Highway Engineering

References:


Syllabus:

- Introduction to Highway Engineering
- Functional Classification of Highways
  - Highway location
  - Highway surveys
  - Design control and criteria
- Elements of geometric design
- Cross-section elements
- Earthwork quantities
- Intersections and interchanges
• Traffic signals and road markings
• Pavement materials
• Flexible (asphalt) pavement design
• Rigid pavement design
• Highway drainage
• Highway maintenance

**Introduction to Highway Engineering**

A highway is a conduit that carries vehicular traffic from one location to another.

It deals with:

• Provisions for meeting public needs for highways
• Planning, design, construction, maintenance and rehabilitation of highways.
• Economics and financing of highway construction.
• Traffic control and safety of those using or affected by the use of highways.

*Each student is required to submit a report about Highway Engineering in general _but more specifically on the geometric design of highways_. A report should include these points:

1- A title, student name and date of submission

2- A research scope.

3- Full research body, which includes an introduction, literature review, the main point of the research and conclusion.

4- Recommendations related to your local or extended area.
5- The research should not be less than 8 pages and not exceeding 12 pages.

*Deadline: From now till 21 Dec 2018.

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Highway classification

Highways and streets are initially categorised depending on the area they are located in. They are functionally divided into Urban and Rural roads.

**Urban roads**, function in communities with a population of 5000 or more people. Functional classification of urban roads:

- Principal arterial system. It carries a high proportion of the total vehicle-miles of travel within the urban area and functions the following:
  - Most trips with an origin or destination within the urban area.
  - Serves trips that bypass the central business district (CBD) of urbanised areas.
  - All controlled access facilities are within this system.
  - Parking, loading and unloading of goods and pedestrian traffic are not permitted on these facilities.
  - They are generally provided with grade-separation at intersections.

*This system includes interstate ways and expressways.*

- Minor arterial system. Highways and streets that interconnect with and augment the major arterial roads. And it functions the following:
- Trips of moderate length, generally spaced at 1.5km in highly developed and central business areas, and at 8km or more in less developed urban areas.
- More land access than the major arterial but still limited.
- Could serve as bus routes and connect communities within urban areas.
  Parking, loading and unloading usually restricted and regulated.
  Pedestrians are allowed to cross at intersections.

*Arterials are typically multi-lane highways.*

- Collector street system. The main purpose of this system is to collect traffic from local streets in residential areas or CBDs and convey it (provide access) to the arterial system. Normally full access is allowed on these streets. There are only a few parking restrictions.

- Local street system. This system consists of all other streets in the urban area that are not included in the three systems described earlier. The main purpose of this system is to provide access to residents and the adjacent land. Such a system normally does not carry a large volume of traffic. Unrestricted parking and pedestrian movement are allowed in this system.
Rural roads, highway facilities outside of urban areas. The functional classification of rural roads:

- Principal arterial system. This system consists of a network that serves in connecting urban trips with the suburban areas or large towns. This system includes freeways (No through movements are allowed on this system) and other arterials not classified as freeways (where minimum through movement is allowed).
- Collector system. Carries traffic between individual counties (villages). Trip distances are usually shorter than those of the arterial system. It also connects traffic from local roads and convey it to other facilities.

- Local roads system. This system consists of all roads within the rural area not classified within the other systems. These roads serve trips of relatively short distances and connect adjacent lands with the collector roads.

Fig.2: A schematic illustration of a functionally classified rural network.
Highway Location and Survey

Principles of highway location

The main objective of transportation planning is to develop a system of transport which will enable people and goods to travel safely and economically. The highway should also cause a minimal disruption to historic and archeological sites and to other land-use activities.

Table 1: Factors commonly considered when locating a new highway.

<table>
<thead>
<tr>
<th>Subject area</th>
<th>Features</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering and</td>
<td>Construction costs</td>
<td>Topography, geology, geomorphology, materials, soils, vegetation, drainage, design criteria, safety</td>
</tr>
<tr>
<td>economics</td>
<td>Maintenance costs</td>
<td>Climate, traffic, soils, materials, topography, drainage, geomorphology</td>
</tr>
<tr>
<td></td>
<td>User costs</td>
<td>Traffic, topography, travel time, safety</td>
</tr>
<tr>
<td></td>
<td>Right-of-way costs*</td>
<td>Land values, land use, replacement costs, traffic, design criteria, utilities, tax base</td>
</tr>
<tr>
<td></td>
<td>Development potential*</td>
<td>Agriculture, forestry, mineral extraction, trade and industry, tourism, personal mobility, political strategy</td>
</tr>
<tr>
<td>Social aspects</td>
<td>Neighbourhood locale</td>
<td>Population, culture, land use, tax rate, land value, institutions, transportation, historical sites, utilities and services, community boundaries, tax base, traffic, employment, dynamic change</td>
</tr>
<tr>
<td>Social/ecology</td>
<td>Recreation and</td>
<td>Land use, vegetation, fish life, scenic areas, wildlife, drainage, topography</td>
</tr>
<tr>
<td>Ecology</td>
<td>conservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollution**</td>
<td>Noise, air, water, spillage, thermal, chemical, waste</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Scenic value</td>
<td>Scenic areas, view from road, view of road, ‘eye sores’, topography, vegetation, drainage</td>
</tr>
</tbody>
</table>

