6. Rear rolls: 40 to 60 kg/cm
7. Wheelbase: 2800mm

UNIT-V
EVALUATION AND MAINTENANCE OF PAVEMENTS

Pavement distress in flexible and rigid pavements – Pavement Management Systems - Pavement evaluation, roughness, present serviceability index, skid resistance, structural evaluation, evaluation by deflection measurements – Strengthening of pavements –Types of maintenance – Highway Project formulation.

PAVEMENT DISTRESS IN FLEXIBLE AND RIGID PAVEMENTS

TYPES OF FAILURES IN RIGID PAVEMENT

1. Scaling of cement concrete
2. Shrinkage cracks
3. Joint spalling
4. Warping cracks
5. Pumping

Scale of cement concrete:

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. The following reasons are

- ✓ improper mix design
- ✓ Excessive vibration during compaction of concrete
- ✓ Laitance of concrete

- ✓ Performing finishing operation while bleed water is on surface.

Shrinkage Cracks

- ✓ Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks.
- ✓ Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.

Joint Spalling:

Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- ✓ Faulty alignment of incompressible material below concrete slab
- ✓ Insufficient strength of concrete slab near joints
- ✓ Freeze-thaw cycle
- ✓ Excessive stress at joint due to wheel load

Warping Cracks:

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause formation of warping cracks of the concrete slab near the joint edge.

This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.

Pumping:

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping.

The common reasons for this defect are

- ✓ Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.
- ✓ When there is void space between slab and the underlying base of sub-grade layer
- ✓ Poor joint sealer allowing infiltration of water
- ✓ Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support. When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks.

This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.

CRACKS AND DEFECTS IN FLEXIBLE PAVEMENTS

1. Consolidation of pavement layers
2. Shear failure
3. Longitudinal cracking
4. Reflection cracking
5. Transverse cracking

6. Shoving or Formation of waves and corrugations
7. Pot holes

Alligator (map) cracking

- ✓ This is the most common type of failure that occurs due to relative movement of pavement layer materials.
- ✓ When cracking is characterized by interconnected cracks, the cracking pattern resembles that of an alligator's skin or map. Therefore, it is referred to as alligator cracking or map cracking.
- ✓ This may be caused by repeated application of heavy wheel loads resulting in fatigue failure.
- ✓ Localized weakness in underlying base course would also cause a cracking of the surface course in this pattern.

Consolidation of pavement layers-Rutting

- ✓ Formation of ruts is mainly attributed to the consolidation of one or more layers of pavement.
- ✓ The repeated application of loads along the same wheel path cause cumulative deformation resulting in longitudinal ruts.

There are two basic types of rutting

- ✓ **Mix rutting** occurs when the sub-grade does the pavement surface exhibits wheel path depressions as a result of compaction/mix design problems.
- ✓ **Sub-grade rutting** occurs when the sub-grade exhibits wheel path depressions due to loading. In this case, the pavement settles into the sub-grade ruts causing surface depressions in the wheel path.
- ✓ **Specific causes of rutting** can be due to insufficient compaction of pavement layers during construction .If it is not compacted enough initially, pavement may continue to consolidate under traffic loads.
- ✓

Joint Reflection Cracking

Possible Causes: Movement of the rigid pavement slab beneath the HMA surface because of thermal and moisture changes. Generally not load initiated, however loading can hasten deterioration.

Repair: Strategies depend upon the severity and extent of the cracking:

Low severity cracks (< 1/2 inch wide and infrequent cracks).

Crack seal to prevent:

1. Entry of moisture into the subgrade through the cracks and
2. Further raveling of the crack edges. In general, rigid pavement joints will eventually reflect through an HMA overlay without proper surface preparation.
   - ✓ High severity cracks (> 1/2 inch wide and numerous cracks). Remove and replace the cracked pavement layer with an overlay after proper preparation of the underlying rigid pavement.

Longitudinal Cracking

Possible Causes:

- ✓ Poor joint construction or location. Joints are generally the least dense areas of a pavement. Therefore, they should be constructed outside of the wheelpath so that they are only infrequently loaded. Joints in the wheelpath will general fail prematurely.

- ✓ A reflective crack from an underlying layer (not including joint reflection cracking)
- ✓ HMA fatigue (indicates the onset of future fatigue cracking)
- ✓ Top-down cracking

Repair: Strategies depend upon the severity and extent of the cracking:

- ✓ *Low severity cracks* (< 1/2 inch wide and infrequent cracks).

Crack seal to prevent:

1. Entry of moisture into the subgrade through the cracks.
2. Further raveling of the crack edges.

- ✓ *High severity cracks* (> 1/2 inch wide and numerous cracks). Remove and replace the cracked pavement layer with an overlay.

