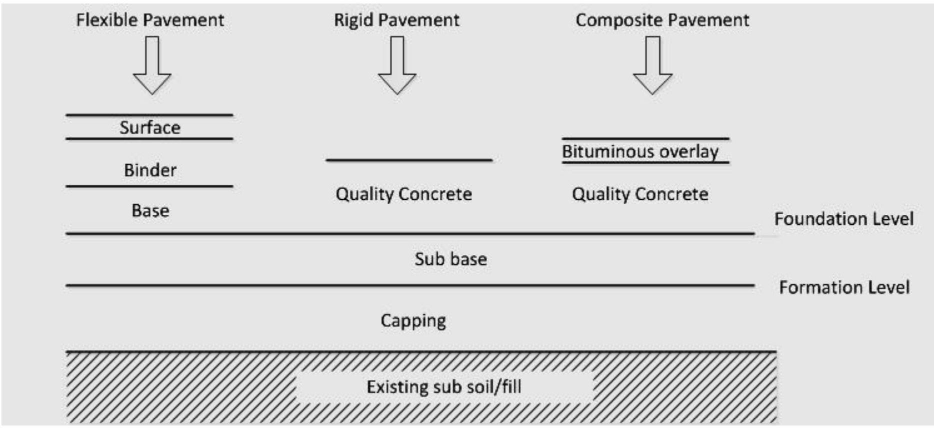
Lecture 1 – Part 2

1.3 Pavement Structures

The main purpose of the pavement or pavement layers is to minimize stresses generated by traffic on the subgrade to such a level where no deformations occur. At the same time, the pavement layers themselves should be withstanding the stresses and strains which are imposed on each layer for the entire life of the pavement. Typically, modern pavement structures are either flexible, rigid or a composite of the two. As can be seen in the figure below, normally bituminous, hydraulic bound or concrete layers are built on foundation courses depending on the design decision. The decision and selection of course and layer type is generally dependent on common practices, availability of the materials, site characteristics, etc.



Modern pavement types

It should be known that a layer is an element of a pavement laid in a single operation, while a course is a structural element of a pavement constructed with a single material; a course may be laid in one or more layers. However, construction of the pavement normally starts with enhancing the subgrade "natural soil" bearing capacity by compaction, and then layers are constructed one by one. A capping course may be constructed over the subgrade depending on the site terrain, and then the sub-base course is placed; both capping and sub-base form the pavement foundation.

In a rigid pavement type, a quality concrete layer is normally constructed over the foundation; in some cases a subbase course is used. The concrete slab could be reinforced or plain concrete; also it could be jointed or continuous. Rigid pavement is preferred for some sites such as petrol stations and heavy vehicle lots. Additionally, a bituminous layer could overlay the concrete course, mainly to enhance ride quality in terms of noise: this pavement structure is called composite pavement.

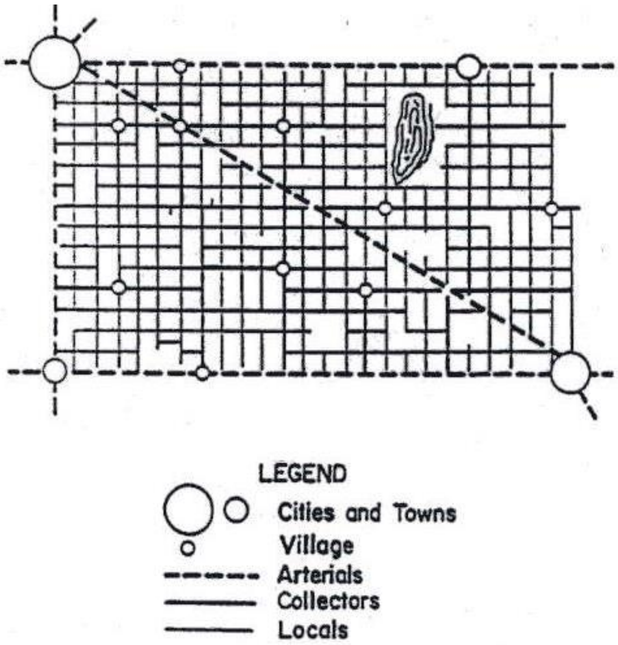
Flexible pavement courses over the foundation may include base, binder and surface courses. The base course is the main structural element and it could be constructed from granular material which may sometimes be mixed with hydraulic or bituminous material. Binder and surface courses are bituminous mixtures; the surface course is exposed directly to weather and traffic actions, so this course should withstand traffic loading, weather action and wearing from tires. Furthermore, the surface course has to provide high riding quality and sufficient skid resistance. Flexible pavements represent the majority of paved roads globally. In Europe and North America, more than 90% of roads and highways are surfaced with flexible pavements (NAPA and EAEA, 2011), due to their unique high quality and riding quality, together with the lower cost compared with other pavement types.

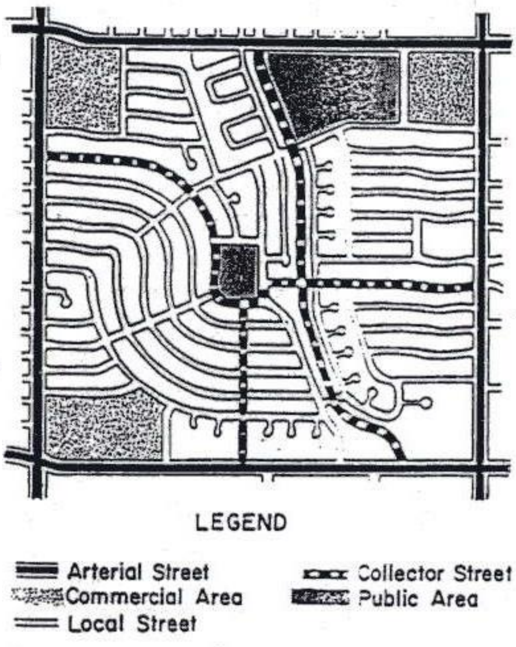
1.4 Functional Classification

1.4.1 Functional Relationships

Functional classification groups streets and highways according to the character of service they are intended to provide. Highways and streets are initially categorised depending on the area they are located in. They are functionally divided into Urban and Rural roads.

Rural highway system **Urban highway system**





1.4.2 Functional System of Rural Roads:

Rural roads facilities outside of urban areas. The functional classification of rural roads:

Principal arterials system	Serves mostly interstate long uninterrupted trips, highest level of mobility and highest speeds. Posted speed is between (100-120 km/h). Principal arterial system includes: freeway and other principal arterials
Minor arterials	The principal arterials, connects cities, large towns, other large traffic generators (such as resort areas). Posted speed limits (90-110 km/h).
Major collectors	Carry traffic to and from counties (villages) and large cities not served by the arterial system. Collectors provide less mobility than arterial at lower speed (70- 90 km/h) and for shorter distance.
Minor collectors	Collects traffic from local roads and convey it to other facilities
Local roads	All roads within the rural area not classified above. Local road system provides access to land adjacent to the collator network and serves travel over relatively short distances with posted speed between (50-70 km/h)

1.4.3 Functional System of Urban Roads:

Function in communities with a population of 5000 or more people. Functional classification of urban roads:

Principal Arterials system	Serves the major activity centres of activity of urbanized areas, highest traffic volume and the longest trip. Urban principal arterial system should be classified as follows: Interstate, expressways, other principal arterials (Interstate, Other freeways, & other principal arterials). Design speed is (90-110 km/h). Parking, loading and unloading of goods and pedestrian traffic are not permitted on these facilities. They are generally provided with grade-separation at intersections.
Minor arterials	Interconnect with and augment principal arterials. It accommodates trips of moderate length at lower level of travel mobility than principal arterial. Design speed is (70-90 km/h)
Collector Streets system	Collect traffic from local streets and convey it to the arterial system. It provides both land access and traffic circulation within residential, commercial and industrial areas. Design speed is (50-70 km/h)
Local Streets system	It comprises all facilities not in one of higher systems. It permits direct access to abutting lands and connections to the higher order systems. Design speed is (20-40 km/h).

1.5 System of Iraqi Highways

1. Primary System

Highways of international importance (the main highways connecting main cities) and highways of special importance should form the primary system of national highways. These highways are to be designed to the highest standards.

2. Secondary system

Highways connecting major cities of economic or other importance, highways connecting agricultural, commercial or recreational areas.

3. Tertiary system

Highway of district and local importance

1.6 Principles of Highway Route Location Process

The basic principle for locating highways is that roadway elements such as curvature and grade must blend with each other to produce a system that provides for the easy flow of traffic at the design capacity, while meeting design criteria and safety standards. The highway should also cause a minimal disruption to historic and archeological sites and to other land-use activities. Environmental impact studies are therefore required in most cases before a highway location is finally agreed upon. The highway location process involves four phases:

1. Office study of existing information.
2. Reconnaissance survey.
3. Preliminary location survey.
4. Final location survey.

1- Office study of existing information:

The first phase in any highway location study is the examination of all available data of the area in which the road is to be constructed. This phase is usually carried out in the office prior to any field or photogrammetric investigation. All the available data are collected and examined. These data can be obtained from existing engineering reports, maps, aerial photographs, and charts, which are usually available at one or more of the state's departments of transportation, agriculture, geology, hydrology, and mining. The type and amount of data collected and examined depend on the type of highway being considered, but in general, data should be obtained on the following characteristics of the area:

- Engineering, including topography, geology, climate, and traffic volumes.
- Social and demographic, including land use and zoning patterns.
- Environmental, including types of wildlife; location of recreational, historic, and archeological sites; and the possible effects of air, noise, and water pollution.
- Economic, including unit costs for construction and the trend of agricultural, commercial, and industrial activities.

Preliminary analysis of the data obtained will indicate whether any of the specific sites should be excluded from further consideration because of one or more of the above characteristics. For example, if it is found that a site of historic and archeological importance is located within an area being considered for possible route location, it may be immediately decided that any route that traverse that site should be excluded from further consideration. At the completion of this phase of the study, the engineer will be able to select general areas through which the highway can traverse.

2- Reconnaissance Survey:

The object of this phase of the study is to identify several feasible routes, each within a band of a limited width of a few hundred meters. When rural roads are being considered, there is often very little or no information available on maps or photographs, and therefore aerial photography is widely used to obtain the required information. Feasible routes are identified by a stereoscopic examination of the aerial photographs, taking into consideration factors such as:

- Terrain and soil conditions.
- Serviceability of route to industrial and population areas.
- Crossing of other transportation facilities, such as rivers, railroads, and other highways.
- Directness of route.

Control points between the two terminals are determined for each feasible route. For example, a unique bridge site with no alternative may be taken as a primary control point. The feasible routes identified are then plotted on photographic base maps.

3- Preliminary Location Survey:

During this phase of the study, the positions of the feasible routes are set as closely as possible by establishing all the control points and determining preliminary vertical and horizontal alignments for each. Preliminary alignments are used to evaluate the economic and environmental feasibility of the alternative routes.

4- Final Location Survey:

It is a detailed layout of the selected route. The horizontal and vertical alignments are determined, and the positions of structures and drainage channels are located.

1.7 Highway Survey Methods

Highway surveys usually involve measuring and computing horizontal and vertical angles, vertical heights (elevations), and horizontal distances. They are used to prepare base maps, contour lines and longitudinal cross-section of the highway. Highway surveys are usually grouped into three general categories:

- Ground surveys, they are the basic location technique for the highway. Common survey equipment such as the total station and the level are used in this method.
- Remote sensing, is the measurement of distances and elevations by using devices located above the earth, such as airplanes or orbiting satellites using Global Positioning Satellite systems (GPS). The most commonly used remote-sensing method is the photogrammetry.

Photogrammetry in highway engineering is for the identification of suitable locations for highways, referred to as corridor study.

- Computer graphics, this method is a combination of photogrammetry and computer techniques. All line styles, objects, feature tables and photographic features are recorded digitally and stored in a computer file. A typical workstation should be controlled by a system software that covers the following points:

- Preparatory work (project setup)
- Photo orientation
- Data transfer
- Plotting and storage

Lecture 1 / 06-12-2020

Highway Engineering

References:

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- **American Association of State Highway and Transportation Officials (AASHTO)**, (2003).
- **Highways**, The Location, Design, Construction and Maintenance of Road Pavements. *By* Coleman O'Flaherty (4th Edition 2009).
- **Highway Engineering**, By Rogers M., (2008), 2nd Edition, Blackwell Publishing Ltd.
- **Principles of pavement design**, By Yoder, E. and Witczak. M., 1975, 2nd edition, New York: John Wiley and Sons, Inc.

Course Description:

Highway engineering subject is a two-course sequence that covers the fundamental elements of highway engineering. Highway engineering is the application of technological and scientific principles to the planning, functional design, operation and management of highway network in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods. Also, the course includes the geometric design, cross section elements, earthwork, paving material properties, structural design of flexible and rigid pavements and maintenance program that can be adopted on highway system.

Course Objectives:

The objectives of these courses are to introduce highway engineering principles to civil engineering undergraduate students and to familiarize the students with highway engineering subject and concepts commonly encountered in engineering practice.

Course Outcomes:

By the end of this course, student will be able to:

1. Determine the best location and route of a highway.
2. Understand the cross section elements of various highway classes.
3. Calculate the earthwork volumes of cut and fill along the highway profile.
4. Understand and design the horizontal and vertical alignment of highway.
5. Understand subgrade and subbase course properties.
6. Classify soil using standard classification schemes;
7. Understand the concept of surface and subsurface drainage;
8. Identify asphalt cement and aggregate properties;
9. Design hot asphalt mixture;
10. Design the structural layers of flexible pavement;
11. Design rigid pavement thickness and joint types.
12. Identify pavement distress and recommend maintenance program.

1. Highways History; Highway Location and economic; Highway surveying

1.1 Road Construction Development:

- In its most general sense, a road is an open, generally public way for the passage of vehicles, people, and animals.
- Covering these roads with a hard smooth surface (pavement) helped make them durable and able to withstand traffic and the environment. Some of the oldest paved roads still in existence were built by the Roman Empire.
- By in large, Roman roads (see Figure) were constructed during the Republican times – the oldest road dates back to 312 BC.
- The Roman road network consisted of over 100,000 km (62,000 miles) of roads.
- The superior quality and structure of its pavements have allowed many Roman roads to survive to this day.

Historically, the Babylonians built the earliest roads using natural asphalt as a binder; also the Egyptians constructed roads to transport stones during the building of the pyramids (Watson, 1994). The Chinese built the Silk Route, which is amongst the best known roads, in about 2600 BC; and the Persian Empire also benefited from this route through its lands for trade between China and Europe (Kendrick et al., 2004). In Europe, in about 2500 BC, roads were built using log-rafts; such roads have been discovered in Britain. Also, similar roads have been discovered in the Swiss Lakeside Villages and across the Pangola Swamps in Hungary (Kendrick et al., 2004). In Indian civilization, brick paving with proper piped surface water drainage systems dating from about 3000 BC has been discovered.

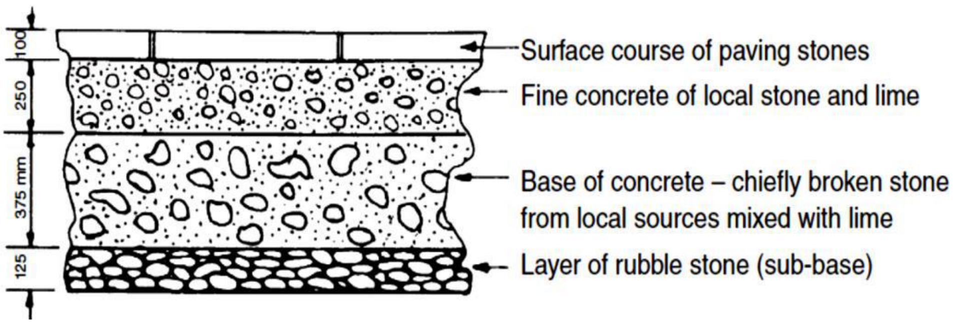


Figure (1-1) Roman Road Structure (All dimensions in mm)

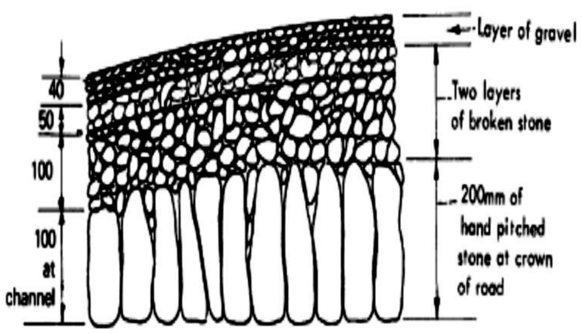
The first insight into today's modern pavements can be seen in the pavements of Thomas Telford (born 1757). Telford served his training as a building mason and extended his masonry knowledge to bridge building. Eventually, Telford became the "Surveyor of Public

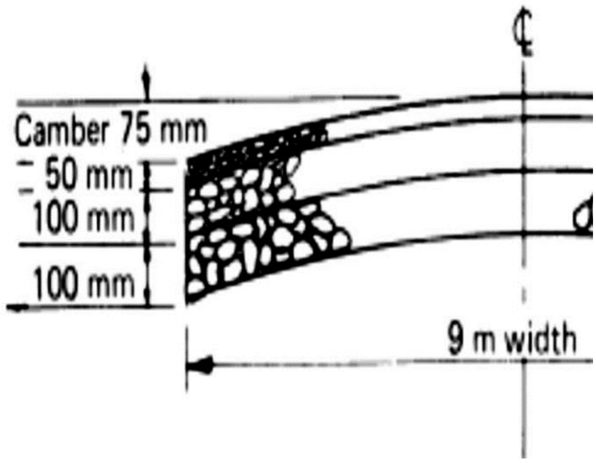
Works" for the county of Salop, thus turning his attention more to roads. Telford attempted, where possible, to build roads on relatively flat grades in order to reduce the number of horses needed to haul cargo.

Telford's pavement section was about 350 to 450 mm (14 to 18 inches) in depth and generally specified three layers. The bottom layer was comprised of large stones 100 mm (4 inches) wide and 75 to 180 mm (3 to 7 inches) in depth. It is this specific layer which makes the Telford design unique. On top of this were placed two layers of stones of 65 mm (2.5 inches) maximum size (about 150 to 250 mm (6 to 9 inches) total thickness) followed by a wearing course of gravel about 40 mm (1.6 inches) thick (see Figure). It was estimated that this system would support a load corresponding to about 88 N/mm (500 lb per in. of width).

1.2 John MacAdam

- Macadam pavements introduced the use of angular aggregates. John MacAdam (born 1756 and sometimes spelled "Macadam") observed that most of the paved U.K. roads in early the 1800s were composed of rounded gravel.
- He knew that angular aggregate over a well-compacted subgrade would perform substantially better. He used a sloped subgrade surface to improve drainage (unlike Telford who used a flat subgrade surface) on which he placed angular aggregate (hand-broken with a maximum size of 75 mm (3 inches)) in two layers for a total depth of about 200 mm (8 inches) (Gillette, 1906).
- On top of this, the wearing course was placed (about 50 mm thick with a maximum aggregate size of 25 mm). Macadam's reason for the 25 mm (1 inch) maximum aggregate size was to provide a "smooth" ride for wagon wheels.