*Right-of-way costs and the development potential of an area also affect the social aspects of that area

**Pollution also affects the aesthetic value of an area.
The highway location process involves four phases:

1- **Office study of existing information.**

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. The obtained data should provide 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.

2- **Reconnaissance Survey**

The objective of this phase of the study is to identify several feasible routes. 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 highways.
- Directness of route.
3- **Preliminary Location Survey**

At this phase, the positions of feasible routes are set as closely as possible. These preliminary locations are compared with respect to their economic and environmental feasibility.

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.
Fig. 1: Flow diagram showing the major site investigation to the main road design activities.
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

Geographic Information System (GIS)

GIS can capture, store, analyze, and manage data and associated attributes, which are spatially referenced to the earth. It is a tool that allows users to create user-
created searches, analyse the spatial information, edit data, maps, and present the results of all these operations.

GIS is a planning tool that can serve as an excellent aid to engineers by presenting a project’s strengths and weaknesses in a wide variety of formats to suit any audience. The GIS technology can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, history, sales, marketing, and route planning.

Generally, the uses of the GIS for highway engineering and road users can be summarised as following:

- Allow planners to calculate emergency response times or evacuation routes in the event of a natural disaster, etc.
- Identify locations of subsurface utilities in proximity to a highway project.
- Determine which cultural or environmental resources may be impacted by a proposed highway corridor alignment and aid in developing alternative alignments.
- Can serve as an excellent aid to engineers by presenting a project’s strengths and weaknesses in a wide variety of formats to suit any audience.

*Quiz, Geometric design. and survey

**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 1 below shows a typical cross section of a two-lane highway, and Figure 2 shows that for a multi-lane highway.

- **Width and number of travel lanes**
  
  Travel lanes are that section of a roadway on which traffic moves.
  
  - 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.

- Shoulders
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.

- 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
A median barrier is defined as a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions. Roadside barriers, on the other hand, protect vehicles from obstacles or slopes on the roadside.

- 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: Curb and gutter
- 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.

- Sidewalks and vertical clearance
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.

- Transverse or Cross slopes
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).

- **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.

- **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.

Figure: Right of way.
Table: Range of desirable right of way width for selected road types.

<table>
<thead>
<tr>
<th>Class of road</th>
<th>Right of way width in metres</th>
<th>Plain and rolling terrain</th>
<th>Mountainous and steep terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural areas</td>
<td>Urban areas</td>
<td>Rural areas</td>
</tr>
<tr>
<td></td>
<td>Normal Range</td>
<td>Normal Range</td>
<td>Normal</td>
</tr>
<tr>
<td>1- National and state</td>
<td>45</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>highways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2- Major district roads</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>3- Other district roads</td>
<td>15</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>4- Rural roads</td>
<td>12</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

**Highway Grades**

The maximum grade on any highway should be selected based on good judgement. 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: Recommended maximum grades

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Rural Collectors Design Speed (mi/h)</th>
<th>Grades (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Level</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Rolling</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mountainous</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Urban Collectors Design Speed (mi/h)</th>
<th>Grades (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Level</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Rolling</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Mountainous</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Rural Arterials Design Speed (mi/h)</th>
<th>Grades (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Level</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Rolling</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Mountainous</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Rural and Urban Freeways Design Speed (mi/h)</th>
<th>Grades (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Level</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rolling</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mountainous</td>
<td>6</td>
<td>6</td>
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</table>

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Urban Arterials Design Speed (mi/h)</th>
<th>Grades (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Level</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Rolling</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Mountainous</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>

-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 customary to use a minimum of 0.5 percent in such cases, although this may be reduced to 0.3 percent on high-type pavement.

**Superelevation**

Travelling at higher speeds on around curves with smaller radii, causes an increase in the centrifugal force. Excessive centrifugal force may cause considerable lateral movement of the turning vehicle and it may become impossible to stay inside the driving lane.

