Advanced construction planning

Topic Objective:

At the end of this topic student would be able to:

- Define the term machine
- Describe the uses of machines
- Highlight the different types of machines

Definition/Overview:

Machine: The scientific definition of a "**machine**" (derived from the Latin machina) is any device that is not a computer that transmits or modifies energy. In common usage, the meaning is that of devices having parts that perform or assist in performing any type of work. Machines normally require some energy source ("input") and always accomplish some sort of work ("output"). Devices with no rigid moving parts can be considered tools.

Key Points:

1. **Machine**
   A machine is anything that makes work easier. People have used mechanisms to, or transform one form of motion or energy into another. The mechanical advantage of a simple machine is the ratio between the force it exerts on the load and the input force applied. This does not entirely describe the machine's performance, as force is required to overcome friction as well. The mechanical efficiency of a machine is the ratio of the actual mechanical advantage (AMA) to the ideal mechanical advantage (IMA). Functioning physical machines are always less than 100% efficient. Modern power tools, automated machine tools, and human-operated power machinery are tools that are also machines. Machines used to

transform heat or other energy into mechanical energy are known as engines. Compound machines are composed of more elementary machines called simple machines, such as the wedge and the pulley. Machines are considered simple machines if they perform their action in one movement. These devices may also be used to support industrial applications, although devices entirely lacking rigid moving parts are not commonly considered machines. Hydraulics are widely used in heavy equipment industries, automobile industries, marine industries, aeronautical industries, construction equipment industries, and earthmoving equipment industries. A machine is any device that uses energy to perform some activity. In common usage, the meaning is that of a device having parts that perform or assist in performing any type of work. A simple machine is a device that transforms the direction or magnitude of a force without consuming any energy. The word "machine" is derived from the Latin machina.

2. **Usage**

Historically, a device required moving parts to be classified as a machine; however, the advent of electronics technology has led to the development of devices without moving parts that are considered machinesthe computer being the most obvious example. "Engines" are machines that convert heat or other forms of energy into mechanical energy. For example, in an internal combustion engine the expansion of gases caused by the heat from an exothermic chemical reaction results in a force being applied to a movable component, such as a piston or turbine blade. Machines are ubiquitous in a wide variety of industrial, commercial, residential and transportation applications. Those employing hydraulics are especially useful in manufacturing and construction.

3. **Types of machines and related components**

Simple machines	Inclined plane, Wheel and axle, Lever, Pulley, Wedge, Screw
Mechanical components	Axle, Bearings, Belts, Bucket, Fastener, Gear, Key, Link chains, Rack and pinion, Roller chains, Rope,

	Seals, Spring, Wheel,	
Clock	Atomic clock, Chronometer, Pendulum clock, Quartz clock	
Compressors and Pumps	Archimedes' screw, Eductor-jet pump, Hydraulic ram, Pump, Tuyau, Vacuum pump	
Heat engines	External combustion engines	Steam engine, Stirling engine
	Internal combustion engines	Reciprocating engine, Gas turbine
Linkages	Pantograph, Peaucellier-Lipkin	
Turbine	Gas turbine, Jet engine, Steam turbine, Water turbine, Wind generator, Windmill	
Aerofoil	Sail, Wing, Rudder, Flap, Propeller	
Electronics	Vacuum tube, Transistor, Diode, Resistor, Capacitor, Inductor	
Miscellaneous	Robot, Vending machine, Wind tunnel,Check weighing machines, Riveting machines	

Topic : Fundamental Concepts Of Equipment Economics

Topic : Fundamental Concepts Of Equipment Economics

Topic Objective:

At the end of this topic student would be able to:

- Define the term engineering vehicles

- Describe the uses of engineering vehicles in industries
- Highlight the working of engineering vehicles.

Definition/Overview:

Engineering Vehicles: Engineering vehicles, known by the other terms: construction equipment, earth movers, heavy equipment or just plain equipment, are machines, specifically designed to execute civil engineering and construction engineering tasks.