Telford's method   Macadam's method

Figure (1-2) Telford's and Macadam's road structures

Road development was negatively affected after the first operation of the railways in 1825, as the numbers of passengers who were using stagecoaches started to decrease continually; consequently the turnpike revenues decreased. However, at the beginning of the 20th century, and especially after the end of World War One, attention to the development of roads and highways was renewed; this interest in road development resulted from the development in motor vehicles. The development started with the spreading of tar on roads to control dust created by vehicles' movement and then to reconstructing existing roads.

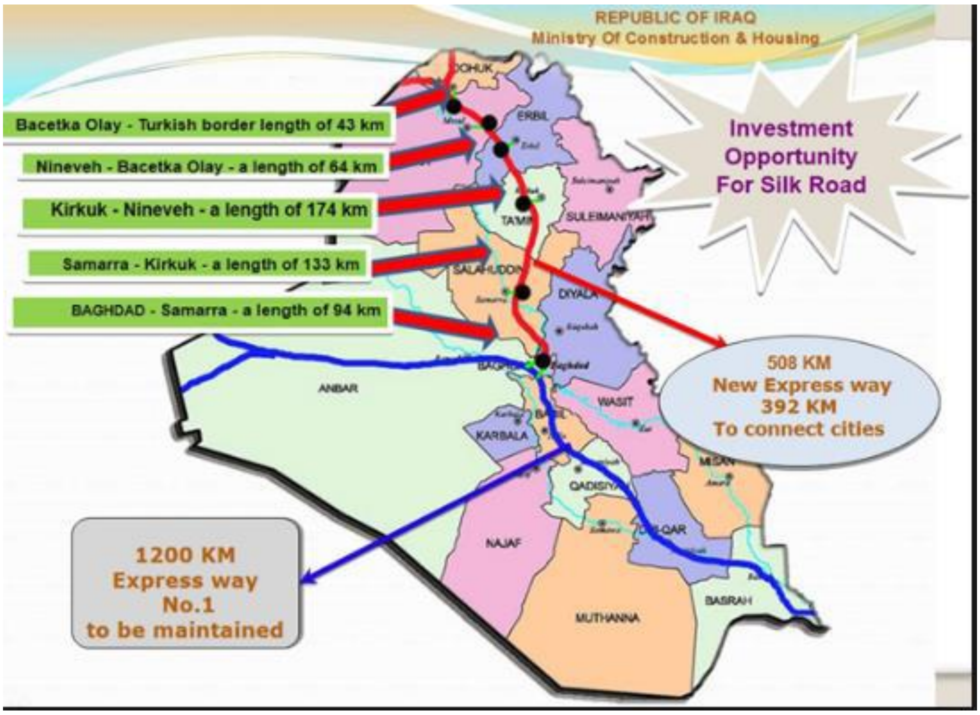
However, the development in vehicles in terms of extra weight and speed has led to the need for new roads and highways; as a result, for example, dual carriageway roads were constructed and road geometric designs were advanced. Also, vehicle development put a huge stress on pavement constructors to build structures that could resist high stresses and bad weather conditions. Accordingly, construction techniques were advanced; more structural layers were built; and the structural layers and subgrade were compacted using different materials to improve their mechanical properties. During the 20th century significant developments in road and highway construction were achieved to satisfy the traffic requirements. Today, roads and highways represent a great achievement, but of course the development will not stop and continued developments are still in demand.

The first research dedicated to highway engineering was initiated in the United Kingdom with the introduction of the Transport Research Laboratory (TRL), in 1930. In the USA, highway engineering became an important discipline with the passing of the Federal-Aid Highway Act of 1944, which aimed to connect 90% of cities with a population of 50,000 or more. With constant stress from vehicles which rose larger as time passed, improvements to pavements were needed. With technology out of date, in 1958 the construction of the first motorway in Great Britain played a major role in the development of new pavement technology.

Design policies standards used in the United States are typically based on publications of the American Association of State Highway and Transportation Officials as well as research circulated by the Transportation Research Board, the Institute of Transportation Engineers, the Federal Highway Administration, and the Department of Transportation.

In Iraq total length of highway network is 45,550 km, paved: 38,400 km and unpaved: 7,150 km. The highways are geometrical designed by [State Commission of Roads and Bridges (SCRB), (2005), Republic of Iraq, Ministry of Housing and Construction, Department of Planning and Studies, Baghdad].

The pavement structure is designed by AASHTO Guide for Design of Pavement Structures in 1993, and The material quality and test results are compared with State Commission of Roads and Bridges (SCRB), (2007), "General Specification for Roads and Bridges", Republic of Iraq, Ministry of Housing and Construction, Department of Planning and Studies, Baghdad.



Lecture 2 / 24-12-2020

Elements of Geometric Design

The geometry of a typical highway comprises three basic components: cross sectional geometry, horizontal geometry, and vertical geometry. The type, size, and number of elements used in a highway are directly related to its class and the corresponding function of the highway.

Cross Section Elements

Figure 2.1 below shows a typical cross section of a two-lane highway, and Figure 2.2 shows that for a multi-lane highway.

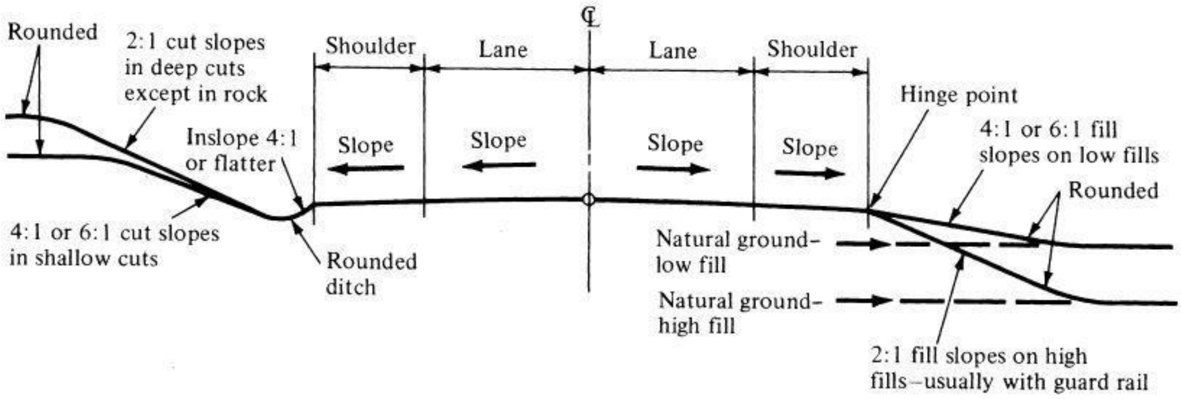


Figure 2.1: Typical cross section of two-lane highways

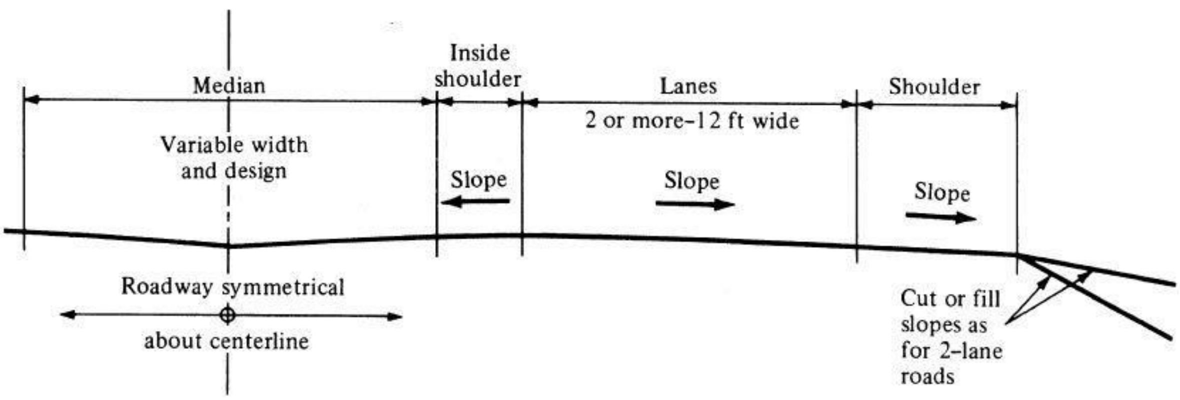


Figure 2.2: Typical cross section of multi-lane highways

Cross- section elements are:

1- Pavement surface types:

The selection of pavement type is based on: Traffic volume and composition, soil characteristics, availability of materials, performance of pavements in the area, weather and cost.

a- High type pavement: such as asphalt concrete and Portland cement concrete;

b- Low type: such as stabilized surface, loose gravel and earth work.

2- Width of lane and number of lanes:

- Travel lane widths usually vary from (2.7-3.6) m.
- Most arterials (multi-lane highways) have 3.6m travel lanes.
- Two-lane, two-way rural roads, have lane widths of (3.0-3.3) m.
- Lanes that are 2.7m wide are used occasionally in urban areas if traffic volume is low and there are extreme right-of-way constraints.

3- Shoulders:

A shoulder is the portion of the roadway continuous with the travelled way that accommodates stopped vehicles, emergency use and lateral support of subbase, base and surface courses. Pavement shoulders are always next to the travel lanes. Shoulders range in width from 0.5m on minor roads to 3.6m on major arterials. When a vehicle stops on the shoulder, it is desirable for it to be at least 0.25m and preferably 0.5m from the edge of the pavement. They typically provide the following:

- An area along the highway for vehicles to stop when necessary.
- Travel lanes for bicycles, particularly on rural roads and collector roads.
- They can support the pavement structure.
- Used to facilitate drainage of surface water.
- Highway capacity is improved because uniform speed is encouraged.
- Space is provided for maintenance operations such as snow removal and storage.
- Lateral clearance is provided for signs and guardrails.

4- Medians:

A median is the section of a divided highway that separates the lanes of opposing directions. The width of a median is the distance between the edges of the inside lanes, including the median shoulders. Widths should be as wide as possible but should be balanced with other elements of the cross section and the cost is involved. The functions of a median include:

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

5- Curb and Gutter:

Curbs are raised structures made of either Portland cement concrete or bituminous concrete (rolled asphalt curbs). They may be designed separately or as integral parts of the pavement. They are necessary for:

- To mark the pavement edges and pedestrian walkways.
- To control drainage, improve aesthetics, and reduce the right of way.
- To prevent vehicles from leaving the highway.

Gutters or drainage ditches are usually located on the pavement side of a curb to provide the principal drainage facility for the highway. They can be designed as V-type sections or as broad, flat, rounded sections.

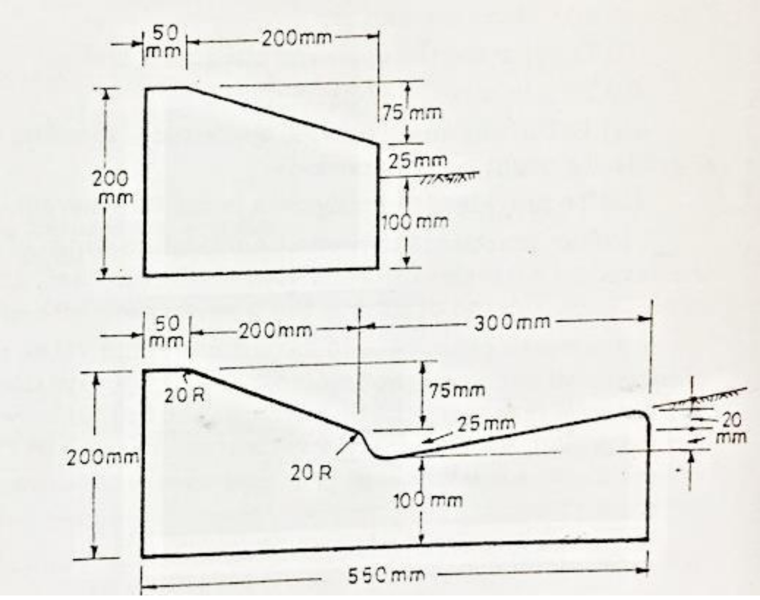


Figure 2.3: Curb and gutter

6- Guard rails:

They are longitudinal barriers placed on the outside of sharp curves and at sections with high fills. Their main function is to prevent vehicles from leaving the roadway. They are installed at embankments higher than 2.4m and when shoulder slopes are greater than 4:1.

7- Sidewalks and vertical clearance:

Sidewalks along city streets are often justified by pedestrian concentration such as residential area, schools, business and industrial plants. They are usually provided on roads in urban areas but are uncommon in rural areas. Nevertheless, the sidewalks in rural areas should be evaluated during the planning process to determine sections of the road where they are required.

Generally, sidewalks should be provided when pedestrian traffic is high along main or high-speed roads in either rural or urban areas.

- Sidewalks should have a minimum clear width of 1.2m in residential areas and a range of 1.2m to 2.4m in commercial areas.
- To encourage pedestrians to use sidewalks, they should have all-weather surfaces since pedestrians will tend to use traffic lanes rather than unpaved sidewalks.
- The minimum vertical clearance should be at least 5m. In urban areas this should be increased to 5.5m so that double decker buses could also be accommodated.

8- Transverse or Cross slopes:

Cross-slope in almost highway is crown slope otherwise may be sloped to inside or outside depending on the drainage requirements. Pavements are sloped from the middle downward to both sides of the highway, resulting in a transverse or cross slope, with a cross section shape that can be curved or plane. They are used to enhance the flow of surface water away from the pavement. High cross slopes are undesirable though, as vehicles may be drifted to the edges of the pavement, especially under icy conditions. Recommended rates of cross slopes are 1.5 to 2 percent for high type pavements (Smooth pavements) and 2 to 6 percent for low-type pavements (Rough pavements).

9- Side Slopes:

Side slopes are provided on embankments fills or cut areas to provide stability for earthworks. They also serve as a safety feature by providing a recovery area for out-of-control vehicles. Three regions of the roadside are important to reducing the potential for loss of control for vehicles that runoff the road, the top of the slope (hinge point), the foreslope and the toe of the slope (the intersection of the foreslope with level ground or with a backslope , forming a ditch) . Foreslope and backslope combination the channel (width: 1.2-2.4 m), can be selected to produce cross sections can be safety traversed by an unrestrained vehicle occupant. Figure shows these three regions.

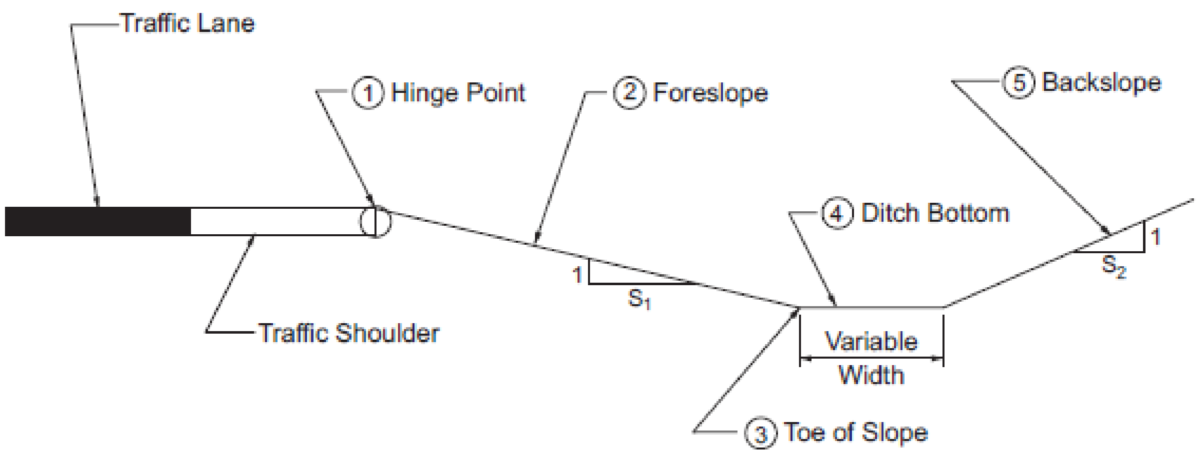


Figure 2.4: Designation of roadside regions

10- Drainage:

Highway drainage facilities carry water across the right-of-way and remove stormwater from the roadway itself. Drainage facilities include bridges, culverts, channels, curbs, gutters and various types of drains.

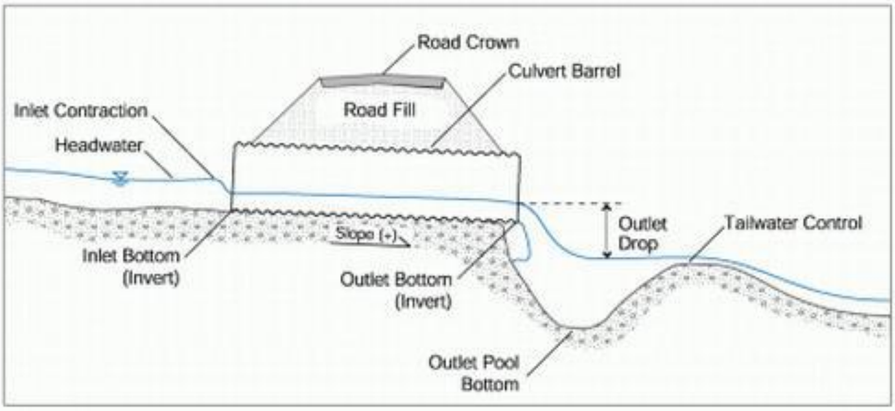


Figure 2.5: Culvert under roadway

Gutter section may be provided on the travelled way side of a vertical or sloping curb to form the principal drainage system for the roadway.

Figure 2.6: Cutter drainage system

Drainage channels perform the key function of collecting and conveying surface water from the highway eight of way. Roadside channels should have adequate capacity for the design runoff and be located and shaped to provide a safe transition from the roadway to the backslope. The primary purpose for construction of roadside channels is to control surface drainage. The most economical method of construction a roadside channel usually envolves the formation of open-channel ditches by cutting into the natural roadside terrain to produce a drainage channel.