- Superelevation is the banking of the roadway such that the outside edge of pavement is higher than the inside edge.

- Superelevation and side friction are the two factors that help stabilize a turning vehicle.

- Side friction is reduced when water, ice, or snow is present or when tires become excessively worn.

- Superelevation is influenced by several factors including design speed, curve radius, and number of travel lanes.

- Minimum curve radius for a horizontal alignment are determined by the design speed and superelevation rate.

- 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, such as:

  Weight of the vehicle, \( W \)
Centrifugal force, \( P \)

Frictional force, \( f_1 \) and \( f_2 \)

Radius of the curve, \( R \)

As in the figure below:

![Diagram of vehicle forces](image)

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

\[
e + f = \frac{V^2}{gR}
\]

Where:

\( e \) = the superelevation rate, (\%)

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

\( V \) = velocity of vehicle, (m/s)

\( g \) = acceleration due to gravity = 9.81 m/s\(^2\),
R = radius of curve, in meters.

If the velocity is in Km/hr, then

\[ e + f = \frac{V^2}{127R} \]

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

(H.W)

Figure: 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.

The chart below shows an example of superelevation rate design with respect to the curvature of the road, and design speed.

Figure: Superelevation design curves.
Highway junctions

Junctions are classified into three general categories:

1- At-grade intersections (Known as intersections).
2- Grade-separated intersections without ramps (Known as grade-separation).
3- Grade-separated intersections with ramps (Known as interchanges)

At-grade intersections (intersections)

It is the junction or crossing of two or more roads at the same or different elevations. This type should be provided with protective and warning devices, which could be signalised or unsignalised.

Two common types of at-grade intersections:

1- Three-leg intersections (T-intersections).
This type is formed when one highway starts or terminates at a junction with another highway.

2- Four-leg intersections.
This type is formed when two highways cross at grade.

Channelisation of intersections

This is a method of creating defined paths for vehicle travel by installing traffic islands or pavement markings at at-grade intersections. These defined paths provide for the safe and orderly movement of both vehicles and pedestrians through the intersections. Also, they may provide a location for traffic-control devices.

* Channelisation may consist of curbed medians or areas delineated by paint.

Factors influencing the design of a channelised intersection:

- Type of design vehicle
- Vehicle speed
- Cross sections of the roadway
- Anticipated volumes of vehicle and pedestrian traffic
- Locations of bus stops
- Type and location of traffic-control devices

*Figures below show the two types of intersections with and without channelisation.

![Figure: Types of at-grade T (three-leg) intersections: (a) simple T-intersection; (b) intersection with a right-turn lane; (c) channelised intersection with a single-turning roadway; (d) channelised intersection with a pair of turning roadways.]
Figure: Types of at-grade four-leg intersections: (a) simple; (b) channelized; (c) flared (widened).
Highway interchanges (grade-separated intersections)

An interchange is a system of interconnecting roadways used in conjunction with one or more grade separations of highways.

Interchanges can accommodate movement of traffic between two or more roadways at different elevations.

Design of an interchange is based on traffic volume, topography of the site, economic considerations, and environmental factors.

Justification of interchanges

1- Highway classification, in the case of freeways
2- Elimination of Bottlenecks
3- Elimination of Hazards
4- Road-User Benefits
5- Traffic Volume

Types of interchanges

1- Three-leg interchanges. These consist of one or more highway grade separations with three intersecting legs. All traffic moves over one-way roadways. In plan view, the roadway layout generally resembles a T or a Y, or delta.

2- Four-leg interchanges. These consist of one or more highway grade separations with four legs. General categories of four-leg interchanges include ramps in one quadrant, diamond, full cloverleaf, partial cloverleaf, and semidirect and direct connection interchanges.

*Figures below show all types of highway interchanges.
(a) T OR TRUMPET

(b) Y OR DELTA

(c) ONE QUADRANT

(d) DIAMOND

(e) FULL CLOVERLEAF

(f) PARTIAL CLOVERLEAF
In order to control merging and conflicting traffic flows at an intersection, a roundabout performs the following two major functions:

- It defines the priority between traffic streams entering the junction, usually on the basis that traffic wanting to join the circulatory flow must give way to the traffic to their left already circulating in the roundabout (In the UK, and some countries that circulate to clockwise the priority is to the right).

- It causes the diversion of traffic from its preferred straight-line path, requiring drivers to slow down as they enter the junction.

*Travel speed is typically less than 30 mile/hour at roundabouts.