Key Points:

1. **Specialized Manufacturing Industries**
   The scope of the specialized manufacturing industries covered by the previously mentioned engineering fields is broad, encompassing in no order: construction, logging, mining, waste management, military engineering and agriculture. These machines are most often associated with earthworks (engineering). These engineering vehicle machines, in the most basic form, are compound machines composed of simple machines. These components make up the five equipment systems: implement, traction, structure, power train, control and information. Through the mechanical advantage of a simple machine, the ratio between input force applied and force exerted is multiplied. Currently most equipment use hydraulics as a primary source of transfering power. The use of heavy equipment has a long history. Vitruvius a 1st century B.C. engineer gives detailed descriptions of Roman heavy equipment and Roman cranes in his treatise De Architectura.

   Heavy equipment requires specialized tires for various construction applications. While many types of equipment have continuous tracks applicable to more severe service requirements, tires are used where greater speed or mobility is required. An understanding of what equipment will be used for during the life of the tires is required for proper selection. Tire selection can have a significant impact on production and unit cost. There are three types of off-the-road tires, transport for earthmoving machines, work for slow moving earth moving machines, and load and carry for transporting as well as digging. Off-highway tires have six categories of service C compactor, E earthmover, G grader, L loader, LS log-skidder and ML mining and logging. Within these service categories are various tread types designed for use on hard-packed surface, soft surface and rock. Tires are a large expense on any construction project, careful consideration should be given to prevent excessive wear or damage.

Topic : Planning For Earthwork Construction

Topic Objective:

At the end of this topic student would be able to:

- Define the term earthworks
- Describe the issues with engineering
- Highlight the earth work construction difficulties

Definition/Overview:

Earthworks: Earthworks are engineering works created through the moving of massive quantities of soil or unformed rock

Key Points:

1. **Issues with Engineering**

Engineers need to concern themselves with issues of geotechnical engineering (such as soil fluidity and friction) and with quantity estimation to ensure that soil volumes in the cuts match those of the fills, while minimizing the distance of movement. In the past, such calculations were done by hand using a slide rule and with methods such as Simpson's rule; now they can be performed simply with a computer and specialized software. Due to the massive amounts of material to be moved millions of cubic yards in the case of large dams earthwork engineering was revolutionised by the development of the (Fresno) scraper and other earth-moving machines such as the loader, production trucks, the grader, the bulldozer, the backhoe and the dragline excavator. Typical earthworks include roads, dams, dikes, canal, bunding and berms ("noise mounds"). In military engineering, earthworks are, more specifically, types of fortifications constructed from soil. Although soil is not very strong, it is cheap enough that huge quantities can be used, generating formidable structures. Examples of older earthwork fortifications include moats, sod walls, motte-and-bailey castles and hill forts. Modern examples include trenches and berms.

The short service life and wide scale failure of earthworks on many roads in developing countries is a cause for concern. Such problems could be reduced significantly by using more appropriate earthwork design, protection and drainage as well as improving construction methods. However the relevant authorities usually do not have the appropriate technical resources to achieve this or the necessary funds to implement these better standards during road construction. An alternative strategy for prolonging the useful life of mountain road networks is to ensure that earthwork deterioration is arrested before it progresses to the stage of failure. To achieve this there are two requirements. The first is a means of assessing the condition of earthworks quickly and at low cost. This must be followed by a method of evaluating the data and providing the authorities with sufficient information to carry out timely repairs. In effect an earthwork project management system. Such a system has been developed at TRL- (Overseas Centre) and tested on a number of roads in Asia with encouraging results. It is based on recording earthworks using a helicopter and subsequently analysing the results under controlled conditions. Information is then entered into a database which forms the basis of the earthwork project management system. All of this can be achieved very quickly and at low cost. It means that the highway authority has no need to invest in expensive equipment, is provided with a comprehensive review of all earthwork problems and is given easy access to information that is needed in making decisions and allocating budgets.

2. **Earthwork construction difficulties**

   The construction of earthworks on mountain roads may account for fifty percent or more of the total road cost and therefore building such roads is inevitably expensive. Having incurred such a high initial expense many highway authorities are surprised to find that high repair costs for earthwork failures are exceedingly common. Such problems are most widespread in tropical countries where high rainfall or weak slope materials contribute to earthwork failure. The term earthwork is here used to describe cut-slopes, embankments and natural slopes modified in some way for road construction purposes.