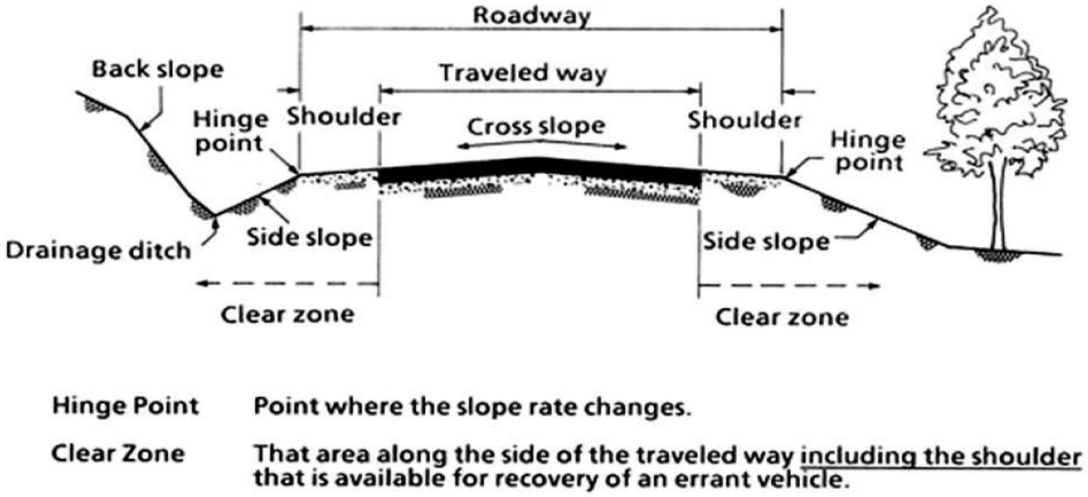


Figure 2.7: Open-channel ditches drainage system

11- Right of Way

It is the total land area acquired for the construction of a highway. The width should be sufficient to accommodate all the elements of the highway cross section, any planned widening of the highway, and public-utility facilities that will be installed along the highway. In major highway, the right of way may reach 100m .In general cases the right of way depends on:

1- Number and width of lanes, shoulder

2- Width of medians;

3- Cost of lane construction and operation;

4- Location (urban or rural).

5- Outer separation

6- Sidewalk

7- Side slope

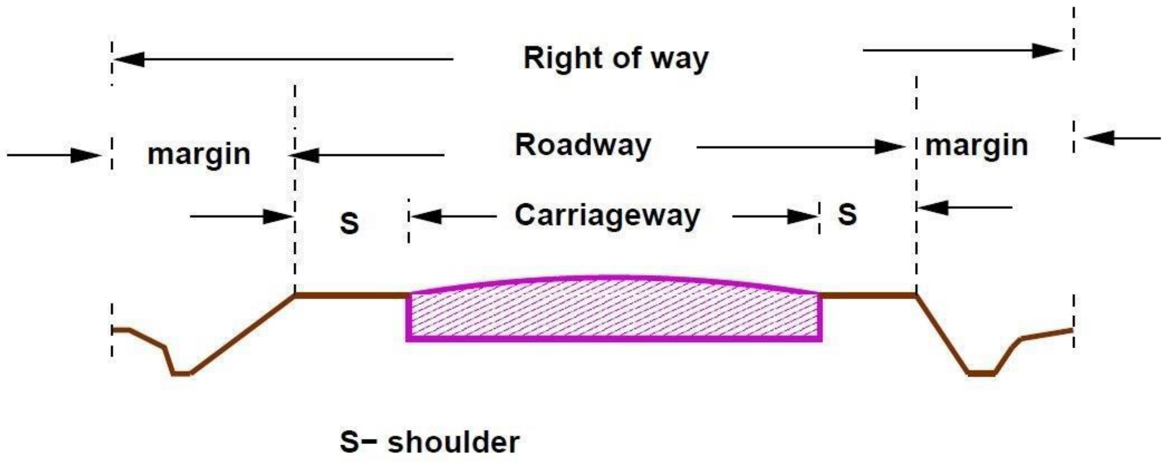


Figure 2.8: Typical right of way section

Table 2.1: Range of desirable right of way width for selected road types

Class of road	Right of way width in metres					
	Plain and rolling terrain				Mountainous and steep terrain	
	Rural areas		Urban areas		Rural areas	Urban areas
	Normal	Range	Normal	Range	Normal	Normal
1- National and state highways	45	30-60	30	30-60	24	20
2- Major district roads	25	25-30	20	15-25	18	15
3- Other district roads	15	15-25	15	12-20	15	12
4- Rural roads	12	12-18	10	10-15	9	9

Lecture 3

Highway Grades

The maximum grade on any highway should be selected based on good judgment. The selection of maximum grades for a highway depends on the design speed and the design vehicle. It is generally accepted that grades of 4 to 5 percent have little or no effect on vehicles.

-Maximum grades have been established based on the operating characteristics of the design vehicle on the highway. These vary from *5 percent* for a design speed of *70 mi/h* to between *7 and 12* percent for a design speed of *30 mi/h*, depending on the type of highway. The table below gives recommended values of maximum grades.

Table 3.1: Recommended maximum grades

Rural Collectors[a] — *Design Speed (mi/h)*

Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
	Grades (%)								
Level	7	7	7	7	7	7	6	6	5
Rolling	10	10	9	9	8	8	7	7	6
Mountainous	12	11	10	10	10	10	9	9	8

Urban Collectors[a] — *Design Speed (mi/h)*

Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
	Grades (%)								
Level	9	9	9	9	9	8	7	7	6
Rolling	12	12	11	10	10	9	8	8	7
Mountainous	14	13	12	12	12	11	10	10	9

Rural Arterials — *Design Speed (mi/h)*

Type of Terrain	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*
	Grades (%)								
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5

Rural and Urban Freeways[b] — *Design Speed (mi/h)*

Type of Terrain	*50*	*55*	*60*	*65*	*70*	*75*	*80*
	Grades (%)						
Level	4	4	3	3	3	3	3
Rolling	5	5	4	4	4	4	4
Mountainous	6	6	6	5	5	–	–

Urban Arterials — *Design Speed (mi/h)*

Types of Terrain	*30*	*35*	*40*	*45*	*50*	*55*	*60*
	Grades (%)						
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

Minimum grades depend on the drainage conditions of the highway. *Zero percent* grades may be used *on uncurbed pavements with adequate cross slopes to laterally drain the surface water*. When pavements are curbed, however, a longitudinal grade should be provided to facilitate the longitudinal flow of the surface water. It is normal to use a minimum of *0.5 percent* in such cases, although this may be reduced to *0.3 percent* on high-type pavement.

Earth Works

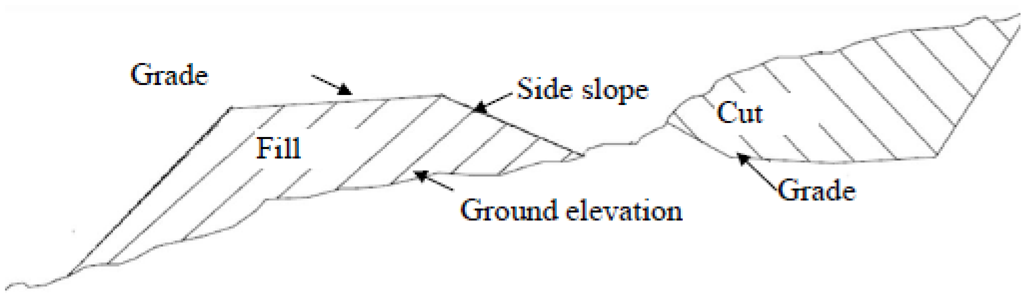
Earthwork quantities are normally, expressed as volume in metric units; they are given in cubic meters. For highway or railway, these volumes are usually calculated by estimating the areas of earthwork on cross sections taken at intervals along the facility and multiplying the average of adjacent cross-sectional areas by the distance between them. The cross sections are usually spaced at stations ranging from 30m to 100m, depending on how close the grade line from the natural ground level.

Estimating Earthwork Quantities:

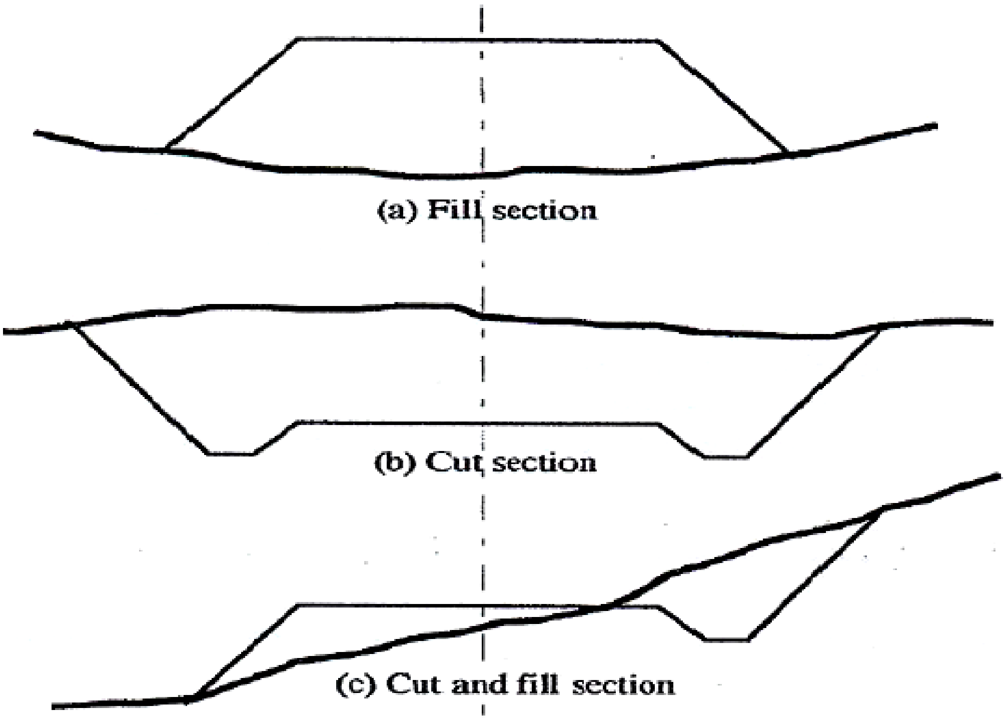
1: Establishing the vertical Alignment:

The first step in the earthwork is determining the rolling grade of each section of the highway.

2: Determining cross-section area (Earth Cross Section):



Cut and Fill



3: Determining earthwork volume:

Volume for sequence of cross-section area can be calculated by one of the following:

A/ Trapezoidal Formula:

$$V = \frac{(A_1 + A_2)}{2} \times D$$

Where: V: the earthwork volume, m^3

A_1 & A_2: cross-section area of two ends, m^2

D: distance between the ends, m.

B/ Prismoidal formula (Simpson rule):

$$V = \frac{D}{6}\,(A_1 + 4A_{mid} + A_2)$$

A_{mid} : the area of midpoint between two ends.

For a series of successive and equally spaced area A_1, A_2, A_3, ... A_n:

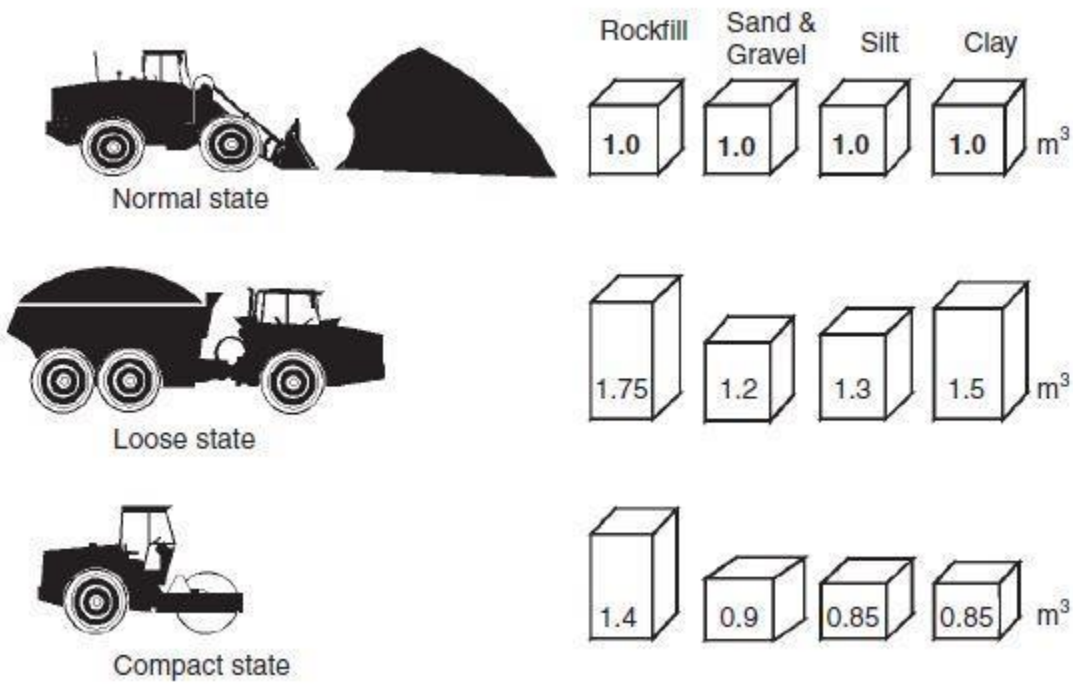
$$V = \frac{D}{3}\,(A_1 + A_n + 2\sum A_{odd} + 4\sum A_{even})$$

Where $\sum A_{odd}$: sum of the odd number areas

$\sum A_{even}$: sum of even number areas.

Correcting earthwork volumes

Some issues are associated with materials during compaction, those issues are swelling/or shrinkage. As shown in the figure below:



The ratio of the loose volume to the in-situ or non-excavated volume is termed the **swelling factor** or the **shrinkage factor**. These factors are applied to **the fill volume** in order to determine the required quantity of fill material.

Example (1): Areas of different cross-sections of pavement earthwork are as shown below. Find the volume of the earthwork using prismoidal formula?

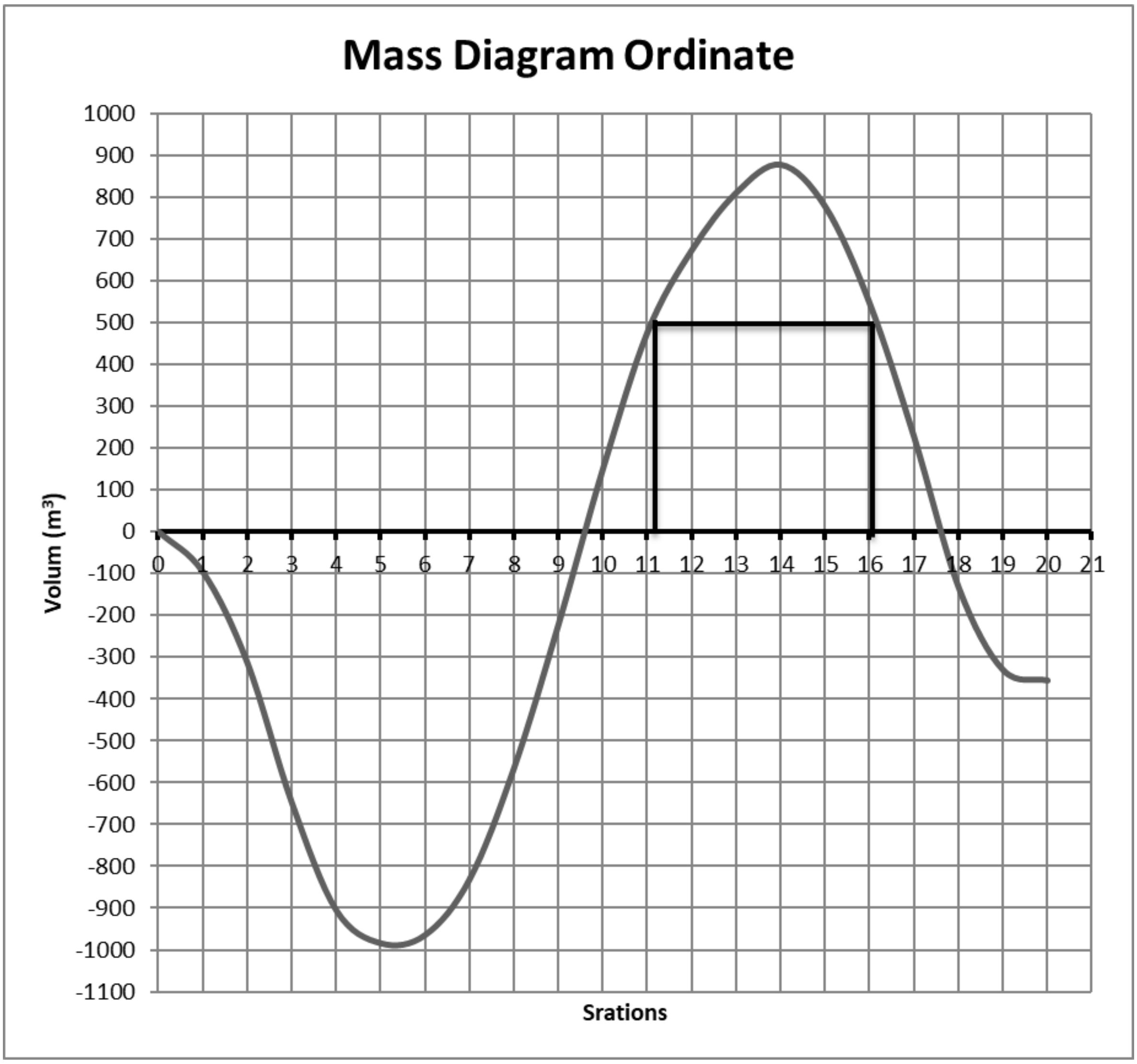
Distance (m)	450	455	460	465	470	475	480	485	490
Area (m^2)	7110	6220	5120	4160	3000	1600	840	116	3

Lecture 4 – Part 2

Example: The free-haul distance in a highway construction contract is 150m and the overhaul price is $15/m^3.station. For the mass diagram shown in the previous example, determine the extra compensation that must be paid to the contractor to balance the cut and fill between balance points (B) and (C).