*In order to work efficiently, sufficient gaps must appear in the circulating flows on the roundabout that drivers can accept for the entry and exit.

*Some roundabouts have difficulty dealing with unbalanced flows, in this case signalisation may be preferable.
*Parking not usually allowed within the circulating roadway.

Definition of number of key dimensions are presented in the figure below, which includes:

Central island: The central island is the raised area in the center of a roundabout around which traffic circulates.

Splitter island: A splitter island is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road in two stages.

Circulatory roadway: The circulatory roadway is the curved path used by vehicles to travel in a counterclockwise fashion around the central island.

Apron: Is required on smaller roundabouts to accommodate the wheel tracking of large vehicles, an apron is the mountable portion of the central island adjacent to the circulatory roadway.

Yield line: A yield line is a pavement marking used to mark the point of entry from an approach into the circulatory roadway and is generally marked along the circle. Entering vehicles MUST yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.

Accessible pedestrian crossings: Accessible pedestrian crossings should be provided at all roundabouts. The crossing location is set back from the yield line, and the splitter island is cut to allow pedestrians, wheelchairs, strollers, and bicycles to pass through.

Bicycle treatments: Bicycle treatments at roundabouts provide bicyclists the option of traveling through the roundabout either as a vehicle or as a pedestrian, depending on the bicyclist’s level of comfort.

Landscaping buffer: Landscaping buffers are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross
only at the designated crossing locations. Landscaping buffers can also significantly improve the aesthetics of the intersection.

**Figure:** Drawing of key features of a roundabout.

**Types of roundabouts**

1- Mini roundabouts
2- Urban compact roundabouts
3- Urban single-lane roundabouts
4- Urban double-lane roundabouts
5- Rural single-lane roundabouts
6- Rural double-lane roundabouts

The characteristics of each of these categories are shown in the table below.

**Table:** Characteristics of Roundabout Categories.
<table>
<thead>
<tr>
<th>Design Element</th>
<th>Mini-Roundabout</th>
<th>Urban Compact</th>
<th>Urban Single-Lane</th>
<th>Urban Double-Lane</th>
<th>Rural Single-Lane</th>
<th>Rural Double-Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended maximum entry design speed</td>
<td>25 km/h (15 mi/h)</td>
<td>25 km/h (15 mi/h)</td>
<td>35 km/h (20 mi/h)</td>
<td>40 km/h (25 mi/h)</td>
<td>40 km/h (25 mi/h)</td>
<td>50 km/h (30 mi/h)</td>
</tr>
<tr>
<td>Maximum number of entering lanes per approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Typical inscribed circle diameter</td>
<td>13 to 25 m (45 ft to 80 ft)</td>
<td>25 to 30 m (80 to 100 ft)</td>
<td>30 to 40 m (100 to 130 ft)</td>
<td>45 to 55 m (150 to 180 ft)</td>
<td>35 to 40 m (115 to 130 ft)</td>
<td>55 to 60 m (180 to 200 ft)</td>
</tr>
<tr>
<td>Splitter island treatment</td>
<td>Raised if possible, crosswalk cut if raised</td>
<td>Raised, with crosswalk cut</td>
<td>Raised, with crosswalk cut</td>
<td>Raised, with crosswalk cut</td>
<td>Raised and extended, with crosswalk cut</td>
<td>Raised and extended, with crosswalk cut</td>
</tr>
<tr>
<td>Typical daily service volumes on four-leg roundabout (veh/day)</td>
<td>10,000</td>
<td>15,000</td>
<td>20,000</td>
<td>Refer to the source</td>
<td>20,000</td>
<td>Refer to the source</td>
</tr>
</tbody>
</table>

1 Assumes 90° entries and no more than four legs.

Traffic Control Devices

These provide for the safe and orderly movement of traffic on a highway by offering guidance and navigation information to drivers.

These are commonly known as road signs, pavement markings and traffic signals.

Road (traffic) signs

Road signs are intended to serve the following purposes:

- To give timely warning of hazard.
- To regulate traffic by showing information to drivers about when to stop, give way or limit speed, where parking is prohibited, etc.
- To provide for guide information on highway routes, directions etc.

*For visibility, signs are typically manufactured from light reflective materials.

*In areas of high traffic and in construction zones, illuminated signs are often used.

Classification of road signs:

- Warning signs: To warn the road users of certain hazardous situations on the road or adjacent lands.
- Mandatory/Regulatory signs: To inform the road users of certain laws, regulations, prohibitions or restrictions. Any cases of violations would lead to legal actions.
- Informatory signs: To provide guidance to the road users with respect to the direction and place identification, facilities like roadside rest areas, petrol stations, parking, etc.
**Pavement markings**

Pavement markings are markers in the form of lines, words, edge striping applied on the roadway surface.