3. **The Solution: A System Of Earthwork Management**

   Ideally earthworks should be monitored regularly, with new monitoring repeated every one to two years depending upon the importance of the road and the likely problems. A typical length of highway network may be 500 km and it is likely to involve 2,500 earthworks or more. The task can be undertaken by engineers, examining the slopes on foot taking notes. But usually this method is avoided because it is very time consuming and therefore costly. Engineering management systems, such as those for pavements, usually involve a method of recording the condition and then analysing the results under controlled conditions. Obviously this is a more difficult task in the case of earthworks because of the vast amount of terrain involved.

4. **An analysis covering a very wide range of earthwork features**

   The objectives of an earthwork assessment must be to identify areas where primary deterioration is occurring and rectify it. However this is not enough, the cause of the problem must be identified and steps taken to stop it re-occurring. This requires very detailed analyses of each situation. The analysis needs to be controlled by well defined procedures so that results are consistent. The system described here goes beyond the study of immediate problems by putting them in context with the overall condition of the highway. This is achieved by making a general inventory of the highway. A long term objective of such an inventory is to evaluate design methods and introduce improved practice.

5. **The storage of the information**

   The storage medium should take information for any number of earthworks and allow additional information to be added to it easily. Computer database systems are ideal for this purpose but the type must be chosen carefully and meet a range of conditions. Ideally the information about earthworks should have a criterion that places each individual slope in a hierarchy depending upon its need for attention. Information should be stored in groupings which reflect such a need.

6. **Providing easy access to information**

   Highway authorities need to use the information about earthworks in a number of ways including the requirement to make decisions about the allocation of maintenance resources, to organise priority repairs and to compare the overall condition of a highway. The information should be presented in a manner which aids these objectives.

7. **Methods of supporting the earthwork information**

   As well as providing details about individual earthwork problems and the overall condition of highways the earthwork project management system can provide a range of management 'tools'. These may assist the road authority to carry out tasks and make decisions. For example it can give guidelines about how repair-work should be allocated; provide the means of carrying out a wide range of -design tasks; list appropriate specifications for each task; cost the repair work for earthworks and provide a unique means of making risk assessments.

8. **Earthwork management system**

   In areas of the world where slope instability problems have been brought under control, for example Hong Kong, Brand (1 984), a rapid method of assessing earthwork condition has been found to be an important element in solving problems. Techniques to accomplish this earthwork condition assessment, including aerial photo-interpretation and photogrammetry, have been developed at TRL, Heath (1980). These techniques have been used on lengthy sections of highway on the Malaysian Peninsula, Heath et al. (1992), Sabah, and Nepal. They now form one element of the earthwork project management system being described.

Topic : Soil And Rock

Topic Objective:

At the end of this topic student would be able to:

- Define the term soil and rock
- Describe the components of soil
- Highlight the types and uses of rocks in construction

Definition/Overview:

Soil: Soil is the naturally occurring, unconsolidated or loose covering of broken rock particles and decaying organic matter (humus) on the surface of the Earth, capable of supporting life.

Rock: Rock is a naturally occurring solid aggregate of minerals and/or mineraloids. The Earth's outer solid layer, the lithosphere, is made of rock. In general rocks are of three types, namely, igneous, sedimentary, and metamorphic. The scientific study of rocks is called petrology, and petrology is an essential component of geology.

Key Points:

1. **Components of Soil**

   In simple terms, soil has three components: solid, liquid, and gas. The solid phase is a mixture of mineral and organic matter. Soil particles pack loosely, forming a soil structure filled with voids. The solid phase occupies about half of the soil volume. The remaining void space contains water (liquid) and air (gas). Soil is also known as earth: it is the substance from which our planet takes its name.

   Soil is the naturally occurring, unconsolidated or loose covering on the Earth's surface. Soil is composed of particles of broken rock that have been altered by chemical and environmental processes including weathering and erosion. Soil is different from its parent rock(s) source(s), altered by interactions between the lithosphere, hydrosphere, atmosphere, and the biosphere. It is a mixture of mineral and organic constituents that are in solid, gaseous and aqueous states. Soil particles pack loosely, forming a soil structure filled with pore spaces. These pores contain sol solution (liquid) and air (gas). Accordingly, soils are often treated as a three state system. Most soils have a density between 1 and 2 g/cm. Soil is also known as earth: it is the substance from which our planet takes its name. Little of the soil composition of the earth is older than Tertiary and most no older than Pleistocene.