Station	End Areas (m^2)		Volume (m^3)						
	Cut	Fill	Total Cut	Fill	Shrinkage 10%	Total Fill	Fill (-)	Cut (+)	Mass Diagram Ordinate
0	0.3	1.7							0
			7.5	94.5	9.45	103.95	96.45		
1	0.2	4.6							-96.45
			6	202.5	20.25	222.75	216.75		
2	0.2	8.9							-313.2
			9	312	31.2	343.2	334.2		
3	0.4	11.9							-647.4
			16.5	249	24.9	273.9	257.4		
4	0.7	4.7							-904.8
			66	132	13.2	145.2	79.2		
5	3.7	4.1							-984
			117	88.5	8.85	97.35		19.65	
6	4.1	1.8							-964.35
			171	34.5	3.45	37.95		133.05	
7	7.3	0.5							-831.3
			277.5	10.5	1.05	11.55		265.95	
8	11.2	0.2							-565.35
			346.5	3	0.3	3.3		343.2	
9	11.9	0							-222.15
			372	0	0	0		372	
10	12.9	0							149.85
			331.5	4.5	0.45	4.95		326.55	
11	9.2	0.3							476.4
			247.5	46.5	4.65	51.15		196.35	
12	7.3	2.8							672.75
			213	69	6.9	75.9		137.1	
13	6.9	1.8							809.85
			172.5	96	9.6	105.6		66.9	
14	4.6	4.6							876.75
			96	178.5	17.85	196.35	100.35		
15	1.8	7.3							776.4
			40.5	247.5	24.75	272.25	231.75		

16	0.9	9.2							544.65
			13.5	303	30.3	333.3	319.8		
17	0	11							224.85
			4.5	330	33	363	358.5		
18	0.3	11							-133.65
			60	234	23.4	257.4	197.4		
19	3.7	4.6							-331.05
			100.5	114	11.4	125.4	24.9		
20	3	3							-355.95



Solution:

Over haul volume = 500 m^3

From station 9.6 – 11.2

1. From 9.6 -10 ----- 150 m^3

6 + 30 + 6 = 42 m = 1.4 station

2. 10 – 11 ----- 475-150 = 325 m^3

15 + 6 = 21 m = 0.7 station

3. 11 – 11.2 ----- 500 – 475 = 25 m^3

   3 m = 0.1 station

Overhaul distance moved between station 9.6 – 11.2

= [(150 x 42) + (325 x 21) + (25 x 3)] / 500 = [6300 + 6825 + 75] / 500 = 26.4 m = 0.88 station

Overhaul cost = contract price ($/$m^3$ station) x overhaul (m^3) x stations

= 15 x 500 x 0.88 = $6600

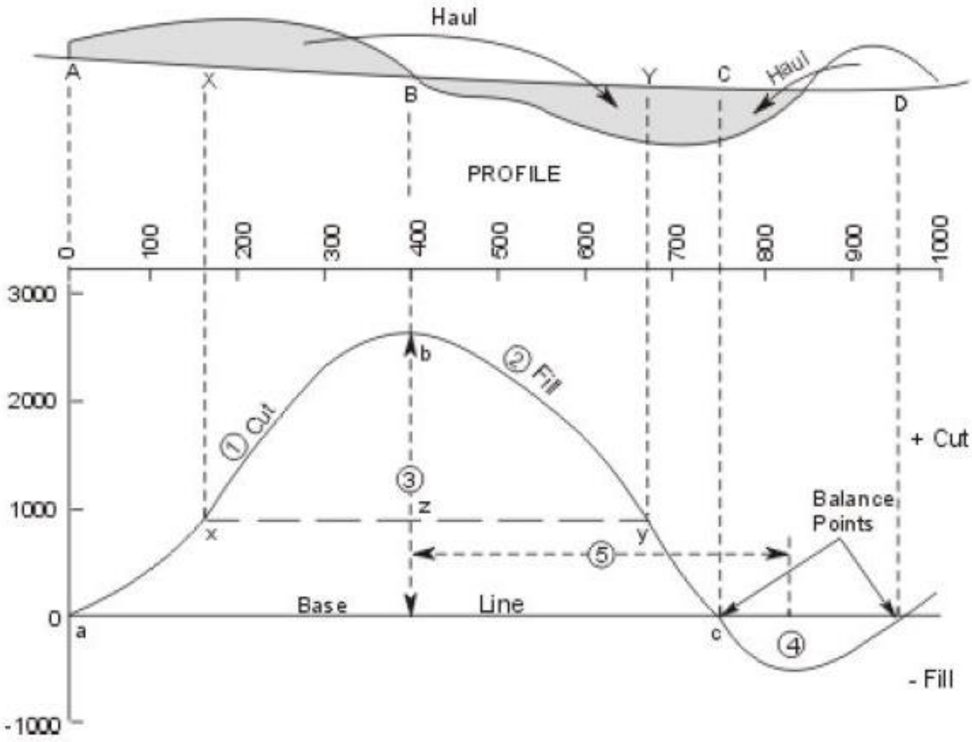
Lecture 4

Example: A roadway section is 600m long (20 stations). The cut and fill volumes are to be computed between each station. Table below lists the station numbers (column 1) and lists the end area values (m^2) between each station that are in cut (column 2) and that are in fill (column 3). Material in a fill section will consolidate (known as shrinkage), and for this road section, is 10 percent. Determine the net volume of cut and fill that is required between stations.

Stations	End Areas (m^2)		Volume (m^3)				Net Volume (m^3)		Mass Diagram Ordinate
	Cut	Fill	Total Cut	Fill	Shrinkage 10%	Total Fill	Fill (-)	Cut (+)	
0	0.3	1.7							
1	0.2	4.6							
2	0.2	8.9							
3	0.4	11.9							
4	0.7	4.7							
5	3.7	4.1							
6	4.1	1.8							
7	7.3	0.5							
8	11.2	0.2							
9	11.9	0.0							
10	12.9	0.0							
11	9.2	0.3							
12	7.3	2.8							
13	6.9	1.8							
14	4.6	4.6							
15	1.8	7.3							
16	0.9	9.2							
17	0.0	11.0							
18	0.3	11.0							
19	3.7	4.6							
20	3	3							

Distribution of Earthwork Quantities:

Mass-Haul Diagram: Is a graphical representation of the amount of the earthworks involved in a highway scheme.



Interpretation of the mass diagram

1- When the mass diagram slopes downward (negative), the preceding section is in fill, and when the slope is upward (positive), the preceding section is in cut.

2- The ordinate at any station along the mass diagram indicates the earthwork quantity accumulated up to that point, and it is the summation of the differences between cut and fill.

3- A horizontal line on the mass diagram defines the locations where the net accumulation between these two points is zero. These are referred to as "***balance points***," because there is a balance in cut and fill volumes between these points.

4- The maximum and minimum points of a mass diagram (MD) occur directly beneath the intersection of the natural ground and the formation grade; such intersections are called *grade points*.

5- The maximum ordinate (+) indicates a change from cut to fill, whilst the minimum ordinate (−) represents a change from fill to cut.

6- Steeply rising (or falling) curves indicate major cuts (or fills), whereas flat curves show that the earthworks quantities are small.
7- The shapes of the mass-haul loops indicate the directions of haul. Thus, a convex loop shows that the haul from cut to fill is from left to right, whilst a concave loop indicates that the haul is from right to left.
8- When the earth excavation and embankment quantities balance at the end of the section, the mass diagram curve would end at the baseline at the zero point.

Haul

This term is commonly used to refer to the distance over which material is transported. Also, it is used to describe the volume-distance of material moved.

Free-haul distance (F.H.D): The distance for which there is no additional charge for moving the earthworks. The contractor is paid a fixed amount per cubic metre, irrespective of the actual distance through which the material is moved. It can be as short as 150m for small roads and up to 350m on big highway projects.

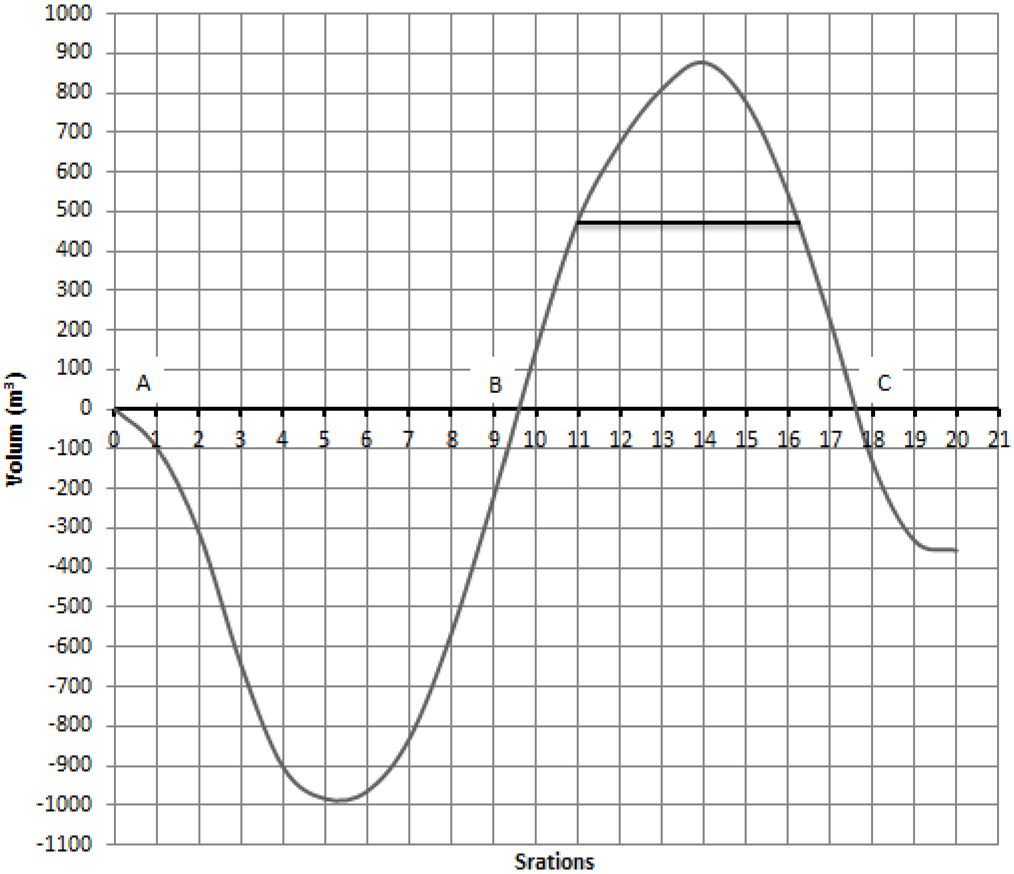
Over-haul distance (O.H.D): The extra distance beyond the free-haul distance for which there will be extra charge for moving earthworks. The unit overhaul price may be based on the cost per station-metre of moving the material beyond the free-haul distance.

Economic over-haul distance (E.O.D): It is the distance that balance the cost of borrow material per m^3, and the cost per m^3.station of over-haul.

$$E.O.D = cost\ of\ borrow\ material\ /\ cost\ of\ over-haul$$

Borrow: is an imported material, which is purchased and transported from an off-site location. The borrow cost includes the material cost plus the cost of excavating, hauling and dipping in embankment.

Example: The free-haul distance in a highway construction contract is 150m and the overhaul price is \$15/m^3.station. For the mass diagram shown in the previous example, determine the extra compensation that must be paid to the contractor to balance the cut and fill between balance points (B) and (C).



1000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
Volum (m³)
A
B
C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Srations

Lecture 5

Alignment and Superelevation

A. Horizontal alignment

The operational characteristics of a roadway are directly affected by its alignment. The alignment, in turn, affects vehicle operating speeds, sight distances, and highway capacity. The horizontal alignment is influenced by many factors including:

- Terrain
- Functional classification
- Design speed
- Traffic volume
- Right-of-way availability
- Anticipated level of service

The horizontal alignment must provide a safe, functional roadway facility that provides adequate sight distances within economic constraints. The alignment must adhere to specific design criteria such as minimum radii, superelevation rates, and sight distance. These criteria will maximize the overall safety of the facility and enhance the aesthetic appearance of the highway. The curves allow for a smooth transition between the tangent sections. Circular curves and spirals are two types of horizontal curves utilized to meet the various design criteria.

1. Circular Curves

The most common type of curve used in a horizontal alignment is a simple circular curve. A circular curve is an arc with a single constant radius connecting two tangents. A compound curve is composed of two or more adjoining circular arcs of different radii. The centers of the arcs of the compound curves are located on the same side of the alignment. The combination of a short length of tangent between two circular curves is referred to as a broken-back curve. A reverse curve consists of two adjoining circular arcs with the arc centers located on opposite sides of the alignment. Compound and reverse curves are generally used only in specific design situations such as mountainous terrain.

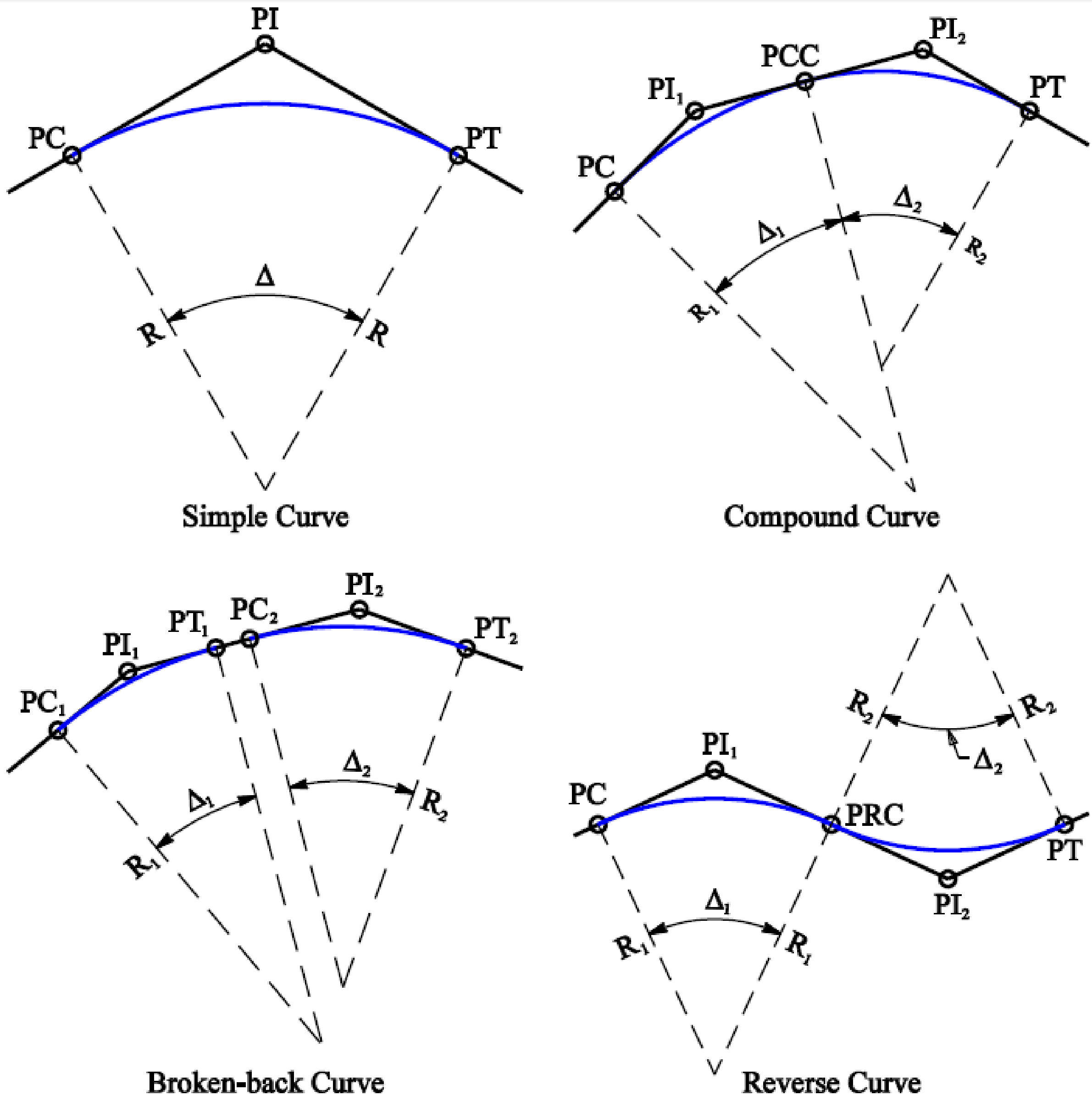


Figure 5-1: Circular curves

Figure 5-1 illustrates four examples of circular curves. The tangents intersect one another at the point of intersection (PI). The point at which the alignment changes from a tangent to circular section is the point of curvature (PC). The point at which the alignment changes from a circular to a tangent section is the point of tangency (PT). The point at which two adjoining circular curves turning in the same direction meet is the point of compound curvature (PCC). The point at which two adjoining circular curves turning in opposite directions meet is the point of reverse curvature (PRC).

Figure 5-2 is an illustration of the standard components of a single circular curve connecting a back and forward tangent. The distance from the PC to the PI is defined by the tangent distance (T). The length of the circular curve (L) is dependent on the central angle (Δ) and the radius (R) of the curve. Since the curve is symmetrical about the PI, the distance from the PI to the PT is also defined by the tangent distance (T). A line connecting the PC and PT is the long chord (LC). The external distance (E) is the distance from the PI to the midpoint of the curve. The middle ordinate (M) is the distance from the midpoint of the curve to the midpoint of the long chord.