TYPES OF OVERLAYS

1. Asphalt overlay over asphalt pavements
2. Asphalt overlays on CC pavements
3. CC overlays on asphalt pavements
4. CC overlays on CC pavements

Steps in Design of Overlays

1. Measurement and estimation of the strength of the existing pavement
2. Design life of overlaid pavement
3. Estimation of the traffic to be carried by the overlaid pavement
4. Determination of the thickness and the type of overlay

Effective Thickness Method

Basic concept:

Thickness of overlay is the difference between the thickness required for a new pavement and the effective thickness of the existing pavement

$$\mathbf{h_{OL} = h_n - h_e}$$

Where,

h_{OL} = thickness of overlay

h_n = thickness of new pavement

h_e = effective thickness of existing pavement

All thicknesses of new and existing materials must be converted into an equivalent thickness of AC

$$\mathbf{h_e = \sum_{i=1}^{n} hi\ Ci}$$

Where,

h_i = thickness of layer ,i

C_i = conversion factor for layer i

EVALUATION BY DEFLECTION MEASUREMENTS

NON-DESTRUCTIVE TESTING METHODS OF PAVEMENT DEFLECTION. (A.U NOV-DEC 2017)

I Static load:

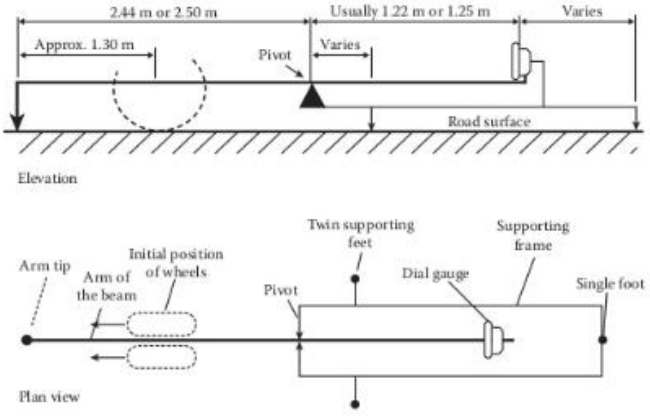
- ✓ In a **static load** the simplest of static load testing could be conductive plate load test.
- ✓ To determining the modulus of sub-grade reaction this is one method of conducting plate load test.

- ✓ Applying static load and then measuring the deflection so from deflection and the load applied
- ✓ To find the parameter about the sub-grade or any layer
- ✓ So we may be getting information about the modulus values or we may be getting information about the modulus of sub-grade reaction and then used for the foundation of concrete pavement.

II Benkelman beam: (A.U APRIL/MAY 2017)

Benkelman beam is a simple apparatus commonly used for measuring the surface deflection of a pavement under standard loading conditions. This can be done either in static load or creep loading condition.

- ✓ Use a standard truck to apply load to the pavement surface then measure the pavement surface deflection. So the load that is applied is standard truck and then measure one single surface deflection which is the maximum deflection
- ✓ When the pavement is loaded by one wheel of a standard truck the pavement deflects so to measure the maximum deflection.



Principle:

- ✓ This is a very slender beam very narrow beam and the tota l length is 3.66 m it is hinged at a distance of 2.44 from the pivot end.
- ✓ a load is applied and in its deflected condition the probe point of the beam rests on the pavement surface this is the corresponding position of the end of the beam which is rotating about this hinge so this deflection can be absorbed this portion of the beam can be absorbed using a dial gauge and when this load is removed this pavement surface rebounds and this would be positioned of the beam corresponding to the rebounded portion of the pavement surface so the end point will come down so this position will be recorded using the dial gauge so the absolute difference gives us an indication of what is the rebound deflection of the pavement.

Maximum surface deflection is measured using Benkelman beam in two different modes. There are two different procedures using which we can measure the maximum deflection.

- ✓ WASHO Western American State Highway Officials – deflection noted as wheel load approaches the point.
- ✓ CGRA Canadian Good Roads Association – rebound deflection measured as the load is removed from the point.

WASHO procedure:

WASHO method of measuring deflection using a Benkelman beam. In this case initially the load is away, the probe point of the beam so to measure the corresponding deflection, so as the wheel load gradually moves forward and is directly above the point and to get the maximum deflection.

CGRA Method- Beam Details:

- ✓ The length of the beam from hinge to probe point is 2.44 m
- ✓ The length of the beam from hinge to dial is 1.22 m
- ✓ The distance from the hinge to the front legs is 0.25 m
- ✓ The distance from the hinge to the rear legs is 1.66 m
- ✓ The lateral spacing of the front legs the spacing between the two front legs is about 0.33

CGRA Method- Loading Details

5 tonne truck is recommended to apply load.
Rear axle=8170 kg (equally distributed over the two dual wheel sets)
Spacing between tyres = 30- 40mm
Tyre pressure = 5.6 kg/cm^2

III Falling Weight Deflectometer :

- ✓ The principle of applying impulse load to the pavement and measuring the shape of the deflection bowl.
- ✓ Do not measure one single deflection but we measure more than one deflection, typically five, six, seven deflections are measured and the load applied is also not a very static or slow moving load. It is impulse load.
- ✓ The load duration will be of such magnitude and duration which simulates to the load that are actually applied by moving traffic vehicles.