2. **Soil forming factors**

   Soil formation, or pedogenesis, is the combined effect of physical, chemical, biological, and anthropogenic processes on soil parent material. Soil genesis involves processes that develop layers or horizons in the soil profile. These processes involve additions, losses, transformations and translocations of material that compose the soil. Minerals derived from weathered rocks undergo changes that cause the formation of secondary minerals and other compounds that are variably soluble in water, these constitutes are moved (translocated) from one area of the soil to other areas by water and animal activity. The alteration and movement of materials within soil causes the formation of distinctive soil horizons. The weathering of bedrock produces the parent material that soils form from. An example of soil development from bare rock occurs on recent lava flows in warm regions under heavy and very frequent rainfall. In such climates plants become established very quickly on basaltic lava, even though there is very little organic material. The plants are supported by the porous rock becoming filled with nutrient bearing water, for example carrying dissolved bird droppings or guano. The developing plant roots themselves gradually break up the porous lava and organic matter soon accumulates. But even before it does, the predominantly porous broken lava in which the plant roots grow can be considered a soil. How the soil "life" cycle proceeds is influenced by at least five classic soil forming factors that are dynamically intertwined in shaping the way soil is developed, they include: parent material, regional climate, topography, biotic potential and the passage of time.

3. **Parent material**

   The material from which soils form is called parent material, they include: weathered primary bedrock, secondary material transported from other locations, e.g. colluvium and alluvium, deposits that are already present but mixed or altered in other ways - old soil formations, organic material including peat or alpine humus, anthropogenic materials - like landfill or mine waste. Few soils form directly from the underlying rocks they develop on. The soils that do form directly from the breakdown or weathering of rocks are often called residual soils and they have the same general chemistry as their parent rocks. Most soils are derived from materials that have been transported from other locations by the wind, water and gravity. Some of these materials may have moved many miles or only a few feet. Windblown material called loess is common in the Midwest of North America and in central Asia and other locations. Glacial till is a component of many soils in the northern and southern latitudes and those formed near large mountains, and is the product of glacial ice moving over the ground, ice can break rock and larger stones into smaller pieces, it also can sort material into different sizes. As glacial ice melts, the melt water also moves and sorts material and deposits it varying distances from its origin. The deeper sections of the soil profile may have materials that are relatively unchanged from when they were deposited by water, ice, or wind.

Weather is the first stage in the transforming of parent material into soil material. In soils forming from bedrock, a thick layer of weathered material called saprolite may form. Saprolite is the result of weathering processes that include: hydrolysis (the replacement of a minerals cations with hydrogen ions), chelation from organic compounds, hydration - the absorption of water by minerals, dissolution by solution - where minerals are dissolved by water, and physical processes that include freezing/thawing or wetting/drying. The mineralogical and chemical composition of the primary bedrock material, plus physical features, including grain size and degree of consolidation plus the rate and type of weathering transforms it into different soil materials.

4. **Climate**

Soil formation is greatly dependent on the climate, and soils from different climate zones show distinctive characteristics. Temperature and moisture affect weathering and leaching. Wind moves sand and other particles from one location to another, especially in arid regions where there is no or little plant cover. The type and amount of precipitation influence soil formation by affecting the movement of ions and particles through the soil, aiding in the development of different soil profiles. Seasonal and daily temperature fluctuations affect the effectiveness of water in weathering parent rock material and affect soil dynamics, freezing and thawing is an affective mechanism to break up rocks and other consolidated materials. Temperature and precipitation rates affect biological activity, rates of chemical reactions, and types of vegetation cover.