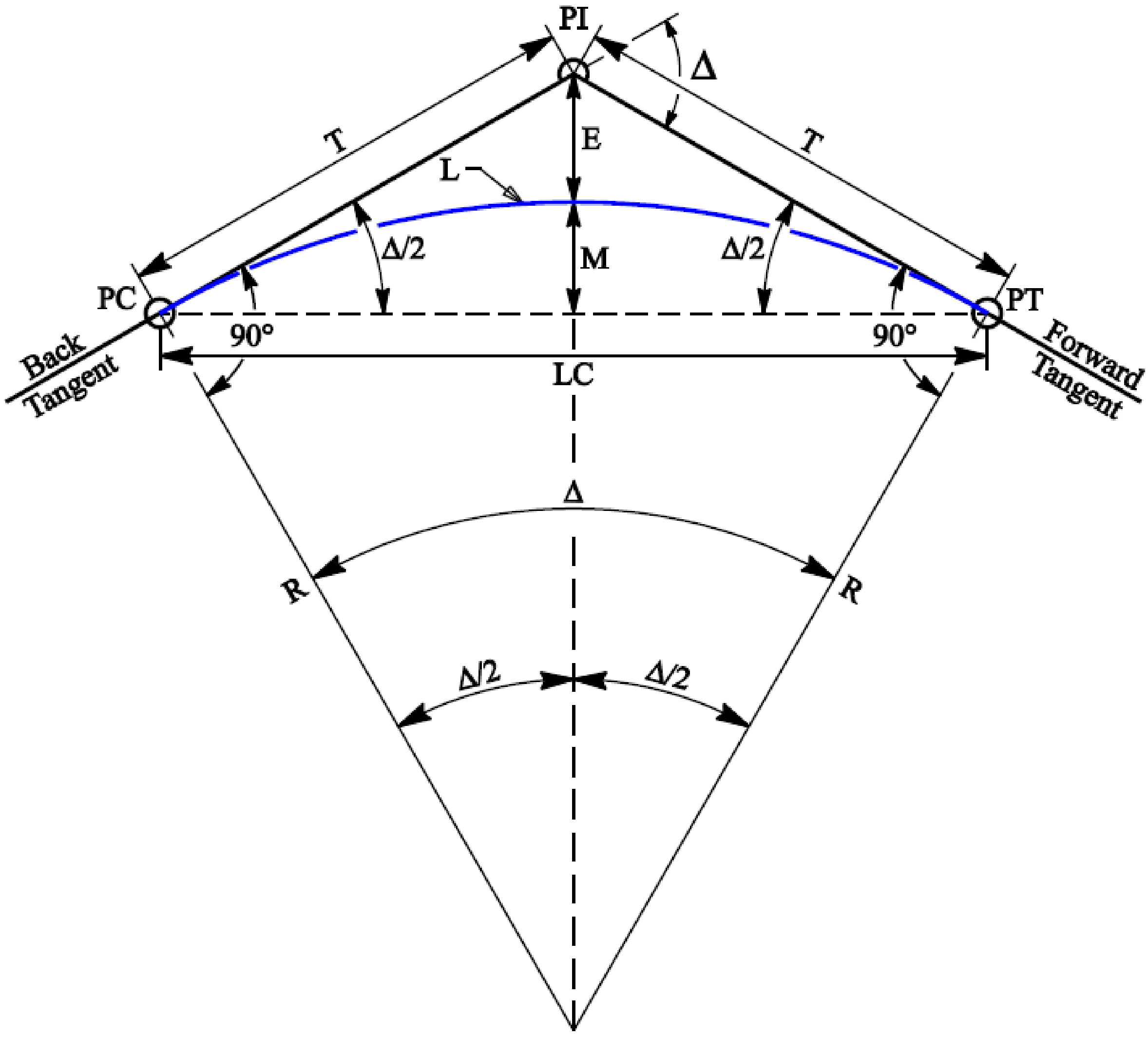


Figure 5-2: Circular curve components

Using the arc definition for a circular curve, the degree of curvature is the central angle (D) subtended by a 100 ft arc. A circle has an internal angle of 360° and a circumference of 2πR. Refer to Figure 5-3 for an illustration of the degree of curvature within a circle. The relationship between the central angle and the radius for a given circular curve is:

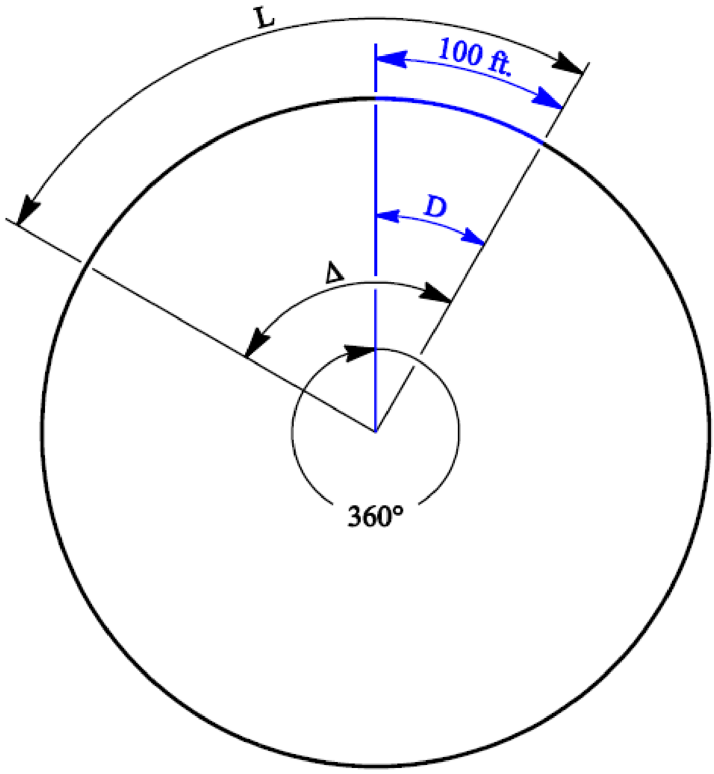


Figure 5-3: Degree of curvature

$$\frac{D}{360°} = \frac{100\,ft}{2\pi R};\ D = \frac{(100\,ft)(360°)}{2\pi R} = \frac{5729.58\,ft}{R}$$

$$\frac{\Delta}{360°} = \frac{L}{2\pi R};\ \Delta = \frac{L * 360°}{2\pi R} = \frac{L * 180°}{\pi R};\ L = \frac{\Delta \pi R}{180°}$$

General Circular Curve Formulas:

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

$$L = \frac{100\Delta R}{5729.58} = \frac{100\Delta}{D}$$

$$LC = 2R\sin\frac{\Delta}{2}$$

$$E = \frac{R}{\cos\frac{\Delta}{2}} - R$$

$$M = E\cos\frac{\Delta}{2}$$

Stationing:

$$Sta.PC = Sta.PI - T$$

$$Sta.PT = Sta.PC + L$$

Example (1):

Given: Sta. PI = 100+00 Find: Sta. PT

Radius = 4200, Δ=27°

Lecture 6

2. Spiral Curves

Spiral curves are used in horizontal alignments to provide a gradual transition between tangent sections and circular curves. While a circular curve has a radius that is constant, a spiral curve has a radius that varies along its length. The radius decreases from infinity at the tangent to the radius of the circular curve that intended to meet.

A vehicle entering a curve must transition from a straight line to a fixed radius. To accomplish this, the vehicle travels along a path with a continually changing radius. Consequently, a spiral will more closely duplicate the natural path of the turning vehicle. If the curvature of the alignment is not excessively sharp, the vehicle can usually traverse this spiral within the width of the travel lane. When the curvature is relatively sharp for a given design speed, it may become necessary to place a spiral transition at the beginning and end of the circular curve. The spirals allow the vehicle to more easily transition into and out of a curve while staying within the travel lane.

Figure 5-1 illustrates the standard components of a spiral curve connecting tangents with a central circular curve. The back and forward tangent sections intersect one another at the PI. The alignment changes from the back tangent to the entrance spiral at the TS point. The entrance spiral meets the circular curve at the SC point. The circular curve meets the exit spiral at the CS point. The alignment changes from the exit spiral to the forward tangent at the ST point. The entrance and exit spiral at each end of the circular curve are geometrically identical.

The length of the circular curve (L_C) is dependent on its central angle (Δ_C) and radius (R). The central angle (Δ) of the spiral-curve-spiral combination represents the deflection angle between the tangent sections. When spirals are placed at either end of the circular curve, the length of the curve is shortened. Instead of extending from the PC to the PT, the curve now extends from the SC to the CS. The offset distance or throw distance (T) represents the perpendicular distance from the back (or forward) tangent section to a tangent line extending from the PC (or PT) points. The length of the spiral (L_S) is typically determined by design speed and superelevation rates. The total length (L) of the spiral-curve-spiral combination is the sum of the length of curve (L_C) and the length of both spirals (L_S).

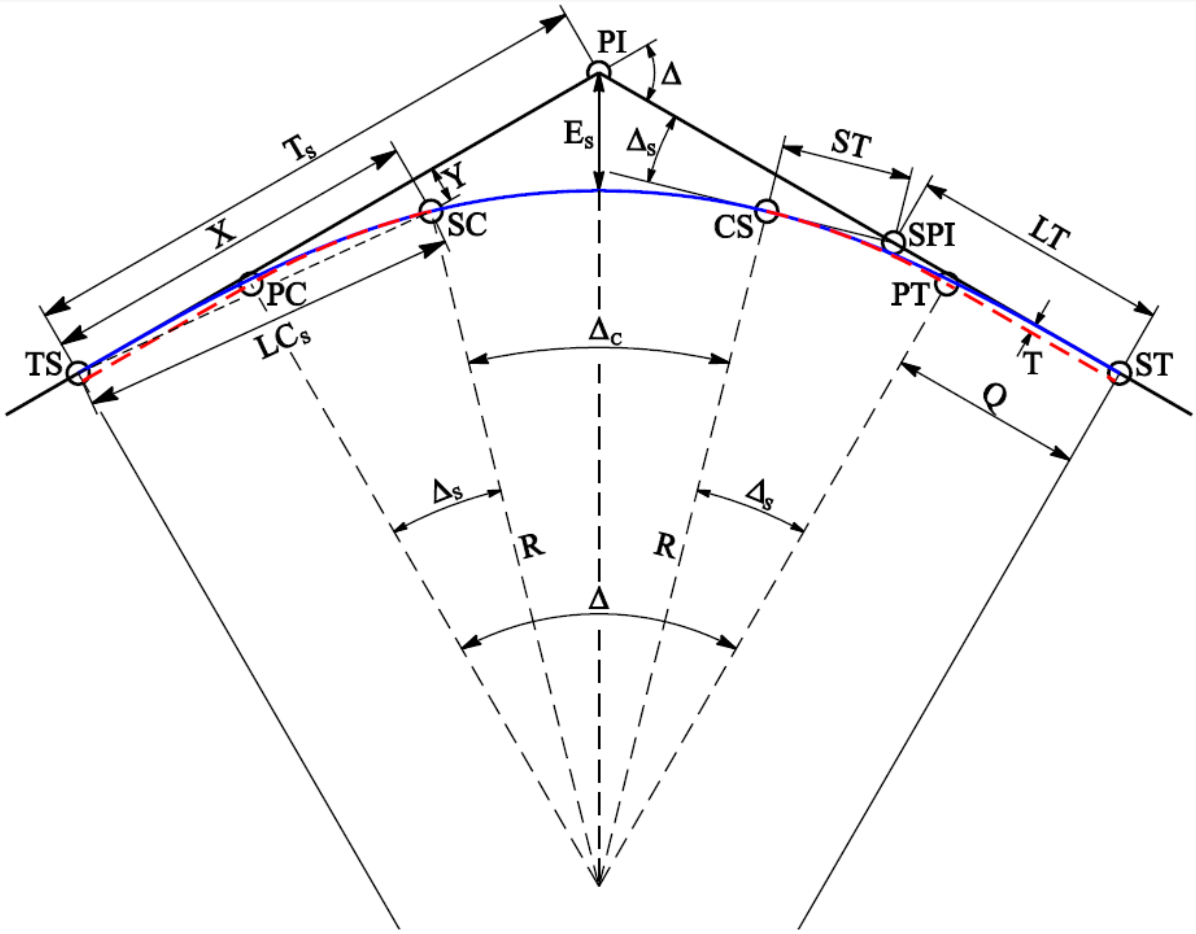


Figure 5-1: Spiral curve components

The distance from the TS to the PI is defined by the tangent distance (T_S). The external distance (E_S) is the distance from the PI to the midpoint of the circular curve. A line connecting the TS and SC (or the CS to the ST) is the long chord (LC_S) of the spiral. The Q dimension is the perpendicular distance from the TS to the PC (and the PT to the ST). The X dimension represents the distance along the tangent from the TS to the SC (and the CS to the ST). The Y dimension represents the tangent offset at the SC (and the CS). The LT and ST dimensions represent the long tangent and the short tangent of the spiral. The spiral tangents intersect at the spiral point of intersection (SPI).

2.1 General Spiral Equations

The central angle of a spiral (Δs) is a function of the average degree of curvature of the spiral. In other words, Δs of a spiral is one half of the central angle (ΔC) for a circular curve of the same length and degree of curvature.

Since $\Delta_C = DL_C/100$ then $\Delta_S = DL_S/200$

$$\Delta = \Delta_C + 2\Delta_S$$

$$L = L_C + 2L_S$$

Spiral components such as X, Y, T, Q, ST, and LT are routinely found in spiral curve tables. Refer to Table D-1 for these values. These measurements are dependent on the spiral length (LS) and central angle (ΔS).

$$T_S = (R + T)\tan\frac{\Delta}{2} + Q$$

$$E_S = \frac{(R + T)}{\cos\frac{\Delta}{2}} - R$$

Stationing:

$$Sta.TS = Sta.PI - T_S$$

$$Sta.SC = Sta.TS + L_S$$

$$Sta.CS = Sta.SC + L_C$$

$$Sta.ST = Sta.CS + L_S$$

Example (1):

Given: Sta. PI = 100+00
L_S = 150 ft
Δ = 35°
D = 10°

Find: Sta. TS, Sta. SC, Sta. CS, and Sta. ST

Solution:

Table (1): Spiral table for L_S = 150 ft

D	Δ_S	R	X	Y	T	Q	LC_S	ST	LT
7° 30' 00"	5° 37' 30"	763.94	149.86	4.91	1.23	74.98	149.94	50.05	100.05
8° 00' 00"	6° 00' 00"	716.20	149.84	5.23	1.31	74.97	149.93	50.05	100.06
8° 30' 00"	6° 22' 30"	674.07	149.81	5.56	1.39	74.97	149.92	50.06	100.06
9° 00' 00"	6° 45' 00"	636.62	149.79	5.88	1.47	74.97	149.91	50.07	100.07
9° 30' 00"	7° 07' 30"	603.11	149.77	6.21	1.55	74.96	149.90	50.07	100.08
10° 00' 00"	7° 30' 00"	572.96	149.74	6.54	1.64	74.96	149.89	50.08	100.09
10° 30' 00"	7° 52' 30"	545.67	149.72	6.86	1.72	74.95	149.87	50.09	100.10
11° 00' 00"	8° 15' 00"	520.87	149.69	7.19	1.80	74.95	149.86	50.10	100.11
11° 30' 00"	8° 37' 30"	498.22	149.66	7.51	1.88	74.94	149.85	50.11	100.12
12° 00' 00"	9° 00' 00"	477.46	149.63	7.84	1.96	74.94	149.84	50.12	100.13
13° 00' 00"	9° 45' 00"	440.74	149.57	8.49	2.12	74.93	149.81	50.14	100.15
14° 00' 00"	10° 30' 00"	409.26	149.50	9.14	2.29	74.92	149.78	50.16	100.18
15° 00' 00"	11° 15' 00"	381.97	149.42	9.79	2.45	74.90	149.74	50.18	100.20
16° 00' 00"	12° 00' 00"	358.10	149.34	10.44	2.61	74.89	149.71	50.21	100.23
17° 00' 00"	12° 45' 00"	337.03	149.26	11.09	2.78	74.88	149.67	50.24	100.26
18° 00' 00"	13° 30' 00"	318.31	149.17	11.73	2.94	74.86	149.63	50.27	100.29

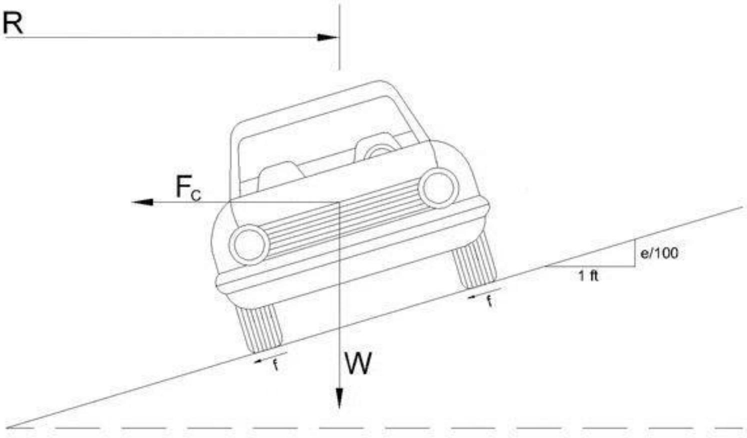
Lecture 7

B. Superelevation

Centrifugal force is the outward pull on a vehicle traversing a horizontal curve. When traveling at low speeds or on curves with large radii, the effects of centrifugal force are minor. However, when travelling at higher speeds or around curves with smaller radii, the effects of centrifugal force increase. Excessive centrifugal force may cause considerable lateral movement of the turning vehicle and it may become impossible to stay inside the driving lane.

Superelevation and side friction are the two factors that help stabilize a turning vehicle. Superelevation is the banking of the roadway such that the outside edge of pavement is higher than the inside edge. The use of superelevation allows a vehicle to travel through a curve more safely and at a higher speed than would otherwise be possible. Side friction developed between the tires and the road surface also acts to counterbalance the outward pull on the vehicle. Side friction is reduced when water, ice, or snow is present or when tires become excessively worn.

The transitional rate of applying superelevation into and out of curves is influenced by several factors. These factors include design speed, curve radius, and number of travel lanes. Minimum curve radii for a horizontal alignment are determined by the design speed and superelevation rate. Higher design speeds require more superelevation than lower design speeds for a given radius. Additionally, sharper curves require more superelevation than flatter curves for a given design speed. Roadways in rural areas are typically designed with a maximum superelevation rate of 8 percent. In mountainous areas, a maximum superelevation rate of 6 percent is used due to the increased likelihood of ice and snow. Urban roadways are normally designed with a maximum superelevation rate of 4 percent. To calculate the superelevation rate, various factors acting on vehicles should be considered.



Superelevation in Highway Engineering

After substituting these factors, an equation to determine the superelevation rate can summerised as:

$$\mathbf{e + f} = \frac{V^2}{gR}$$

Where:

e= the superelevation rate, (%),

f= lateral friction factor, usually 0.15 (if not given),

V= Speed of vehicle, (m/s)

g= acceleration due to gravity = 9.81 m/s^2,

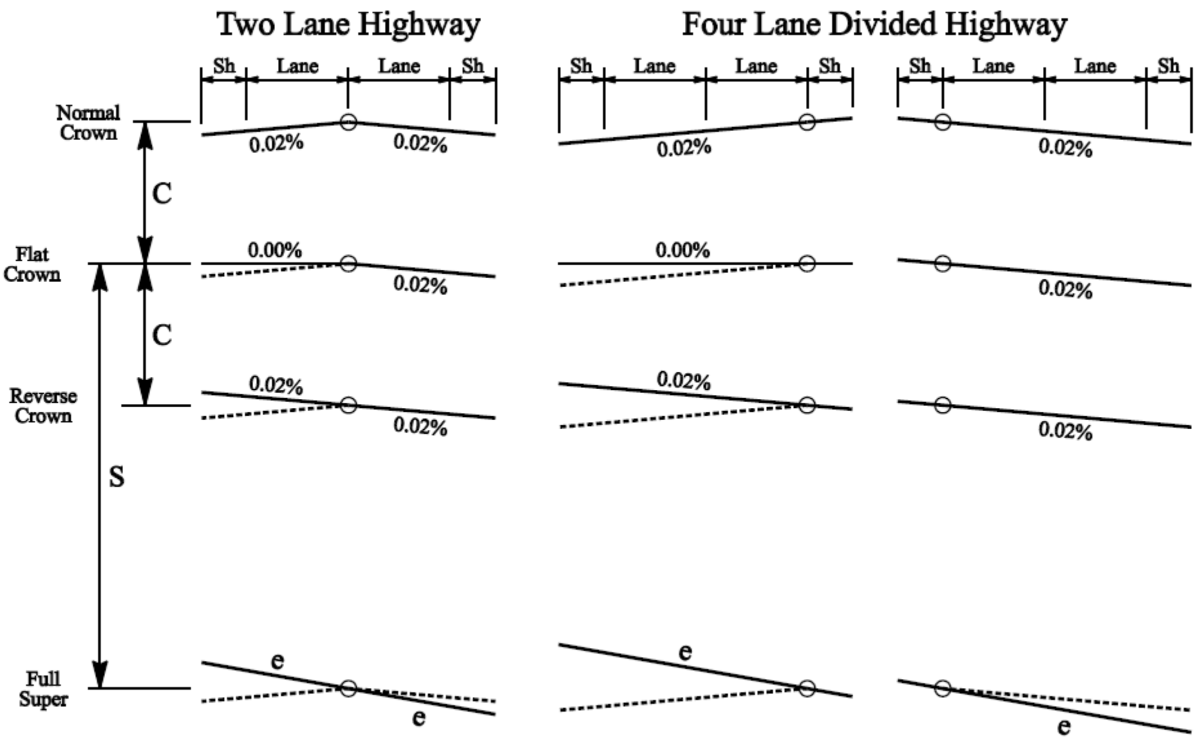
R= radius of curve, in meters.

