GEOMETRIC DESIGN OF HIGHWAYS

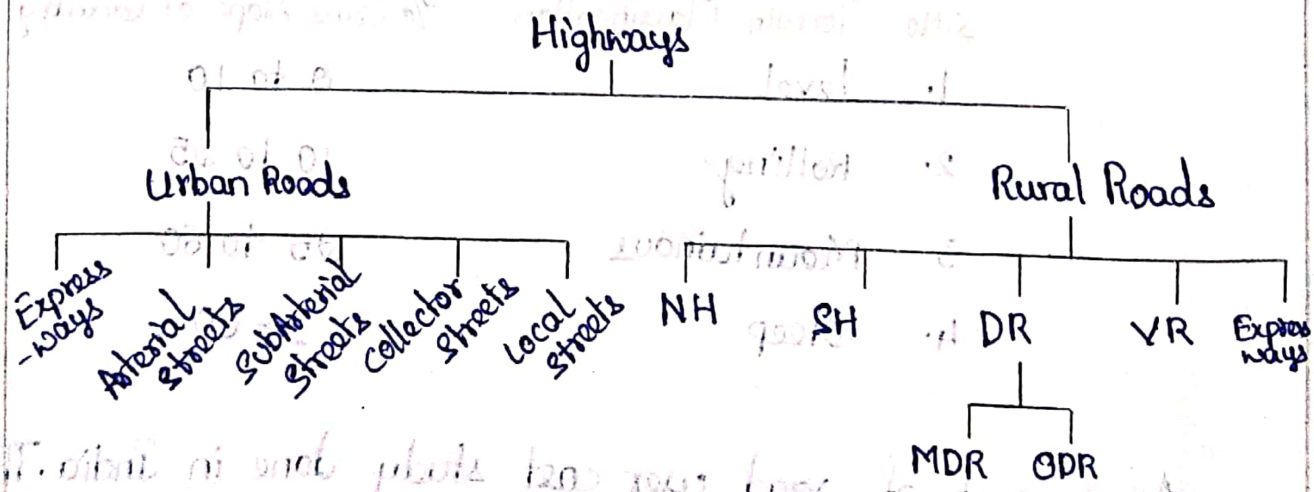
Geometric design of highway is an aspect that deals with the visible dimensions of a roadway. The geometric design of a highway must be done by considering the important aspects like safety, efficient and economic operations.

STANDARDS:-

The geometric design standards followed in various countries are as follows:

1. Indian Road Congress (IRC)
2. American Association of State Highway and Transportation Officials (AASHTO)
3. Australian guide to Road Design etc.,

HIGHWAY CLASSIFICATION :-



DESIGN CONTROLS

The basic design controls that govern the geometric features of highway are:

1. TOPOGRAPHY :-

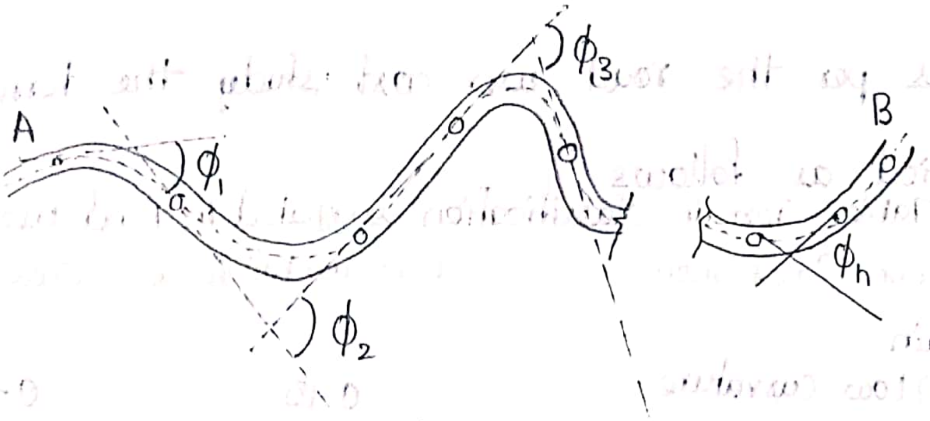
The topography of earth is not uniform in all directions. For preparing an economical and sound design various design elements are to be related with topographical features.