Painting is the most common method of applying pavement markings. An alternative is plastic striping fixed to pavement with an adhesive. This method is often used for marking temporary lanes.

**Role of pavement markings**

- To guide and control traffic on the roadway.
- To serve as a psychological barrier.
- To mark the traffic path and its lateral clearance from traffic hazards.

*Pavement markings are usually white in colour except for the following, where they are yellow:

- Lines indicating parking restrictions.
- No overtaking zone markings.

**Traffic signals**

Signals can be used to emphasize a hazardous location, supplement conventional signs, and provide control at railroad-highway grade crossings.

Red, yellow, and green signal lights are widely used.

Placement of traffic signals should ensure visibility, meet pedestrian requirements, and integrate with the highway geometry.

Traffic signals may be pretimed, traffic-actuated, or pedestrian-activated.

[https://www.highwaycodeuk.co.uk](https://www.highwaycodeuk.co.uk)
Earthworks and Mass Haul Diagram

To determine the amount of earthwork involved for a given grade line, cross sections are taken at regular intervals along the grade line. 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.

The figure below shows three types of cross-sections of highways.

A common method of determining the volume is the average end areas. This procedure assumes that the volume between two consecutive cross sections is the average of their areas multiplied by the distance between them. As follows:

\[ V = \frac{L(A_1 + A_2)}{2} \]

Where: \( V \) is the volume (cubic units),
A\textsubscript{1} and A\textsubscript{2} are the end areas (square units),

L is the distance between end areas (unit length).

**Correcting earthwork volumes**

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

![Diagram showing normal, loose, and compact states of materials with volume ratios for Rockfill, Sand & Gravel, Slit, and Clay](image)

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.

**Ex.** 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\textsuperscript{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 station 0 and station 1.

Ans.

\[ V = L(A_1 + A_2)/2 \]

Station (0), \( V_{\text{cut}} = 30(0.3+0.2)/2 = 7.5 \text{m}^3 \)

\[ V_{\text{fill}} = 30(2+5)/2 = 93.7 \text{m}^3 \]

**Shrinkage=10%, Total fill volume=93.7+(93.7*0.10)=103m^3**

Net vol. between st.0 and st.1 = total cut - total fill = 7.5-103= -95.5 m\(^3\) and this can be applied to all stations as in table below.

*Net CUT volumes are always positive (+), and net FILL volumes are always negative (-).*
<table>
<thead>
<tr>
<th>Stations</th>
<th>End areas (m²)</th>
<th>Volume (m³)</th>
<th>Net Volume</th>
<th>Mass diagram ordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut Fill</td>
<td>Total cut Fill Shrinkage Total fill</td>
<td>Fill Cut (-) (+)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.3 1.7</td>
<td>7.5 93.7 9.4 103.0</td>
<td>95.5 0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.2 4.6</td>
<td>6 202.5 20.2 222.7</td>
<td>216.7 -95.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.2 8.9</td>
<td>9 312.7 31.3 343.9</td>
<td>334.9 -312.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.4 11.9</td>
<td>16.5 249.3 24.9 274.2</td>
<td>257.7 -647.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.7 4.7</td>
<td>66 132.2 13.2 145.5</td>
<td>79.5 -904.9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.7 4.1</td>
<td>117 89.5 9.0 98.5</td>
<td>18.5 -825.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.1 1.8</td>
<td>171 34.4 3.4 37.9</td>
<td>133.1 -807.0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>7.3 0.5</td>
<td>277.5 9.6 1.0 10.6</td>
<td>266.9 -673.8</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>11.2 0.2</td>
<td>346.5 2.8 0.3 3.0</td>
<td>343.5 -407.0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>11.9 0.0</td>
<td>372 0.0 0.0 0.0</td>
<td>372.0 -63.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>12.9 0.0</td>
<td>331.5 4.1 0.4 4.5</td>
<td>327.0 308.5</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>9.2 0.3</td>
<td>247.5 45.5 4.5 50.0</td>
<td>197.5 635.5</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>7.3 2.8</td>
<td>213 68.9 6.9 75.8</td>
<td>137.2 833.0</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>6.9 1.8</td>
<td>172.5 96.4 9.6 106.1</td>
<td>66.4 970.2</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4.6 4.6</td>
<td>96 179.1 17.9 197.0</td>
<td>101.0 903.8</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.8 7.3</td>
<td>40.5 247.9 24.8 272.7</td>
<td>232.2 802.8</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.9 9.2</td>
<td>13.5 303.0 30.3 333.3</td>
<td>319.8 570.6</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0.0 11.0</td>
<td>4.5 330.6 33.1 363.6</td>
<td>359.1 250.7</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.3 11.0</td>
<td>60 234.2 23.4 257.6</td>
<td>197.6 -108.4</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>3.7 4.6</td>
<td>97.5 110.2 11.0 121.2</td>
<td>23.7 -306.0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3 3</td>
<td>- - - -</td>
<td>- -326.7</td>
<td></td>
</tr>
</tbody>
</table>
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.