If the speed is in Km/hr, then

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

Ex: Design a superelevation rate necessary for 75% design speed, assuming icy road where no lateral friction is developed.

Superelevation rotation



- The length of crown runoff (C) is the distance required for the outside lane(s) to transition from a normal crown to a flat crown. It is also the distance for the outside lane(s) to transition from a flat crown to a reverse crown.
- The length of the superelevation runoff (S) is the distance required for the transition from a flat crown to the full superelevation rate (e).
- The values of C and S are determined from superelevation tables for various combinations of design speed and degree of curvature located on Roadway Design Manual.

Lecture 8

2. Vertical Curves

Vertical curves are needed to provide smooth transitions between straight segments (tangents) of grade lines for highways and railroads in vertical planes (see figure below).

Two basic types of vertical curves exist, crest and sag. Crest type undergoes a negative change in grade; that is, the curve turns downward. Sag type undergoes a positive change in grade; that is, the curve turns upward. There are several factors that must be taken into account when designing a grade line of tangents and curves on any highway or railroad project. They include:

- Providing a good fit with the existing ground profile, thereby minimizing the depths of cuts and fills,
- Balancing the volume of cut material against fill,
- Maintaining adequate drainage,
- Not exceeding maximum specified grades, and
- Meeting fixed elevations such as intersections with other roads.

In addition, the curves must be designed to:

• Fit the grade lines they connect,

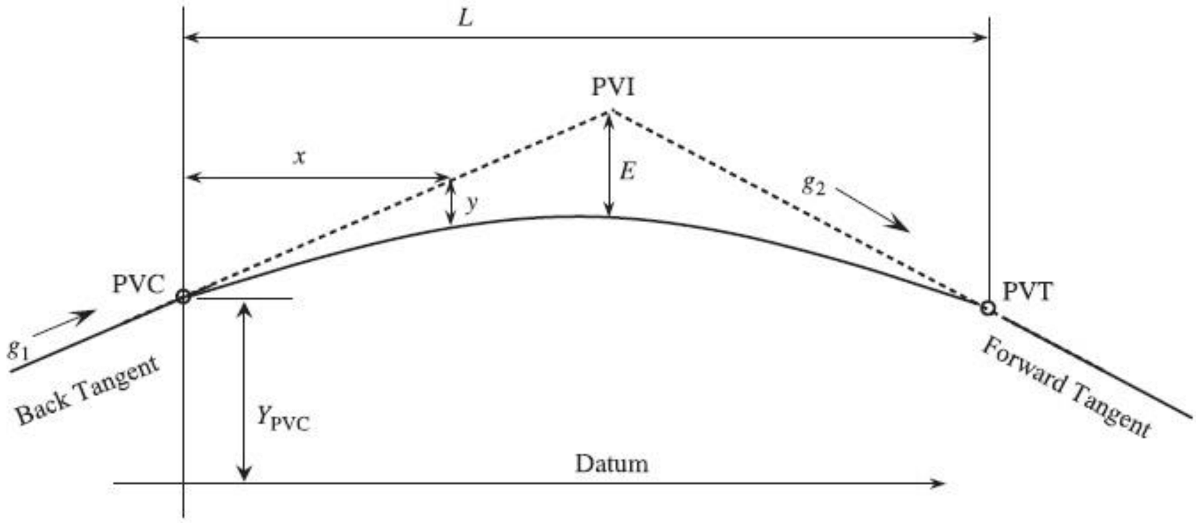
• Have lengths sufficient to meet specifications covering a maximum rate of change of grade (which affects the comfort of vehicle occupants), and

• Provide sufficient sight distance for safe vehicle operation.

Equation of an Equal Tangent Vertical Curve

Figure below shows a parabola that joins two intersecting tangents of a grade line. The parabola is essentially identical to that in this figure, except that the terms used are those commonly employed by surveyors and engineers.

In the figure, PVC denotes the point of vertical curve, VPI is the vertex, often called vertical point of intersection; and PVT is the point of vertical tangency. The percent grade of the back tangent (straight segment preceding PVI) is g_1, and that of the forward tangent (straight segment following PVT) is g_2. The curve length L is the horizontal distance (in stations) from the PVC to the PVT. The curve in the figure is called equal tangent because the horizontal distances from the PVC to PVI and from PVI to the PVT are equal, each being L/2. On the xy axis system, x values are horizontal distances measured from the PVC, and y values are elevations measured from the vertical datum of reference. The following formulas can be derived from the above figure using trigonometry:



distances measured from the PVC, and y values are elevations measured from the vertical datum of reference. The following formulas can be derived from the above figure using trigonometry:

The general equation of parabola is $Y = c + bx + ax^2$

Now, let us find out how this equation can be applied to a vertical curve. First of all, when $x = 0$, $Y = c$. That means $c = Y_{PVC}$ (i.e., the elevation of the PVC) as $x = 0$ at the PVC.

Now let us find out b and a. On differentiation of the above equation,

$$\frac{d(Y)}{dx} = \frac{d}{dx}(c + bx + ax^2)$$

$$\frac{dY}{dx} = 0 + b + 2ax = b + 2ax$$

Now recall that $\frac{dY}{dx}$ means the slope of the curve at x. When $x = 0$, $\left.\frac{dY}{dx}\right|_{x=0} = b + 2a(0) = b$

That means, slope at $x = 0$ (at the PVC) is b, i.e., $b = g_1$.

Differentiating the equation one more time, $\frac{d}{dx}\frac{d(Y)}{dx} = \frac{d}{dx}(b + 2ax)$

$$\text{Or, } \frac{d}{dx}\frac{dY}{dx} = 2a$$

The above second-differentiation means the rate of change of slope $= 2a$

$$\text{i.e., } \frac{\text{Change in slope}}{L} = 2a$$

$$\text{or, } \frac{g_2 - g_1}{L} = 2a$$

$$\text{Therefore, } a = \frac{g_2 - g_1}{2L}$$

Finally, the equation of the parabolic vertical curve can be written as:

$$Y = Y_{PVC} + g_1 x + ax^2 = Y_{PVC} + g_1 x + \left[\frac{g_2 - g_1}{2L}\right]x^2$$

Some additional features can be derived as follows:

Horizontal distance to min or max elevation on curve, $x_m = -\frac{g_1}{2a} = \frac{g_1 L}{g_1 - g_2}$

Tangent elevation $= Y_{PVC} + g_1 x$ and $= Y_{PVI} + g_2\left(x - \frac{L}{2}\right)$

Coefficient, $a = \frac{g_2 - g_1}{2L}$

Tangent offset at PV, $E = a\left(\frac{L}{2}\right)^2$

Rate of change of grade, $r = \frac{g_2 - g_1}{L}$

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

Station of PVC = Station of PVI − $L/2$
Station of PVT = Station of PVI + $L/2$

Elevation of PVC = Elevation of PVI − $g_1\ (L/2)$
Elevation of PVT = Elevation of PVI + $g_2\ (L/2)$

where L = Length of curve
PVC = Point of vertical curvature
PVI = Point of vertical intersection
PVT = Point of vertical tangency
g_1 = Grade of back tangent (decimal)
g_2 = Grade of forward tangent (decimal)
x = Horizontal distance from PVC to point on curve
a = Parabola constant
y = Tangent offset
A = Absolute value of algebraic difference in grades (%)
E = Tangent offset at PVI $= \frac{AL}{800}$
r = Rate of change of grade
K = Rate of vertical curvature

Example : Tangent Slope of Sag Vertical Curve A sag vertical curve connects −2.3% and +3% tangents, and has a curve length of 300 ft. The station of the PVC is 12 + 00. Determine the tangent slope at station 14 + 00.

Solution

Length of curve, $L = 300$ ft
Grade of back tangent, $g_1 = -2.3\% = -0.023$
Grade of forward tangent, $g_2 = 3.0\% = 0.03$
Distance to the point of concern, x = station (14 + 00) − station (12 + 00) = 200 ft

$$Y = Y_{PVC} + g_1 x + \left[\frac{g_2 - g_1}{2L}\right] x^2$$

$$\frac{d}{dx}(Y) = \frac{d}{dx}\left(Y_{PVC} + g_1 x + \left[\frac{g_2 - g_1}{2L}\right] x^2\right)$$

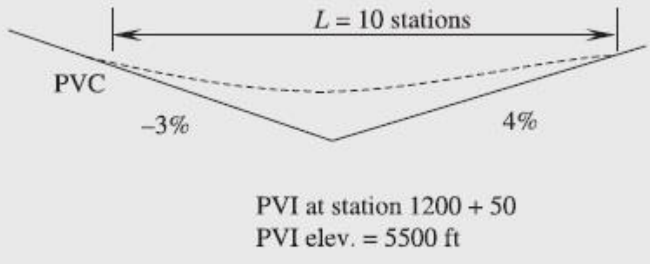
$$\frac{dY}{dx} = 0 + g_1 + 2\left(\frac{g_2 - g_1}{2L}\right) x$$

$$\frac{dY}{dx} = g_1 + \left(\frac{g_2 - g_1}{L}\right) x$$

$$\left.\frac{dY}{dx}\right|_{x=200\text{ ft}} = -0.023 + \left(\frac{0.03 - (-0.023)}{300}\right)(200\text{ ft}) = 0.0123 = 1.23\%$$

Answer *The tangent slope at station 14 + 00 is 1.23%.*

Example : Parameters of Vertical Curve In a vertical curve, a back tangent with a −3% grade meets at station 1200 + 50 with a forward tangent of 4%, as shown in Fig. 19.28.



Calculate the horizontal distance to the lowest point of the sag curve, and the tangent offset at the PVI.

Solution

Length of curve, $L = 10$ stations
Grade of back tangent, $g_1 = -3\% = -0.03$

Grade of forward tangent, $g_2 = 4.0\% = 0.04$

$$x_m = \frac{g_1 L}{g_1 - g_2} = \frac{-0.03(10 \text{ stations})}{-0.03 - 0.04} = 4.29 \text{ stations} \approx 4.3 \text{stations}$$

Absolute value of algebraic difference in grades (%), $A = |g_2 - g_1| = |4 - (-3)| = 7$

$$E = \frac{AL}{800} = \frac{7(10 \text{ stations})}{800} = 0.088 \text{ station} = 0.088 \text{ station}\left(100 \frac{\text{ft}}{\text{station}}\right) = 8.8 \text{ ft}$$

Answers *The horizontal distance to the lowest point of the sag curve is 4.3 stations and the tangent offset at the PVI is 8.8 ft.*

Highway Engineering

Lecture 9:

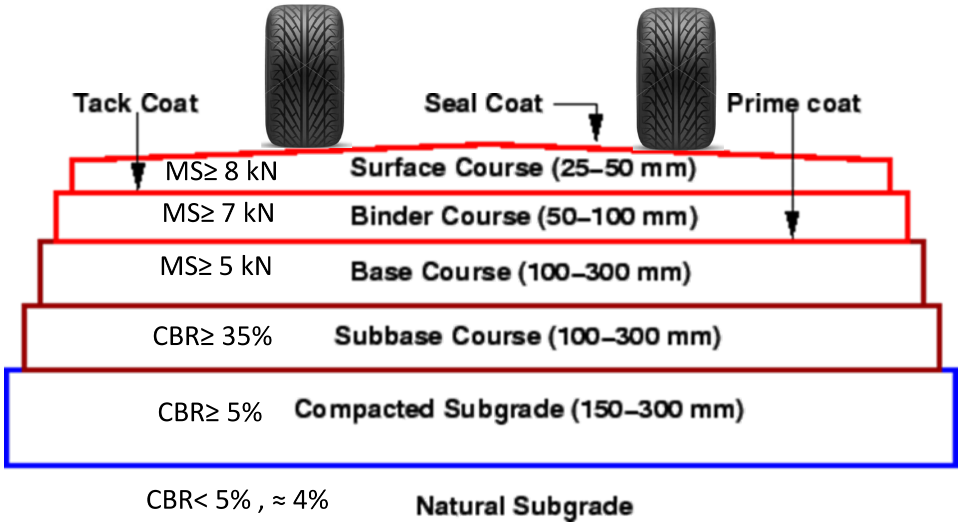
Pavement Materials

Dr. Hayder Kamil Shanbara
Department of Civil Engineering / College of Engineering
Al-Muthanna University

2020-2021

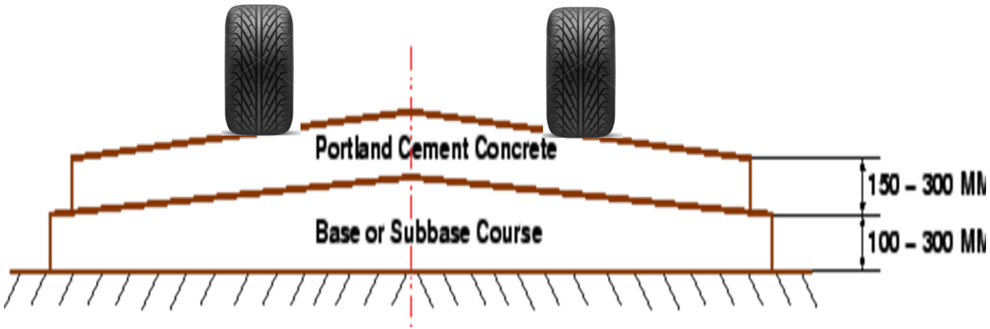
Flexible Pavement Layers

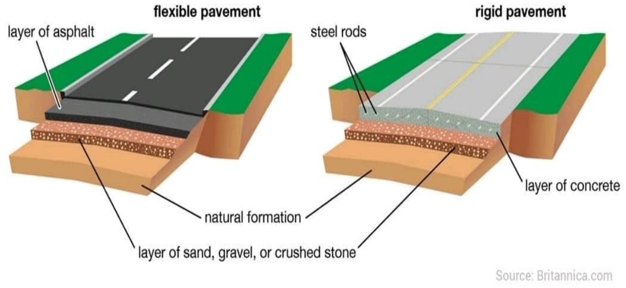
- Surface (Wearing) course, binder course and base course are made of asphalt mixes but with different gradation for each course.
- Base course could be asphalt mixture or crushed stone
- Subbase is quality gradation soil
- Subgrade is natural soil with improvement (normally compaction)

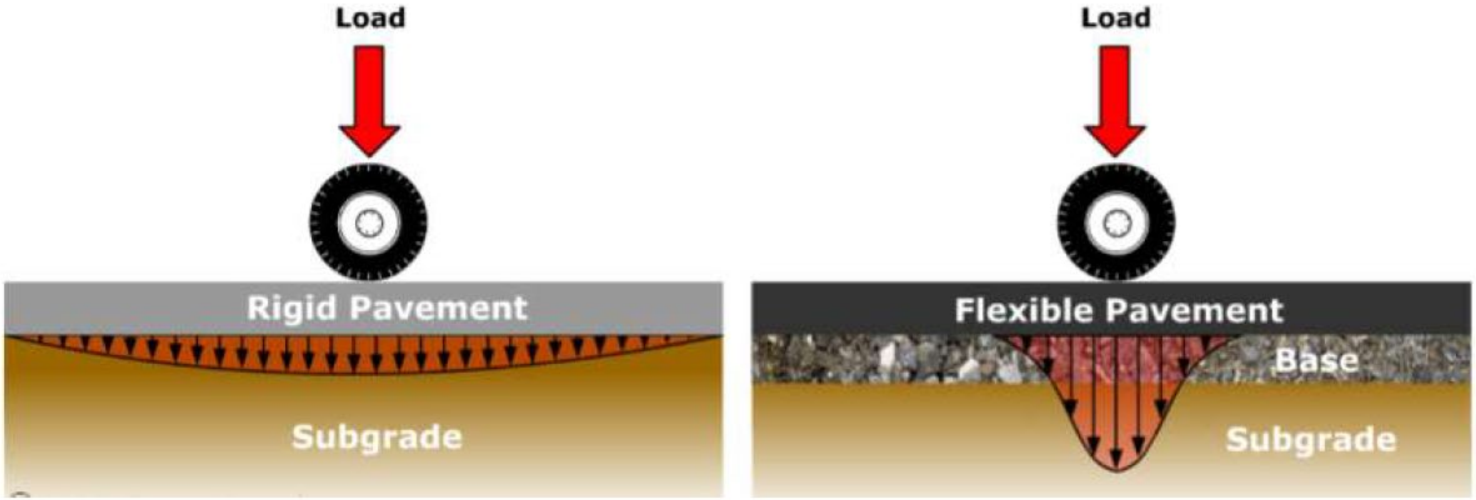


Rigid Pavement Layers

- Concrete panels are made of quality concrete
- Base or Subbase course could be quality gradation soil
- Subgrade is natural soil with improvement (normally compaction)



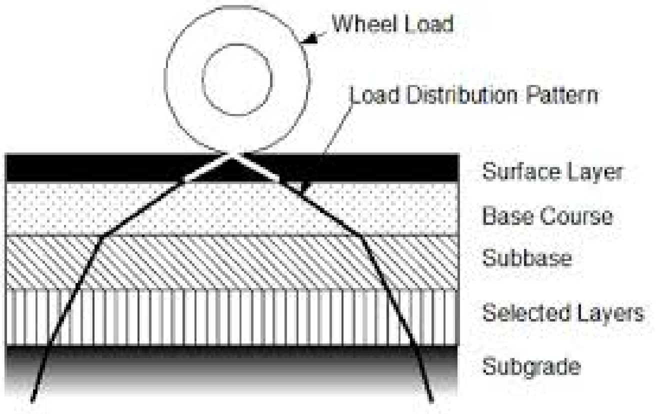




Stresses distribution under rigid and flexible pavements

The Materials used in the construction of the pavement are:

1. Soil
2. Aggregates
3. Bituminous binders (for flexible pavement)
4. Portland cement (for rigid pavement)
5. Additives (optional)



The main functions of a road pavement are:

- To distribute the traffic load over subgrade soil.
- To provide a good riding surface.
- To protect subgrade soil from the adverse climatic effects.

1. Soil:

Soil: is a complex material produced by the weathering of the solid rock. It is the uncemented deposits of mineral and/or organic particles of fragments covering large portions of the earth's crust. It is the foundation material for the highways. Undisturbed soil beneath the pavement is called natural subgrade. Compacted subgrade is the soil compacted by controlled movement of heavy compactors.

In order to attain the above objectives of a road pavement, soil should have the following desirable properties:

1. **Adequate stability** or resistance to permanent deformation under traffic loads.
2. **Incompressibility** to prevent differential settlement.
3. **Ease of compaction** to attain higher dry densities and strength.
4. **Good drainage** to avoid excessive water retention and to reduce freezing and thawing action.
5. **Permanency of strength** to retain the desired subgrade support for the pavement structure.
6. **Minimum variations in volume** and stability to withstand adverse climatic and ground water conditions.