The classification of terrain is normally done by means of the cross slope of the country, viz., the slope approximately perpendicular to the centre line of the highway location. The classification generally followed are

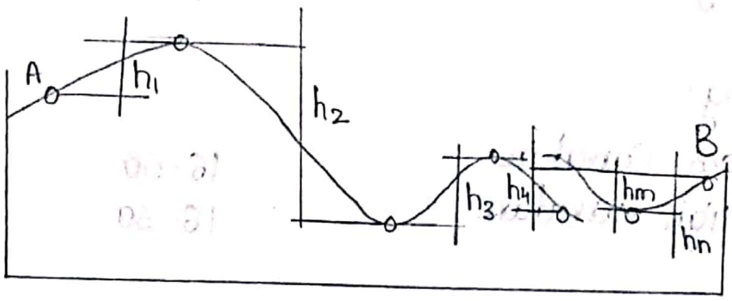
Table 1 :- Terrain Classification

S.No	Terrain Classification	% Cross Slope of Country
1.	Level	0 to 10
2.	Rolling	10 to 25
3.	Mountainous	25 to 60
4.	Steep	> 60

As a part of road user cost study done in India. The quantification of curvature and rise and fall has been done on the basis of Fig 1.



PLAN



LONGITUDINAL PROFILE

Plan :-

Avg Curvature (CV) of section AB is given by.

$$CV = \frac{\phi_1 + \phi_2 + \cdots + \phi_n}{\text{Dist. of AB (km)}}$$ Expressed in degrees/km

Longitudinal Profile

Avg rise of (RS) section AB is given by

$$RS = \frac{h_1 + h_3 + \cdots + h_n \text{ (metres)}}{\text{Dist AB (km)}}, \text{ m/km}$$

Avg fall (FS) of section AB is given by

$$FL = \frac{h_2 + h_4 + \cdots + h_m \text{ (m)}}{\text{Dist AB (km)}}, \text{ m/km}$$

Avg Rise and fall (RF) of section AB is given by

$$RF = \frac{h_1 + h_2 + h_3 + \cdots + h_m + h_n \text{ (m)}}{\text{Dist AB (km)}}, \text{ m/Km.}$$

As per the road user cost study the terrain is classified as follows.

Table 1:- Terrain classification suggested in Road user cost study

S.No	Terrain Classification	Rise and Fall (m/km)	Curvature (Deg/km)
1.	Plain		
	(a) Low Curvature	0-15	0-50
	(b) High Curvature	0-15	>51
2.	Rolling		
	(a) Low Curvature	16-30	0-100
	(b) High Curvature	16-30	>101
3.	Hilly		
	(a) Low Curvature	>31	0-200
	(b) High Curvature	>31	>201

2. TRAFFIC

Current and future estimates of traffic data are important in design of traffic highway.

i. Design Hour Volume:- Traffic on highway is measured in Annual Average Daily Traffic Volume. (AADT).

$$AADT = \frac{\text{Total annual vol of traffic}}{\text{no of days in the year}}$$

=> A commonly used unit for geometric design is the 30th highest hourly volume (30HV).

=> 30HV - The hourly volume that is exceeded by 29 hourly volumes during a designated year.

The design hour Volume (D.H.V) should be the 30HV for the future year selected for design.

ii) Directional Distribution of Traffic:-

For highways with more than two lanes the traffic distribution is identified by taking a rough approximation. It is assumed as 67% of total traffic to travel in one direction under the design conditions.

iii) Traffic Composition:-

As the traffic composition in our country is heterogeneous in character for easiness the traffic volume is expressed in terms of PCUs to evaluate the traffic data. The table below shows the PCU values as per Indian practice.

Table-1-PCU values as per Indian Practice.

S.NO	Vehicle Type	PCU
1.	Passenger Car, Pick-up Van & auto-rickshaw	1.00
2.	Motor Cycle & Scooter & Cycle	0.50
3.	Agricultural tractor, Light Commercial Vehicle	1.50
4.	Truck & bus	3.00
5.	Cycle Rickshaw	2.00
6.	Tractor trailer, agricultural tractor trailer	4.50
7.	Hand Cart	3.00
8.	Horse drawn vehicle	4.00
9.	Bullock-Cart	6.00-8.00

iv Future Traffic Estimate:-

The design of geometric elements are done considering the future traffic recieved by the road in the design year. The design period used for flexible pavements generally varies from 15 to 25 years. A period of 20 years is widely used as a basis for design.

v Design Vehicle Dimension:-

The dimensions and operating characteristics of a vehicle deeply influences the geometric design aspects such as radii, width of pavements, clearances, parking geometrics etc. Because of its crucial importance the vehicle design dimensions and weight were standardised in various countries, according to geometric design of highway formulae.