5. **Topography**

Slope and surface orientation affect the moisture and temperature of soil and affect the rate of weathering of parent material. Steep slopes facing the sun are warmer. Steep land areas may erode faster that soil formation process or deposition rates add material, causing a net loss of topsoil. Low areas receive deposits from areas up slope, often producing deeper soils. Topography effects erosion and depositional rates; water moves materials from steep higher elevations to lower, flatter locations. Sediments along river banks, on flood plains and deltas have different textures, dependent on the rate and duration of water flow; fast moving water can move larger material along with fine material, while slow moving water moves finer material only. Water in rivers and wind with strong enough currents leave gravel, rocks, and sand behind while removing smaller sized particles which are deposited when the currents slow down. Bodies of water like lakes, ponds and shallow seas leave fine textured material, which form fine textured sediments like clay and silt

6. **Biological factors**

Plants, animals, fungi, bacteria and humans affect soil formation. Animals and micro-organisms mix soils and form burrows and pores allowing moisture and gases to seep into deeper layers. In the same way, plant roots open channels in the soils, especially plants with deep taproots which can penetrate many meters through the different soil layers bringing up nutrients from deeper in the soil. Plants with fibrous roots that spread out near the soil surface, have roots that are easily decomposed, adding organic matter. Micro-organisms, including fungi and bacteria affect chemical exchanges between roots and soil and act as a reserve of nutrients. Humans can impact soil formation by removing vegetation cover which promotes greater erosion and they can mix the different soil layers freely, restarting the soil formation process as less weathered material is mixed with and diluting the more developed upper layers.

Vegetation impacts soils in numerous ways; it can prevent erosion from rain or surface runoff, it shades soils - keeping them cooler and slows down the evaporation of soil moisture or can cause soils to dry out by transpiration. Plants can form new chemicals that break down or build up soil particles. Vegetation cover is dependent on climate, land form topography, and biological factors. Soil factors such as soil density, depth, chemistry, and Ph; plus temperature, and moisture levels greatly affect the type of plants that can grow in any given location. Dead plants and dropped leaves and stems of plants fall to the surface and decompose on the soil, where organisms feed on them and mix it with the upper soil layers; these organic compounds become part of the soil formation process, ultimately shaping the type of soil formed.

7. **Rocks**
   Igneous rocks are formed when molten magma cools and are divided into two main categories: plutonic rock and volcanic. Plutonic or intrusive rocks result when magma cools and crystallizes slowly within the Earth's crust (example granite), while volcanic or extrusive rocks result from magma reaching the surface either as lava or fragmental ejecta (examples pumice and basalt)

8. **Rock classification**
   Rocks are classified by mineral and chemical composition, by the texture of the constituent particles and by the processes that formed them. These indicators separate rocks into igneous, sedimentary and metamorphic. They are further classified according to particle size. The transformation of one rock type to another is described by the geological model called the rock cycle. Igneous rocks are formed when molten magma cools and are divided into two main categories: plutonic rock and volcanic. Plutonic or intrusive rocks result when magma cools and crystallizes slowly within the Earth's crust (example granite), while volcanic or extrusive rocks result from magma reaching the surface either as lava or fragmental ejecta (examples pumice and basalt)

Sedimentary rocks are formed by deposition of either clastic sediments, organic matter, or chemical precipitates (evaporites), followed by compaction of the particulate matter and cementation during diagenesis. Sedimentary rocks form at or near the Earth's surface. Mud rocks comprise 65% (mudstone, shale and siltstone); sandstones 20 to 25% and carbonate rocks 10 to 15% (limestone and dolostone) Metamorphic rocks are formed by subjecting any rock type (including previously-formed metamorphic rock) to different temperature and pressure conditions than those in which the original rock was formed. These temperatures and pressures are always higher than those at the Earth's surface and must be sufficiently high so as to change the original minerals into other mineral types or else into other forms of the same minerals (e.g. by recrystallisation). The three classes of rocks the igneous, the sedimentary and the metamorphic are subdivided into many groups. There are, however, no hard and fast boundaries between allied rocks. By increase or decrease in the proportions of their constituent minerals they pass by every gradation into one another, the distinctive structures also of one kind of rock may often be traced gradually merging into those of another. Hence the definitions adopted in establishing rock nomenclature merely correspond to selected points (more or less arbitrary) in a continuously graduated series

Topic : Compaction And Stabilization Equipment

Topic Objective:

At the end of this topic student would be able to:

- Define the term soil compaction and consolidation
- Describe the spring analogy
- Highlight the primary and secondary consolidation

Definition/Overview:

Soil compaction: Soil Compaction occurs when weight of livestock or heavy machinery compresses soil, causing it to lose pore space. Affected soils become less able to absorb rainfall, thus increasing runoff and erosion.