According to the State Commission of Roads and Bridges (SCRB) the properties of the suitable soils for embankment construction are:

- The **Dry Unit Weight** of natural ground shall comply with minimum **88%** of that determined by AASHTO TI 80-74 (Modified AASHTO Compaction Test) up to the depth **25cm**.
- Subgrade soil **compaction** (the active soil layer) **30 cm below** the formation level in all parts of the embankment and cut areas throughout the whole length and width of section shall be **not less than 95%.**
- The minimum **CRB shall be 5** at 95% of the maximum density.
- Liquid limit and plasticity index should be less than **55% & 30%,** respectively.
- Dry unit weight in modified compaction is greater than **1.70** g/cm^{3}

Soil stabilization:

Soil is one of nature's most abundant construction materials. Almost all construction is built with or upon soil.

When unsuitable construction conditions are encountered, a contractor has four options:

(1) Find a new construction site
(2) Redesign the structure so it can be constructed on the poor soil
(3) Remove the poor soil and replace it with good soil
(4) Improve the engineering properties of the site soils

In general, options 1 and 2 tend to be impractical today, while in the past, option 3 has been the most commonly used method. However, due to improvement in technology coupled with increased transportation costs, option 4 is being used more often today and is expected to dramatically increase in the future.

Soil stabilization is the treatment of natural soil to improve its engineering properties

There are many advantages to soil stabilization:

1. Stabilized soil functions as a working platform for the project
2. Stabilization waterproofs the soil
3. Stabilization improves soil strength
4. Stabilization helps reduce soil volume change due to temperature or moisture
5. Stabilization improves soil workability
6. Stabilization reduces dust in work environment
7. Stabilization upgrades marginal materials
8. Stabilization improves durability
9. Stabilization dries wet soils
10. Stabilization conserves aggregate materials
11. Stabilization reduces cost
12. Stabilization conserves energy

Soil stabilization can be achieved by:

1. Mechanical stabilization

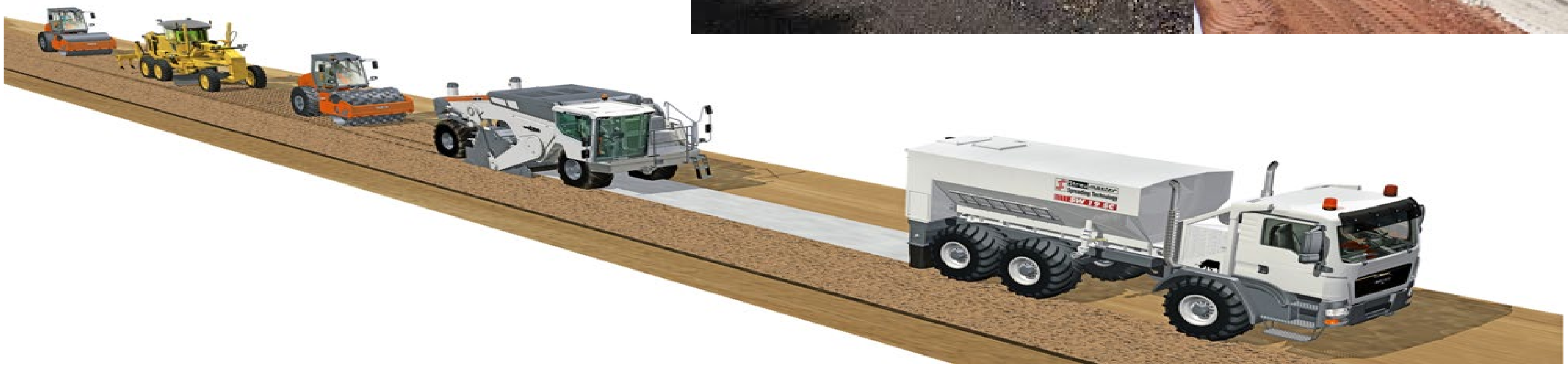
Mechanical soil stabilization refers to either compaction or the introduction of fibrous and other non-biodegradable reinforcement to the soil. There are several methods used to achieve mechanical stabilization:

- **Compaction**
- **Soil Reinforcement**
- **Addition of Graded Aggregate Materials**

2. Chemical stabilization

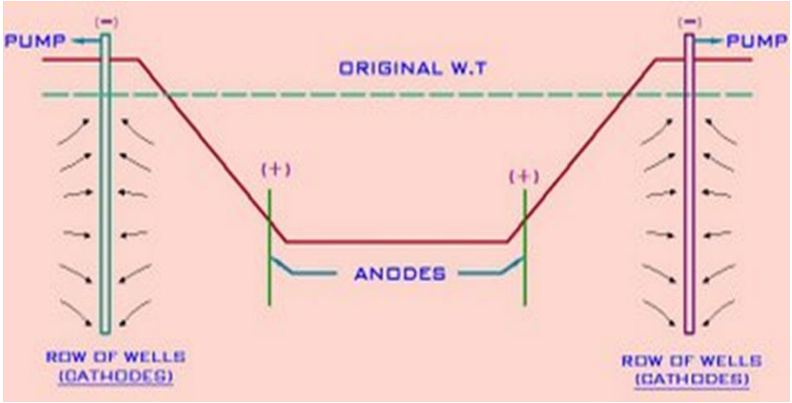
Improving the engineering properties of soil by adding chemicals or other materials to improve the existing soil, these materials or additives such as:

- **Portland Cement**
- **Quicklime/Hydrated Lime**
- **Fly Ash**
- **Calcium Chloride**
- **Bitumen**
- **Chemical or Bio Remediation**



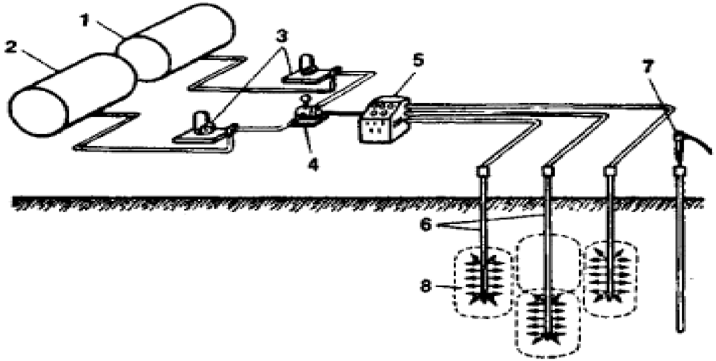
3. Electrical stabilization

Electrical stabilization of cohesive soil is performed using a process known as Electro-osmosis. A direct current (D.C) is supplied through clayey soil to migrate pore water to negative electrode (cathode). The strength of such soil is increased substantially as water is removed from it.



4. Thermal stabilization

Thermal methods of foundation soil stabilization, freezing or heating, are complex and their costs are high.



2. Subbase Course

The sub-base is the first layer constructed over the subgrade (formation level). Materials of subbase layer must consist of: **sand, gravel or sand-gravel mixture**.

The sub-base performs the following basic functions:

1. It reduces the loads, transfers and distributes them to the subgrade.
2. It eases the traffic of the worksite vehicles during construction.
3. It protects the base course materials from contamination from soil material (clay, silt, organic materials, etc.).
4. It acts as an anti-frost protective layer (prevent the capillary action) in cases where soil material is frost susceptible.
5. It reduces the intrusion of fines (typically micron-size mineral mater) from the subgrade in the rigid pavement.

Requirements According to the State Commission of Roads and Bridges (SCRB).

- **Coarse Aggregate** (that retained on 2 mm (No.10) sieve)). Coarse aggregate shall consist of hard, durable particles or fragments of gravel free from dirt and other objectionable matter. It shall have a percentage of wear not exceeding 45.
- **Fine aggregate** (passing the 2mm sieve), it shall consist of sharp natural sand or a well graded mixture of sharp natural sand, silt, clay and stone dust. It shall not contain more than 2% of organic matter. The material passing the 0.425 mm (No.40) sieve has a L.L & P.I as 25% , 6% respectively.
- Soluble salts shall not be more 10 % with a maximum dilution of 1:50. The sulphate content in terms of SO3 shall not be more than 5 % by weight (i.e. gypsum content equals to 10.75 %).

The granular sub-base gradations follow the limitations of Table (1)

Selected Granular Material – Grade Requirements

US Sieve Size		Percent Passing by Weight			
mm	Alternative	Type A	Type B	Type C	Type D
75	3 in	100			
50.0	2 in	95-100	100		
25.0	1 in		75-95	100	100
9.5	3/8 in	30-65	40-75	50-85	60-100
4.75	No. 4	25-55	30-60	35-65	50-85
2.36	No. 8	16-42	21-47	26-52	42-72
0.3	No. 50	7-18	14-28	14-28	23-42
0.075	No. 200	2-8	5-15	5-15	5-20

The **California Bearing Ratio (CBR**) for the type **B, C,& D**, when tested in accordance with (ASTM D 1883) using modified compaction, shall **not be less than 35% for type B, 30% for type C, and 20% for type D,** at 95 % of the maximum density established according to AASHTO T 180 0r ASTM D 1557.

3. Aggregates

These are the basic materials of highway pavement construction. **They are not only support the main stresses occurring within the pavement but also resist wear due to abrasion by traffic as well as the effect of weathering agencies.**

Aggregate is a collective term for the **mineral materials such as sand, gravel, and crushed stone** that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete).

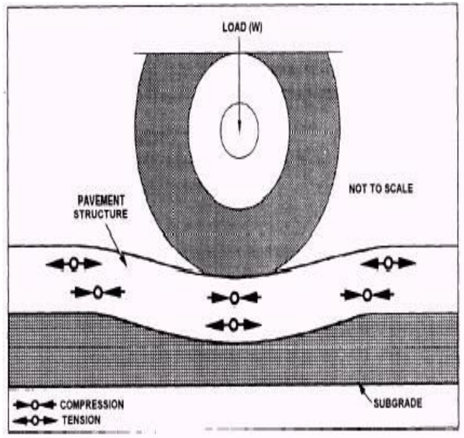
The behavior of the pavement structure depends on the **inherent properties** and **qualities of the individual particles** and on the means by which they are held together, i.e. by interlocking, by cementitious binders, or by both.

In general, the aggregates may be classified as:

(a) Natural aggregates.
(b) Artificial aggregates.

Characteristics of Good Road Aggregates

The following properties of aggregates are taken into consideration while selecting aggregates for road construction:



1. Hardness:

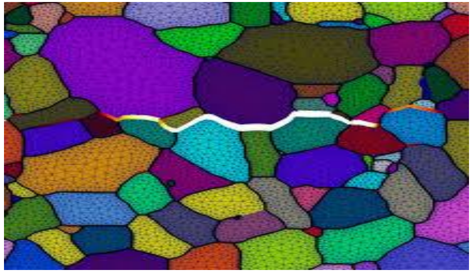
It is the quality of road aggregates which measures **it's resistance to abrasion at the surface**. The road aggregates should possess adequate hardness to resist abrasion action between tires of moving vehicles and the aggregate exposed at the top surface. The presence of foreign materials like sand between the vehicle tires and the road surface increases the abrasion.

2. Attrition:

Mutual rubbing of stones caused due to pavement deformation under wheel loads. The pavement deformation results in relative movement of aggregates thereby causing mutual rubbing of stones within the pavement layer.

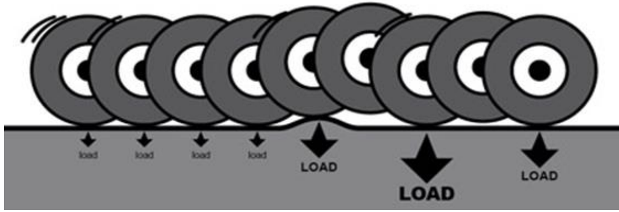
3. Toughness:

It may be defined as the **power** possessed by an aggregate to resist the **fracture** under an applied load. In all form of flexible pavement, the aggregate must be tough enough to support the weight of the roller during construction and the repeated impact action of traffic. The impact effect increases with the increase of road surface roughness, the speed of vehicle and other vehicular characteristics.



4. Strength:

The measure of the resistance of an aggregate to **crushing**. The aggregates to be used in surfacing course of the pavement structure should be able to withstand the stresses due to traffic wheel loads in addition to wear and tear.

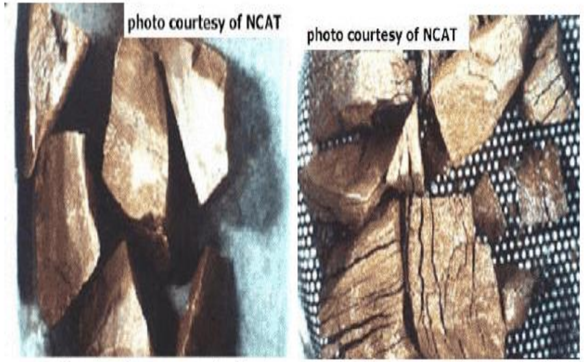


5. Texture:

It is the measure of **degree of roughness or smoothness of the stone**. It can be glossy, smooth, rough or crystalline. Glossy texture gives conchoidal fracture. Gravels are smooth. It depends upon the size, degree of uniformity and arrangement of mineral grains. As a rule, an even, fine grained rock being highly resistant to wear, which is most suitable.

6. Durability:

It may be defined as the **resistance of stone to disintegration under the influence of weathering action**. The property by virtue of which a stone is able to withstand the adverse weathering action is known as soundness. The composition of stone should be such that it can withstand or resist the action of rain and ground water and that of atmosphere.

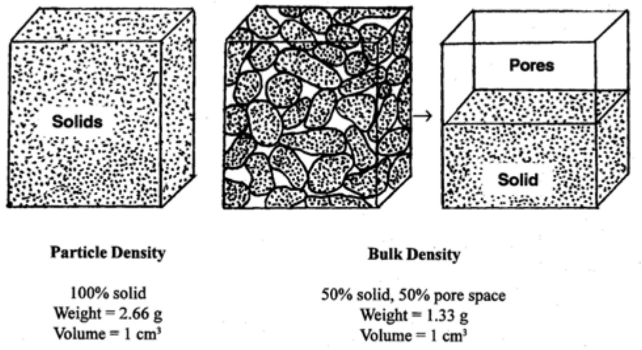


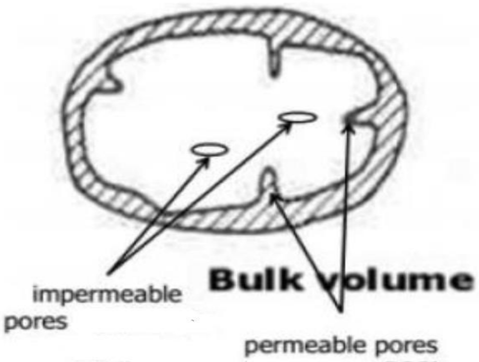
Typical aggregate before and after soundness testing

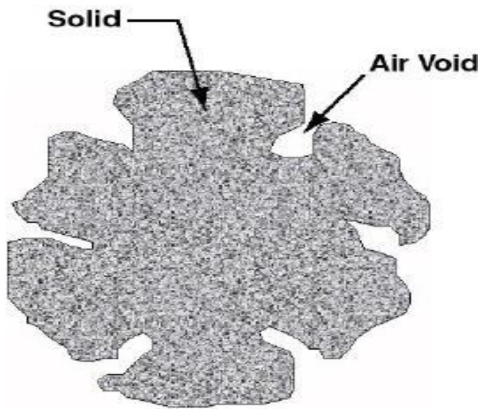
7. Specific gravity:

The specific gravity is of vital importance in determining the proper proportions of road works mixture by weight. Stone having high specific gravity values are generally stronger than those having low specific gravity. Thus, a rock of high porosity has a low specific gravity.

- **The bulk specific gravity** is the ratio of the weight in air of a volume of aggregate (including permeable and impermeable voids) to the weight in air of an equal volume of distilled water.
- **The apparent specific gravity** is the ratio of weight in air of volume of aggregate (including impermeable voids) to the weight in air of an equal volume of distilled water.

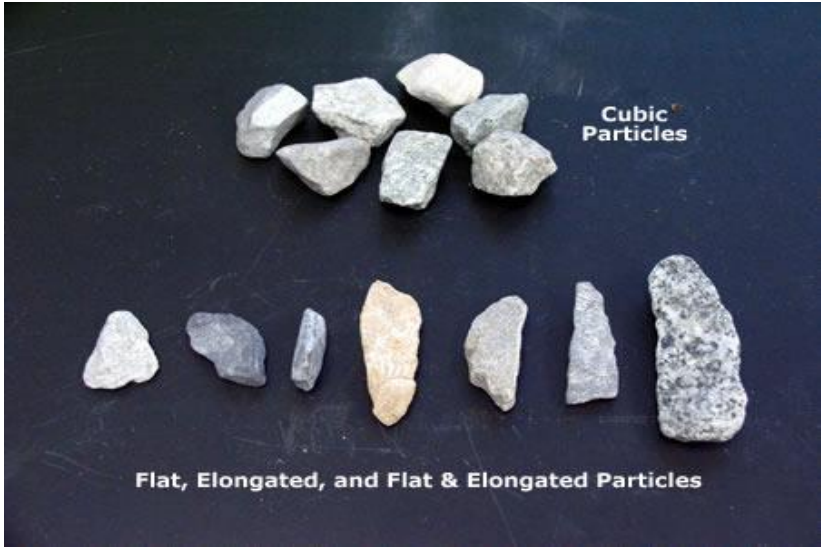






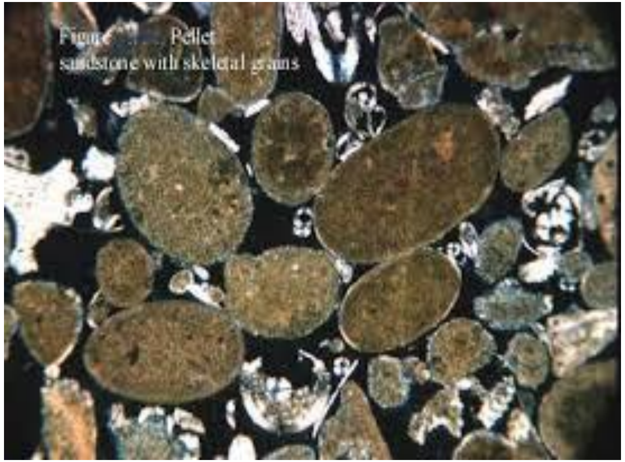
8. Shape of aggregate:

The aggregate may either be rounded, cubical, angular, flaky or elongated. The shape of **cubical** aggregate resemble to that of cube. **Angular** stone possess well define edges. **Flaky** stone have smaller thickness as compared to the sides. Too flaky and too much elongated aggregates have less strength and durability. Therefore, they are avoided for their use in pavement constructions. **Rounded** particles, because of their better workability, are preferred for cement concrete pavement construction. **In case of flexible pavement where stability is mainly due to interlocking, angular or cubical particles is the best choice.**



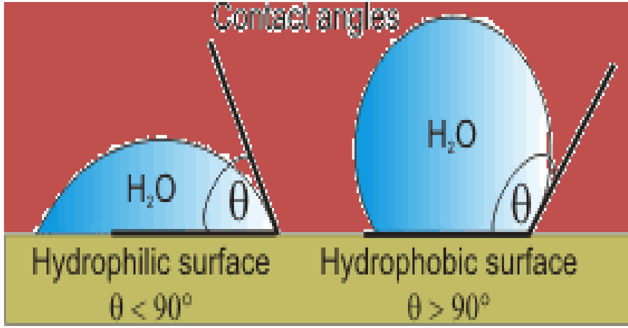
9. Cementation:

Is the ability of the road stone to form its own binding material under traffic so as to make the rough broken stone pieces, grip together imparting resistance to displacement. **Limestone, clinker and laterite have good cementation properties**, particularly in dry weather.