Hence the selection of the design vehicle for the design of a highway is governed by the type and volume of traffic that is expected to use the highway.

3. DESIGN SPEED :-

It is the maximum safe speed that can be maintained over a specified section of a highway when conditions are so favourable that the design features of the highway govern.

⇒ "Design Speed" is a speed determined for design and correlation of the physical features of a highway that influence vehicle operation.

⇒ The 95th percentile speed and 98th percentile speed are frequently chosen as the Design speed.

⇒ The suggested design speeds in India for rural and urban roads are tabulated below.

(K.P.H)

Table :- Suggested design speeds in India for rural highways

Classification	Plain Terrain		Rolling Terrain		Mountainous		Steep Terrain	
	Ruling	Mini.	Ruling	Mini.	Ruling	Mini	Ruling	Mini.
National and State Highways	100	80	80	65	50	40	40	30
Major District Road	80	65	65	50	40	30	30	20
Other District Road	65	50	50	40	30	25	25	20
Village Road	50	40	40	35	25	20	25	20

Table Suggested Design speeds in India for urban streets

Classification	Speed in K.P.H
Arterial	80
Sub Arterial	60
Collector Streets	50
Local Streets	30

4. Traffic Capacity:-

Capacity is the maximum flow that can be accomodated in a highway facility. The design of highway is done for maximum capacity conditions and flows much below the capacity.

⇒ Capacity for a highway facility is determined by using the formula given below.

$$C = \frac{1000V}{S}$$

Where,

C = Capacity in vehicles per hour per lane

V = Speed in K.P.H

S = Avg. spacing in metres b/w successive moving vehicles.

The value S is determined by the following equation.

$$S = L + 0.278Vt + \frac{V^2}{254f}$$

where,

S = Spacing b/w vehicles in m

L = Length of vehicles in m

V = Speed in KPH

t = perception-brake reaction time in sec.

f = coefficient of friction

g = acceleration due to gravity, m/sec^2

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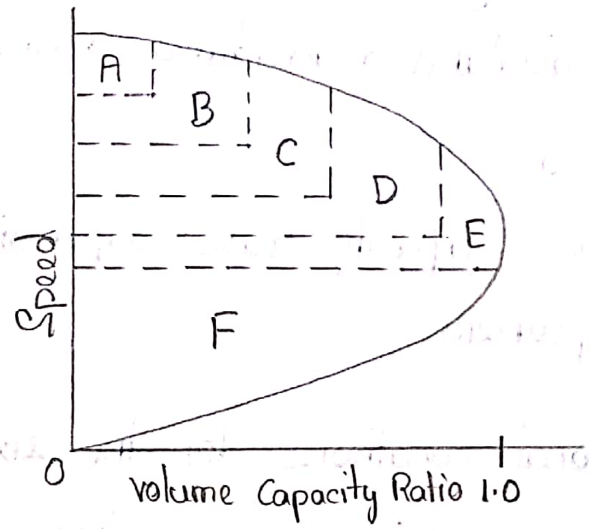
Late O.K. Normann has been recognized for his work on Highway capacity. The Highway capacity Manual (1965) recommends several "design service volumes" related to a group of desirable operating conditions collectively termed as "level of service".



HCM classification of level of Service

The volume/Capacity ratio is defined as the ratio between the design service volume and the capacity and has values between 0 and 1.

LEVEL OF SERVICE :-

The level of service denotes the level of facility one can derive from a road under different operating characteristics and traffic volumes. The level of service is evaluated using following parameters.

1. Speed and travel time.

Level of Service C: Still in the zone of stable flow but speeds and manoeuvrability are more closely controlled by higher volumes. A relative satisfactory operating speed is still obtained, with service volumes perhaps suitable for urban design practice.

Level of Service D:- Approaches unstable flow. Fluctuations in volume and temporary restrictions to flow may cause substantial drops in operating speeds. Temporary discomfort and inconvenience is caused.

Level of Service E: operating speeds are even lower than level D, with volumes at or near the highway capacity. Flow is unstable with stoppages for short duration.

Level of Service F:- Forced flow operations at low speeds where volumes are below capacity. Speeds are reduced substantially and stoppages may occur for short or long periods of time, because of downstream congestion.