A good amount of trial is needed to balance the cut and fill.

**Ex.** Compute the balance point stations for the mass diagram of the previous example.

**Ans.**

Balance points are computed by interpolation using the even stations where the ordinates change from cut to fill (or vice versa).

Balance point B occurs between stations 9+00 and 10+00 (since ordinate values are −63.5 and +308.5).

*Assuming that the mass diagram ordinate changes linearly between stations, by similar triangles:

Station at balance point B = (63.5*30)/(308.5+63.5) = 9+06

Station at balance point C = (108.4*30)/(250.7+108.4) = 17+09

**Thursday: 6/12 monthly test**

**Thursday: 20/12 monthly test**
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.

\[
E.O.D = \frac{\text{cost of borrow material}}{\text{cost of over-haul}}
\]

**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.

**Limit of economical haul distance (L.E.H.D):** Max. overhaul distance plus free haul distance beyond which it will be more economical to (waste and borrow) rather than to pay for the cost of overhauling.

The *limit of economic haul distance* (L.E.H.D) = E.O.D + F.H.D

The figure below gives an explanation of borrow and waste materials.
**Ex.** The free-haul distance in a highway construction contract is 150m and the overhaul price is $15/m^3\text{. 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 station 9 + 06 (B) and station 17 + 09 (C).**

**Ans.**

**Step 1:** Find the volume of overhaul:
The overhaul volume will occur between stations \(9 + 06\) and \(10 + 28\), and between stations \(15 + 28\) and \(17 + 09\).

The overhaul value is obtained by interpolation between stations \(10 + 00\) and \(11 + 00\) or by reading the value from the mass diagram.

By interpolation, the value is:

\[
\text{Overhaul volume at 10+28} = \text{ordinate at station 10+00 (308.5)} + \frac{28}{30} (\text{ordinate at 11+00 (635.5)-ordinate at 10+00 (308.5)}) = 613.6 \text{ m}^3
\]

This obtained value should equal to that at station 15+28, which is:

\[
= \text{ordinate at 15+00 (802.8)} - \frac{28}{30} (\text{ordinate at 15+00 (802.8)} - \text{ordinate at 16+00 (570.6)}) = 586.2 \text{ m}^3
\]

Since the values (613.6 and 586.2) are not equal, use the average, which is: \(599.9 \text{ m}^3\)

**Step 2:** Determine the over-haul distance:

- Beginning with stations 9+06 to 10+00, the volume moved is 308.5 m\(^3\), and the average distance to the free-haul station (10+28) is:
  \[
  \frac{(10+00 (300m)) - (9+06 (276m))}{2} + 28 = 40 \text{ m}
  \]

- From station 10+00 to station 10+28, the volume is 599.9 − 308.5 = 291.4 m\(^3\)

And the average distance is 28/2 = 14 m.

* The over-haul distance moved between stations 9+06 and 10+28 is:

\[
(308.5 \times 40 + 291.4 \times 14) / 599.9 = 27.4 \text{ m}.
\]

Similarly, compute the overhaul distance between the balance point at station 17 + 09 and the beginning of free haul at station 15 + 28.
- From station 17+09 to 17+00, the volume moved is 250.7 m³, and the average distance to the free-haul station is:
\[
\frac{(17+09\ (519\text{m})) - (17+00\ (510\text{m}))}{2} + \frac{(17+00\ (510\text{m})) - (15+28\ (478\text{m}))}{2} = 36.5\text{m}.
\]

- From station 17+00 to 16+00, the volume moved is 570.6 – 250.7 = 319.9 m³, and the average distance to the free-haul station is:
\[
\frac{(17+00) - (16+00)}{2} = 17\text{m}.
\]

- From station 16+00 to station 15+28, the overhaul volume moved is:
\[
599.9 - 570.6 = 29.3\ \text{m}^3,
\]
and the average distance is: 2/2 = 1 m.

\[\wedge\text{The over-haul distance moved between stations 15+28 to 17+09 is:}\]
\[
\frac{(250.7 \times 36.5) + (319.9 \times 17) + (29.3 \times 1)}{599.9} = 24.4\ \text{m}
\]

\[\wedge\text{Total over-haul distance is: 27.4 + 24.4 = 51.8 m.}\]

**Step3:** Compute the over-haul cost due to the contractor:

Over-haul cost = 15 * 599.9 * (51.8/30) = $15537.4
H.W-1/ For the previous example, calculate the L.E.H.D if there was availability of earth to borrow. Borrow cost is $60/m³.