10. Hydrophobic characteristics:

It is the property by virtue of which the **stone aggregate resists stripping off of the bitumen** in the presence of water. The aggregate used in black top pavements should have less affinity of water when compared with bituminous binders.



ASPHALT MIXTURE ORADIGS

Sieve size	mm	Type I	Type II	Type IIIA	Type IIIB
		Base Course	Binder or Leveling Course	Surface or Wearing Course	
		% Passing by Weight of Total aggregate + Filler			
1 ½ in	37.5	100			
1	25.0	90-100	100		
¾	19.0	76-90	90-100	100	
½	12.5	56-80	76-90	90-100	100
⅜	9.5	48-74	56-80	76-90	90-100
No. 4	4.75	29-59	35-65	44-74	55-85
No. 8	2.36	19-45	23-49	28-58	32-67
No. 50	300 µm	5-17	5-19	5-21	7-23
No. 200	75 µm	2-8	3-9	4-10	4-10
Asphalt Cement (% weight of total mix)		3-5.5	4-6	4-6	4-6

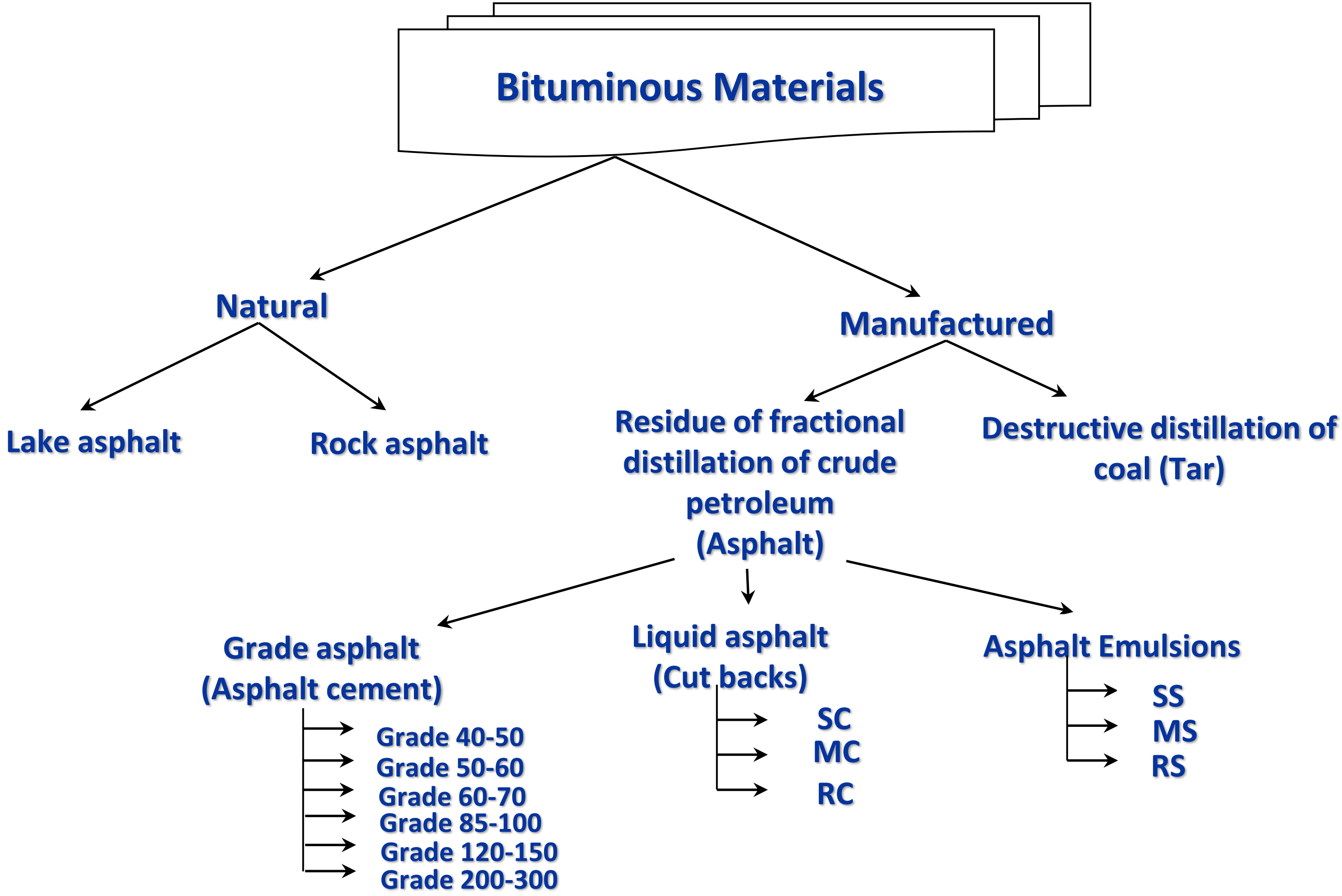
Aggregate gradation limits according to the **State Commission of Roads and Bridges (SCRB).**

Bituminous Material (Bitumen)

Bitumen: is a viscous liquid or solid material, black or dark brown in colour, having adhesive properties, consisting essentially of hydrocarbons. It is substantially nonvolatile, nontoxic, and softens gradually when heated.

There are two main categories of bitumen:

- Natural bitumen.
- Refinery bitumen.


Bituminous Materials
Natural
Manufactured
Lake asphalt
Rock asphalt
Residue of fractional distillation of crude petroleum (Asphalt)
Destructive distillation of coal (Tar)
Grade asphalt (Asphalt cement)
Liquid asphalt (Cut backs)
Asphalt Emulsions
Grade 40-50
Grade 50-60
Grade 60-70
Grade 85-100
Grade 120-150
Grade 200-300
SC
MC
RC
SS
MS
RS

- **Lake asphalt (Native asphalt):**

Lake asphalt is obtained from asphalt lakes in Trinidad and Bermudez. Trinidad asphalt contain about (40%) insoluble organic and inorganic materials, and Bermudez asphalt contain about (6%) of such material.

- **Rock asphalt:**

Rock asphalt is natural deposits of sand stone or lime stone rocks filled with asphalt. The amount of asphaltic material varies from (4.5%) to (18%). Rock asphalt is not widely used because of it's high transportation cost.

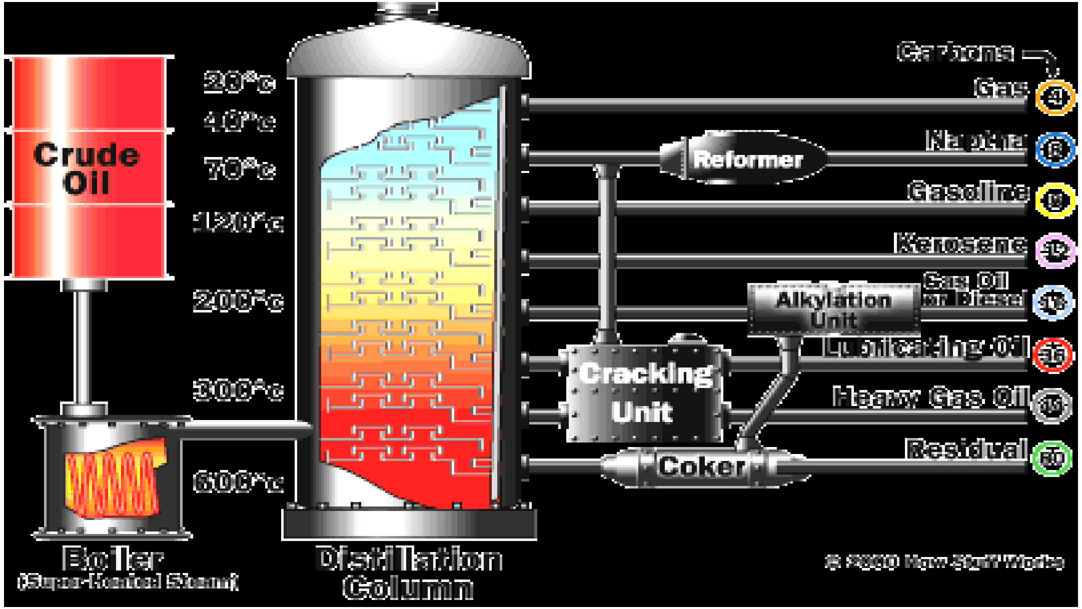
- **Tar:**

Tar is a viscous liquid, black in colour, with adhesive properties, obtained by the destructive distillation of coal. **It is not used in Iraq.**

- <u>**Petroleum Asphaltic Materials:**</u>

1. Asphalt cement (grade asphalt):

These asphalts produced by fractional distillation of **crude petroleum**. The residual material after separation of light oils is contain the asphalt which is refined into specific grades and called **penetration grades**, i.e. **40-50, 50-60, 60-70, 85-100, 120-150, and 200-300**.



2. Cutbacks Asphalt (liquid asphalt):

Cutback asphalt is asphalt that is liquefied by the addition of diluents (typically petroleum solvents) and is generally designated as liquid asphalt However, it is important to note that the asphalt binder is the base material that has been liquefied by cutting back with a solvent.

In producing cutback bitumen for asphalt, a **cutter** and sometimes a **flux oil** are used. The processes are defined as following:

I. **Cutting:-** The addition of a **volatile oil** which produces a temporary reduction in binder viscosity.
II. **Fluxing:-** The addition of an **oil** which has a long term effect on binder viscosity.

Cutback bitumen can be divided into **three main types**, depending upon the type of solvent used to dilute the bitumen, these are:

a. **Slow–Curing asphalt (SC)**: can be obtained directly through the **distillation process** or by cutting back or fluxing asphalt cement with a **heavy distillation such as diesel oil**. It is used onto the surfaces of soil–aggregate roads in warm climates, in order to keep the dry soil particles from creating a dust under traffic.

b. **Medium–Curing asphalt (MC)**: are produced by cutting back the residual asphalt (usually 120-150) with **kerosene**. The fluidity of MC asphalts depends on the amount of solvent by volume in the material. MC asphalt can be used for the construction of pavement stabilized bases, surfaces and surface treatments, also used as a prime coat between the stabilized base and binder course in flexible pavement construction.

Notes:

- In ISSRB - R8A the prime coat is provided by cutting-back (85-100) Pen asphalt with kerosene (1 kerosene : 1.5 Asphalt cement) by volume.
- The application more than 0.5 l/m^2 and less than 1.2 l/m^2. Prime coat must be spread before paving asphalt by at least 24 h.

c. **Rapid–Curing asphalt (RC)**: RC asphalts are produced by blending asphalt cement with a petroleum distillate that will easily evaporate, such as **Gasoline or nephtha**. RCs are used as a tack coat between the binder and wearing course.

Notes:

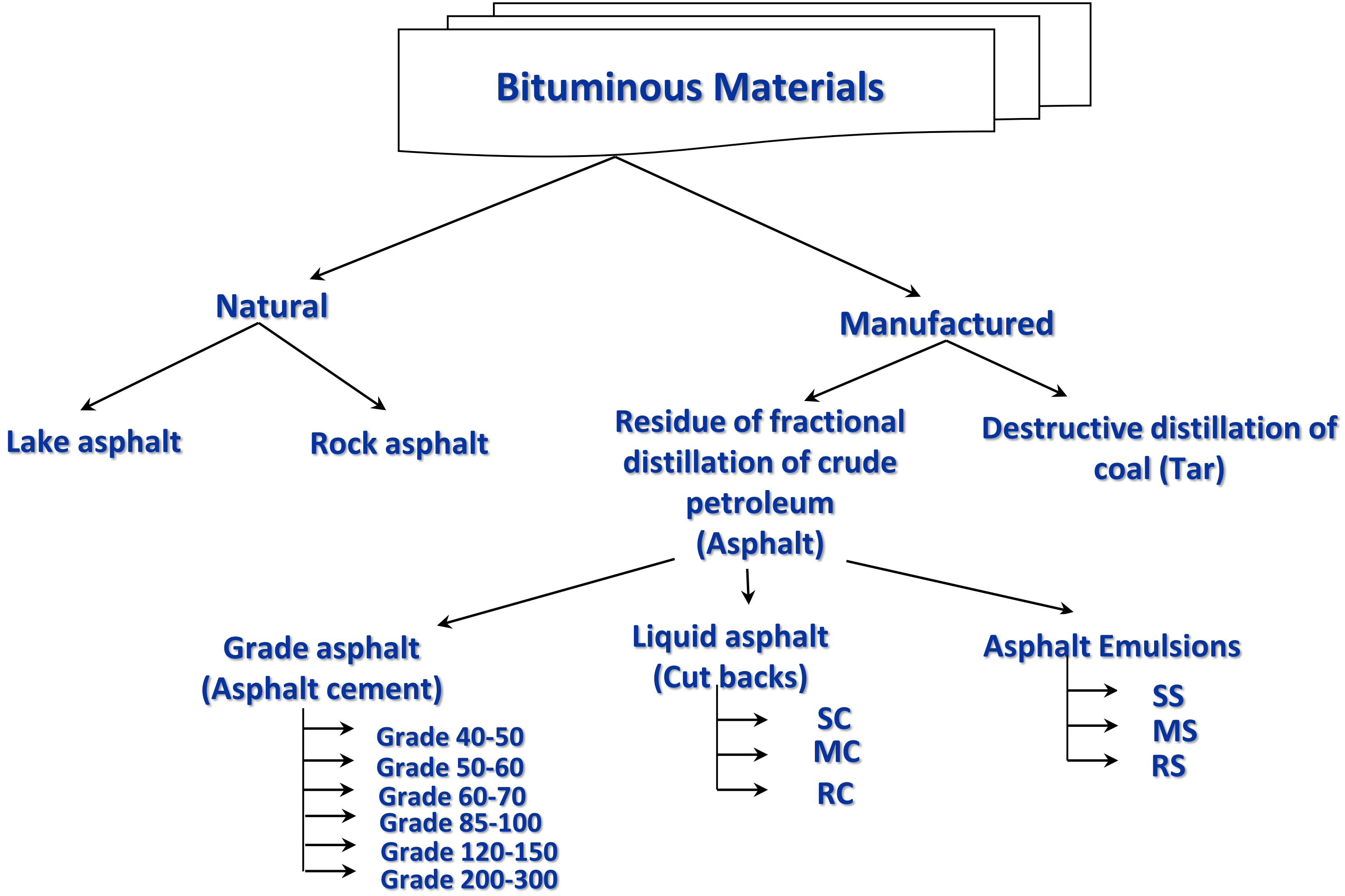
- RC is used of construction pavement as a tack coat. In ISSRB - R8B the tack coat is provided by cutting-back (85-100) Pen asphalt with Gasoline (1 Gasoline : 2 Asphalt cement) by volume.
- The application is more than 0.15 l/m2 and less than 0.5 l/m2. Tack coat must be spread before paving asphalt by at least 2 h.

Bituminous Material (Bitumen)

Bitumen: is a viscous liquid or solid material, black or dark brown in colour, having adhesive properties, consisting essentially of hydrocarbons. It is substantially nonvolatile, nontoxic, and softens gradually when heated.

There are two main categories of bitumen:

- Natural bitumen.
- Refinery bitumen.


Bituminous Materials
Natural
Manufactured
Lake asphalt
Rock asphalt
Residue of fractional distillation of crude petroleum (Asphalt)
Destructive distillation of coal (Tar)
Grade asphalt (Asphalt cement)
Liquid asphalt (Cut backs)
Asphalt Emulsions
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Grade 50-60
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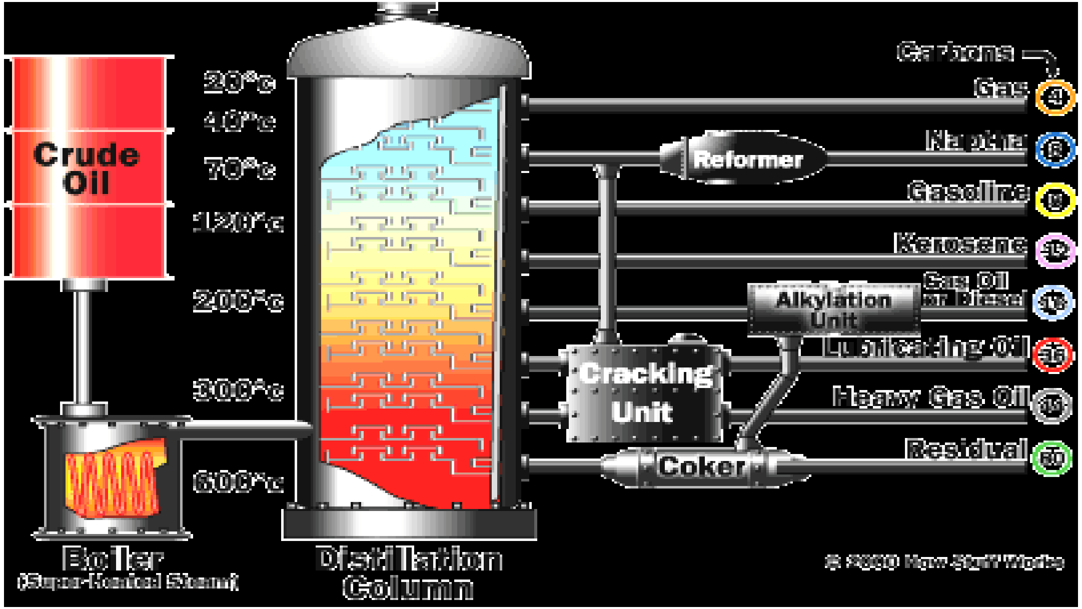

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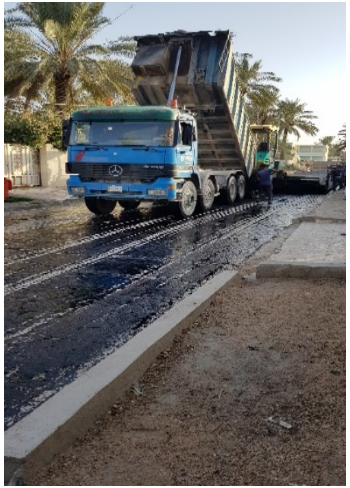

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