The HCM terms the traffic volumes that can be served at each level of service as the service volume. The HCM manual contains no recommendations regarding the applicability of different level of service for the design of different types of highway facility.

Objectives of Geometric Design of Highway:

1) It gives maximum efficiency in the traffic operation.
2) It gives maximum safety to the users
3) It helps to save time of travel
4) It increases the speed of vehicles
5) It increases the no. of vehicles on road
6) It reduces the cost of construction
7) It reduces the cost of transportation
8) It gives pleasure of travel.

Road Margins:

The portion of the road beyond the carriageway and on the roadway can be generally called road margin.

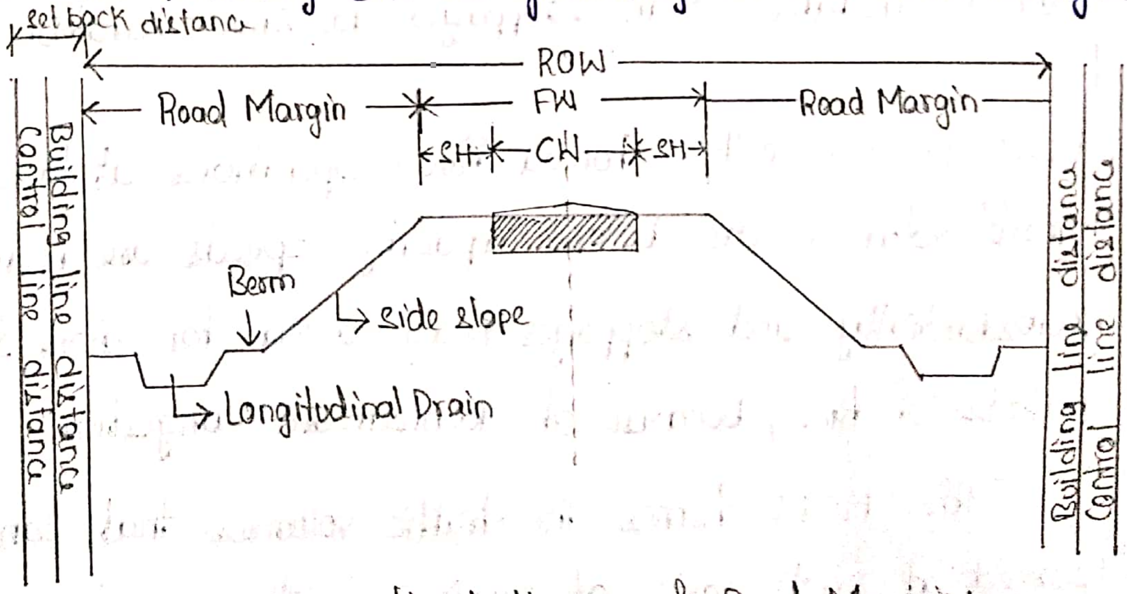


Fig:- Crossectional diagram of Road Margins.

CW = Carriage Way ; FW = Formation Width ; SH = Shoulder ; Right of Way = ROW

The various elements of road margins are given below.

i) Shoulders
ii) Parking lanes
iii) Bus bays
iv) Service roads
v) Cycle tracks
vi) Foot paths
vii) Guard rails

i) Shoulders:- Shoulder is a portion of roadway, connected with the carriageway and is intended for accomodation of stopped vehicles, emergency use and provide lateral support for base and subbase course.

The width of shoulder should be adequate for giving working space around a stopped vehicle.

According to AASHTO minimum 3m wide of shoulder is provided for high facilities and 1.2m to 2.4m for low facilities.

According to IRC suggest a minimum width of 2.5m is required for 2 lane rural highways.

Standards:-

IRC:86-2018 = Geometric design of urban roads
IRC:73-2018 = Geometric design standards for rural highways

ii) Parking lanes! Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for vehicles moving on the road. The parking lane should have a minimum of 3m width in case of parallel parking.

IRC:SP:12 = Recommendations on provision of parking spaces for urban areas.

iii) Bus Bays!- Busbays are provided by raising the kerb for bus stops. Busbays should be atleast 75m away from the intersection so that the traffic near intersection is not affected by the busbay.