Principle of FWD:

- ✓ It consists of an arrangement to raise a specified mass to specified height to let it fall freely on a loading plate placed on the pavement surface through a spring.
- ✓ The mass, the height to which the mass is raised, and the stiffness of the spring are suitably selected to produce load of magnitude and duration that are similar to those of the load pulses produced by moving traffic on the pavement.

TYPES OF MAINTENANCE

a. Routine Maintenance - day to day work necessary like pot hole patching, crack sealing etc.,
b. Periodic Maintenance – work carried out periodically onceo few years to prevent deterioration
c. Rehabilitation and Strengthening – work intended to restoreo or upgrade the pavement

Deterioration of pavement:

Pavements Deteriorate with Time

- ✓ Rate of Deterioration Depends on Traffic, Climate, Drainage Environmental Factors and Structural Adequacy
- ✓ Failure to do Routine Maintenance Requires Premature

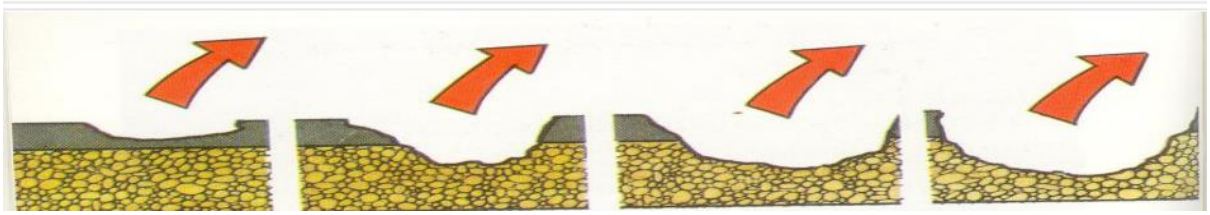
- ✓ Periodic Maintenance - 20 times Costlier than RM
- ✓ Failure to Carryout Periodic Maintenance Requires
- ✓ Strengthening with Overlay – 3 times costlier than PM Failure to Strengthen at the Appropriate Time Requireso Rehabilitation - 15 times costlier than PM or 5 times costlier than strengthening.

Vehicle Operation Cost

- ✓ Neglect of Maintenance – Appearance ofo Cracks and Potholes – VOC increases by 15%
- ✓ Neglect of Further Maintenance – Disintegrationo of Pavement – VOC increases by 50% = twice the cost of construction of the road
- ✓ During the Design Life, Total VOC is 4 timeso initial construction cost Whereas Maintenance is only 1 to 2 % of Total Transportation Cost.

Types of Defects in Bituminous Surfacing

- ✓ Surface Defect – Fatty Surface, Smooth Surface, Streaking, Hungry Surface
- ✓ Cracks – Hairline Cracks, Alligator Cracks, Longitudinal Cracks, Edge Cracks, Shrinkage Cracks and Reflection Cracks
- ✓ Deformation – Slippage, Rutting, Corrugations, Shoving, Shallow Depressions, Settlements and Upheavels
- ✓ Disintegration – Stripping, Loss of Aggregates, Ravelling, Potholes and Edge Breaking



HIGHWAY PROJECT FORMULATION

1. Technical appraisal report

The project preparation starts with the preparation of technical appraisal report (TAR). It consist of ,

1. Background
2. Technical parameters and technical designs
3. Preliminary cost estimate
4. Economic feasibility

2. Preliminary project report:

Preliminary project report is prepared covering the following,

1. Background
2. Technical provisions, their basis and technical designs
3. Economic evaluation
4. Environmental impact assessment
5. Source of funding

3. Detailed project report:

After the PPR is approved, detailed project report is prepard complying with the observations received with approval.

4. Check list of items for a highway project report

1. Project report
   a. Preliminary
   b. Road features
   c. Road design and specification
   d. Drainage facilities including cross-drainage structures
   e. Material,labour and equipment
   f. Rates
   g. Construction programming
   h. Miscellaneous
2. Estimate
   a. General abstract of cost
   b. Detailed estimates for each major head
      - ✓ Abstract of cost
      - ✓ Estimates of quantities
      - ✓ Analysis of rates
      - ✓ Quarry/material source charts
3. Project drawings
   a. Locality map-cum-site plan
   b. Strip plan showing the location of utilities,right-of-way, trees and junction
   c. Land acquisition plans.