(Ans. 9 stations)

H.W-2/ Net volumes of cut and fill for a proposed section of a road is as in the table below:

<table>
<thead>
<tr>
<th>Chainage (m)</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>480</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>+290</td>
<td>+760</td>
<td>+1680</td>
<td>+620</td>
<td>+120</td>
<td>-20</td>
</tr>
<tr>
<td>Chainage (m)</td>
<td>500</td>
<td>600</td>
<td>700</td>
<td>800</td>
<td>900</td>
<td>1000</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>-110</td>
<td>-350</td>
<td>-600</td>
<td>-780</td>
<td>-690</td>
<td>-400</td>
</tr>
<tr>
<td>Chainage (m)</td>
<td>1100</td>
<td>1200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>-120</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1- Draw the MHD

2- Determine the overturn distance if the free-haul distance is 300m.

(Ans. 350m)
Pavement Materials

The materials used in the construction of highway pavements are:

1- Soil
2- Aggregate
3- Binders (Bitumen or Cement)

The main functions of road pavements are:

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

Subgrade: is the material foundation or fill which directly receives the loads from the pavement. It is considered the supporting structure on which the pavement surface and its under courses rest.

1. Soil (subgrade soil)

Soil is the foundation of highways. It is a complex material produced by the weathering of rocks. It consists of the uncemented deposits of minerals and/or organic particles or fragments covering large parts of the earth’s crest.

In order to obtain the objective of a good foundation of highways, soils should have the following properties:

1- Adequate stability and resistance to permanent deformation under traffic loads.
2- Incompressibility to prevent differential settlement.
3- Ease of compaction to obtain 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.
Soil Tests in Highway Engineering

- Grain size distribution test
- Atterberg limits (L.L & P.L)
- Compressive strength
- CBR test (California Bearing Ratio)
- Plate-Bearing test

Soil Stabilisation

It is the treatment of the natural soil to improve its engineering properties such as the strength and vulnerability to water. This can be achieved by:

i- Mechanical or granular stabilisation, where the stability of soils is increased by blending the available soil with imported soil or aggregate so as to obtain a desired particle-size distribution, and a desired density by compacting and mixing. Compacting a soil at an appropriate moisture content is itself a form of mechanical stabilisation.

ii- Chemical stabilisation, by additives such as lime, cement, sodium silicate, calcium chloride and bituminous materials.

Practically, soil stabilisation is used to achieve one or more of the following:

- To improve the strength of subbase, base, and surface courses (in the case of low-cost roads)
- To bring about economy in the cost of a road
- To make use of locally available soils and other materials which are otherwise inferior.
- To eliminate or improve certain undesirable properties of soils, such as excessive swelling or shrinkage, high plasticity, difficulty in compacting, etc.
- To facilitate compaction and increase load bearing capacity
- To reduce frost susceptibility
- To reduce compressibility and thereby settlement
- To improve permeability characteristics

**Mechanical stabilisation**

It is the blending of different grades of soils to obtain the required grade. This method is done without adding any chemical material.

The principle of mechanical stabilisation covers the following specifications:

1. Soil-aggregate mixtures
2. Sand-clay mixtures
3. Sand-gravel mixtures
4. Stabilisation with soft aggregate

Improving the gradation of a raw soil by admixing a coarse and/or fine material *(usually 10 to 50 per cent)*, with the aim of achieving a dense homogeneous mass when compacted.