Standards!-

IRC: 80-1981 = Design for pickup busstops on rural highways

IRC:SP:84-2014 = Manual of specifications & Standards for 4 laning of highways through PPP.

iv) Service Road!- Service roads give access to access controlled highways like expressways. They run parallel to the highway and will be usually isolated by a seperator and access to highway will be provided only at selected points provided to reduce congestion of highway and increase speed of traffic flow.

v) Cycle Track:- Cycle tracks are provided in urban areas when the volume of cycle traffic is high. A minimum width of 2m is required can increase by 1m for every additional track

Standards:-

IRC: SP: 84-2014.

vi) Foot Paths:- Foot paths are exclusive right of way to pedestrians, especially in urban areas provided for the safety of pedestrains when both pedestrain and vehicular traffic is high. A minimum width of 1.5m is provided for foot paths and may be increased by based on traffic

IRC: SP: 84-2014.

vii) Guard Rails:- They are provided at the edge of the shoulder usually when the road is on an embankment at a height of 3m from the ground. Guard stones or rails are painted in alternated black and white are usually used. They also give better visibility of curves at night.

IRC: SP: 84-2014.

Cross Sectional Elements:-

The features of the cross-section of the pavement influences the life of the pavement as well as the riding comfort and safety. out of these pavement surface characteristics affect both these. The various cross-sectional elements of pavement are listed below.

1. Camber :- It is the cross slope provided to raise middle of the road surface in the transverse direction to drop off rain water from road surface.

2. Width of Carriage Way :- It depends on the width of the traffic lane and number of lanes.

3. Kerb :- It indicates the boundary between the carriage way and the shoulder or islands or foot paths.

4. Width of Formation :- it is the sum of width of carriage way including seperators and shoulders.

5. Right of Way :- It is the width of land acquired for the road, along its alignment.

Pavement:-

Pavement is a hard surface that's covered in concrete or asphalt, like a road on which people walk. A highway pavement is designed to support the wheel loads imposed on it from traffic moving over it.

Pavement Surface Characteristics:-

For a safe and comfortable driving four aspects of the pavement surface are important.

1) The friction between the wheels and the pavement surface.
2) Smoothness of the road surface.
3) The light reflection characteristics of the top of pavement surface
4) Drainage

1. Friction :- Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed.

⇒ It also affect the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skiding or slipping of vehicles.

Various factors that affect friction are

a) Type of the pavement (like bituminous, concrete & gravel)

b) Condition of the pavement (dry & wet, hot & cold etc)

c) Condition of the tyre (new & old) and

d) Speed and load of the vehicle.

The frictional force that develops between the wheel and pavement is the load acting multiplies by a factor called the coefficient of friction and denoted as f.

⇒ IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15.

2. Smoothness :-

A well constructed cement concrete pavement and bituminous pavement surfaces must be smooth enough providing permanent non skid surface. If the surface become very smooth with ~~faulty surfa~~ faulty design it becomes tough and costlier to restore the non skid characteristics of pavement.

3. Light Reflection:-

It is necessary that the road surface should be visible at night.

-> White roads have good visibility at night, but caused glare during day time.

-> Black roads has no glare during day, but has poor visibility at night.

-> Concrete roads has better visibility and less glare.

Drainage:-

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Hence, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

SKID RESISTANCE :-

Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface.

FACTORS GOVERNING SKID RESISTANCE:-

The factors governing skidding of vehicles are grouped under four major categories. They are as follows:

Contd...

1. Roadway Factors
2. Vehicle factors
3. Traffic factors
4. Environmental factors.

i) ROADWAY FACTORS:-

The various roadway factors that govern the skidding of vehicles are as follows.

→ Polishing characteristics of the aggregates: Aggregates like sandstone and limestone provide high resistance to polishing due to movement of traffic.

→ Shape of Aggregates: Aggregate with angular shape possess higher skid resistance than rounded aggregates.

→ Microtexture of Aggregate: Aggregate with fine-scaled coarseness contains good microtexture promoting anti-skid properties in the surface.

→ Surface specifications: Specifications such as open graded premixed chipping carpet and surface dressing generally result in high skid resistance surfaces.

→ Texture of the surface

→ Wetness of the surface: The reduction in friction caused due to wetness of pavement surface is done by lubricating effect of the wet film of water. It can be controlled by
i) Providing good camber
ii) Providing a coarse texture

ii) VEHICLE FACTORS :-

The vehicle factors which govern safety against ~~skidding~~ skidding include tyre tread depth, tyre tread pattern, tyre rubber composition, tyre pressure, speed of the vehicle and vehicle brake design.

iii) TRAFFIC FACTORS :-

Traffic Factors include the intensity of traffic (wearing of aggregates) and presence of iron tyred traffic (polish the aggregate)

iv) ENVIRONMENTAL FACTORS :-

It includes rainfall and snowfall which cause wetness on the surface.