*Generally, the mechanical stabilisation *maximise* of the use of cheap locally available poorly-graded materials, e.g. dune- or river-deposited sands, silty sands, sandy clays, and silty clays.*

**Cement stabilisation**

Cement stabilisation of soils usually involves the addition of (5-15) % of Portland cement by volume of compacted mixture of soil being stabilised. This type is
most commonly used in subbase or base layers in major road pavements to
improve moisture-resisting and stability properties without much increasing its
elastic modulus and tensile strength. Nearly all types of soils can be stabilised
with cement (except organic soils). Factors which ensure that cement stabilisation
is widely used are:

- Cement is available in most countries at a relatively low price
- the use of cement usually involves less care and control than many other
  stabilisers
- more technical information is available on cement-treated soil mixtures
  than on other types of soil stabilisation
- most soils can be stabilised with cement if enough is used with the right
  amount of water and proper compaction and curing

The procedure of stabilising soils with cement involves the following:

1- Pulverising the soil
2- Mixing the required quantity of cement with the pulverised soil
3- Compacting the soil-cement mixture
4- Curing the compacted layer, a 7-day curing is preferred.

**Bituminous stabilisation**

With coarse-grained non-plastic soils, the main function of the bituminous
material is to add cohesive strength. Thus, the stabilization emphasis with
granular soils such as gravels and sands, and sandy soils, is upon the thorough
admixing of an optimum amount of binder so that particles are thinly coated with
binder and held together without loss of particle interlock.

The following are the variations in the bituminous stabilisation techniques:

- Sand-bitumen
- Soil-bitumen
- Soil-aggregate-bitumen
- Spraying bitumen on earth/gravel roads.

Bituminous stabilisation is carried out to achieve one or both of the following:

1- **Waterproofing the natural materials**, which means maintaining the water content at required level by providing a membrane that impedes the penetration of water. Thereby, reducing the effect of any surface water that may enter the soil when used as a base course. In addition, surface water is prevented from seeping into the subgrade, which protects the subgrade from failing due to increase in moisture content.

2- **Binding the natural materials**. This improves the durability characteristics of the natural soil by providing adhesive characteristics whereby the soil particles adhere to each other, increasing cohesion.

**Factors affecting bituminous stabilisation of soils:**

1- Nature and type of soil
2- Amount and type of asphalt
3- Mixing process
4- Compaction conditions
5- Curing conditions
6- Admixtures

Generally, bituminous stabilisation is most appropriately used in hot climatic areas where there is normally a need for additional fluid to be added to a soil at the time of construction, to ensure adequate mixing and compaction.
Lime stabilisation

It is one of the oldest ways to improving the engineering properties of soils, which can be used for stabilising both subgrade and subbase materials. In general, the oxides and hydroxides of calcium and magnesium are considered as lime. The materials that are most commonly used for lime stabilisation are:

1- High-Calcium quick lime, CaO, (only available as dry granular materials)
2- Dolomite quick lime, CaO+MgO
3- Hydrated High-Calcium lime, Ca(OH)$_2$, (available in both powder and slurry forms)
4- Normal hydrated dolomite lime, Ca(OH)$_2$+MgO
5- Pressure-hydrated dolomite lime, Ca(OH)$_2$+Mg(OH)$_2$

Lime uses in soil stabilisation

- As a modifier, to improve the soils, especially high plasticity soils, and the plasticity index can be reduced when lime is added.
- As an additive with cement to produce lime-cement stabilisation
- As an additive with bitumen to produce lime-bitumen stabilisation
- As an additive with fly ash to produce lime-fly ash stabilisation

The immediate modifying effect of lime upon soil plasticity has a corresponding effect on stability, and this is reflected in an equally-immediate increase in, for example, California Bearing Ratio test values. As curing time progresses, the CBRs increase further as the pozzolanic reactions begin to take effect and tensile and unconfined compressive strength gains occur.
**Quantity of lime**

The strength of a soil-lime mixture is greatly influenced by the amount of lime content used. A quantity of (3-10) % by weight of dry soil is normally required to stabilise most soils. Hydrated lime (Ca(OH)$_2$) in a powder form is preferred to CaO (quicklime) because of the dangers from burns that could happen to unprotected workmen when handling it.

*The figure below suggests recommendations for the type of soil stabilisation used in relation to the particle-size distributions and plasticity indices of soils that are generally suitable for stabilisation.*

![Guide to selecting a method of soil stabilisation](image)

*Should be taken as a broad guideline only.*

Figure: Guide to selecting a method of soil stabilisation.
Important questions:

1- What is the purpose of soil stabilisation?
2- What are the broad categories of soil stabilisation techniques available?
3- What is meant by mechanical stabilisation?
4- What are the principles behind mechanical stabilisation?
5- Describe the mechanism of soil-lime stabilisation.
6- What is the usual quantity of lime needed to stabilise soils?
7- What are the improvements in soil properties brought about by soil-lime stabilisation?
8- Describe the actions involved in soil-cement stabilisation.
9- What are the factors affecting soil-cement stabilisation?
10- What are the basic principles behind soil-bitumen stabilisation?