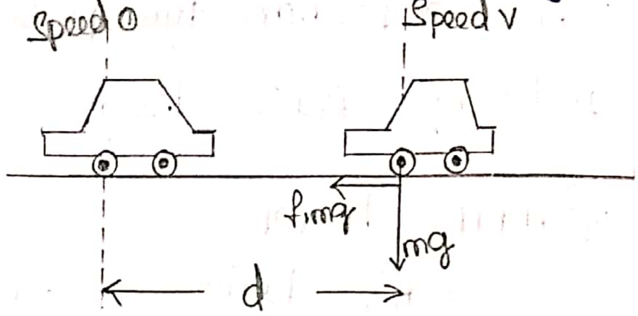
MEASUREMENT OF SKID RESISTANCE :-

A common measure of skid resistance is the coefficient of friction between the tyre and road interface. There are number of methods standardised for measuring skid resistance. The most common methods in use are.

1. Stopping of test vehicles
2. Braking of trailers towed by vehicles
3. Braking of vehicles with a test wheel
4. Measuring sideway force that develops when a wheel placed at an inclination sideslips.
5. Portable laboratory instrument.

Stopping of test Vehicle / Stopping Car Method:-

In this method, a vehicle driving at a certain known speed is braked and the distance it takes to bring it to a stop is measured.



Friction developed $f = \frac{v^2}{2gd}$ —— (1)

⇒ Deceleration of vehicle can be recorded directly by fixing a decelerometer to the vehicle.

$$\text{Friction factor } f = \frac{\alpha}{g} \quad \text{—— (2)}$$

where f = friction

v = speed in m/sec.

m = mass of vehicle kg

d = distance at which vehicle comes to stop after application of brakes

α = rate of vehicle deceleration in m/sec²

⇒ In the trailer wheel method, the trailer wheel is locked and the force developed at the tyre pavement interface is recorded by a suitable device.

⇒ In swedish test vehicle method, a fifth wheel is mounted in the vehicle itself and is made to slip at various values.

Measuring of Sideway Force Coefficient:-

The standard testing equipment, commonly known as the SCRIM (Sideway force coefficient routine investigation machine), consists of a standard four wheeled vehicle carrying a fifth wheel ~~and~~ set at an angle of 20° to the direction of travel.

⇒ A smooth tyre (3 x 20 inch) is fitted to the 5th wheel with a dead wt load of 200kg.

⇒ Speeds in the range of 15-100 kmPH can be adopted.

⇒ A common speed of measurement is 50kmPH.

⇒ About 50km - 70km of road section is tested in a day.

The sideway force coefficient is expressed

$$SFC = \frac{\text{Sideways Force}}{\text{Vertical reaction b/w tyre and road surface}}$$

Sand Patch Method:- In this method a known volume (≃ 25cc) of sand is spread over the surface to form a circular patch. The texture depth is calculated from the diameter D (in mm) of the patch from the formula:

$$\underset{(mm)}{\text{Texture}} = \frac{\text{volume of sand}}{\text{Area of patch}} = \frac{31000}{D^2} \quad \text{——— (1)}$$

Pavement Roughness:-

It can be defined as "Deviations of a travelled surface from a true planar surface with characteristic dimensions that affect riding quality, vehicle dynamics, dynamic pavement load and pavement damage".

Measurement of Road Roughness:-

The methods of measuring roughness can be broadly grouped under 2 categories,

1. Direct measurement of the longitudinal profile
2. Response type instrument methods.

1. Direct Measurement of the longitudinal Profile.

It is an accurate method of measuring the longitudinal profile. The simplest profiling method is by running along a desired straight line at intervals of 50cm. This methods give an ~~absou~~ absolute measurement.

The various devices used for measuring a longitudinal profile are

1. CHOLG Profilometer
2. TRRL Beam.
3. GMR (General Motor Research) Profilometer.

2. Response type instrument Method..

In this method the mechanical systems travelling over the rough road is recorded. Thus, this system gives only a relative measurement of roughness and depends on the characteristics of the mechanical system and the speed of travel.

The well known response type of instruments are.

1. Bureau of public roads (BPR) roughometer
2. The British Towed fifth wheel bump integrator unit.
3. APL Trailer
4. Mays meter
5. Car mounter integrator