Consolidation: Consolidation is a process by which soils decrease in volume. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil. The magnitude of consolidation can be predicted by many different methods. In the Classical Method, developed by Karl von Terzaghi, soils are tested with an oedometer test to determine their compression index. This can be used to predict the amount of consolidation.

Key Points:

1. **Soil Compaction**
   The ability of a soil to recover from compaction depends on climate, mineralogy and fauna. Soils with high shrink-swell capacity, such as Vertisols, recover quickly from compaction where moisture conditions are variable (dry spells shrink the soil, causing it to crack). But clays which do not crack as they dry cannot recover from compaction on their own unless they host ground-dwelling animals such as earthworms the Cecil soil series is an example.
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2. **In construction**

Increasing the density of soil, along with its side effects of increased strength and decreased permeability, is usually desirable in earthwork construction and below building foundations. Compaction is accomplished by use of heavy equipment. In sands and gravels, the equipment usually vibrates, to cause re-orientation of the soil particles into a denser configuration. In silts and clays, a sheepsfoot roller is frequently used, to create small zones of intense shearing, which drives air out of the soil. The result of soil compaction is measured by determining the bulk density of the compacted soil and comparing it to a maximum density obtained from a compaction test, to determine the relative compaction.

When stress is removed from a consolidated soil, the soil will rebound, regaining some of the volume it had lost in the consolidation process. If the stress is reapplied, the soil will consolidate again along a recompression curve, defined by the recompression index. The soil which had its load removed is considered to be overconsolidated. This is the case for soils which have previously had glaciers on them. The highest stress that it has been subjected to is termed the preconsolidation stress. The over consolidation ratio or OCR is defined as the highest stress experienced divided by the current stress. A soil which is currently experiencing its highest stress is said to be normally consolidated and to have an OCR of one. A soil could be considered underconsolidated immediately after a new load is applied but before the excess pore water pressure has had time to dissipate.

3. **Spring analogy**
   The process of consolidation is often explained with an idealized system composed of a spring, a container with a hole in its cover, and water. In this system, the spring represents the compressibility or the structure itself of the soil, and the water which fills the container represents the pore water in the soil.

- The container is completely filled with water, and the hole is closed. (Fully saturated soil)

- A load is applied onto the cover, while the hole is still unopened. At this stage, only the water resists the applied load. (Development of excessive pore water pressure)
- As soon as the hole is opened, water starts to drain out through the hole and the spring shortens. (Drainage of excessive pore water)
- After some time, the drainage of water no longer occurs. Now, the spring alone resists the applied load. (Full dissipation of excessive pore water pressure. End of consolidation)

4. **Primary Consolidation**

   This method assumes consolidation occurs in only one-dimension. Laboratory data is used to construct a plot of strain or void ratio verses effective stress where the effective stress axis is on a logarithmic scale. The plot's slope is the compression index or recompession index. The equation for consolidation settlement of a normally consolidated soil can then be determined to be:

Where,

δ_c is the settlement due to consolidation.

C_c is the compression index.

e_0 is the initial void ratio.

H is the height of the soil.

σ_{zf} is the final vertical stress.

σ_{z0} is the initial vertical stress.

C_c can be replaced by C_r (the recompession index) for use in overconsolidated soils where the final effective stress is less than the preconsolidation stress. When the final effective stress is greater than the preconsolidation stress, the two equations must be used in combination to model both the recompression portion and the virgin compression portion of the consolidation process, as follows:

Where,

σzc is the preconsolidation stress of the soil.

5. **Secondary consolidation**

Secondary consolidation is the compression of soil that takes place after primary consolidation. Secondary consolidation is caused by creep, viscous behavior of the clay-water system, compression of organic matter, and other processes. In sand, settlement caused by secondary compression is negligible, but in peat, it is very significant. Secondary consolidation is given by the formula:

Where,

H0 is the height of the consolidating medium

e0 is the initial void ratio

Ca is the secondary compression index

6. **Time dependency**

The time for consolidation to occur can be predicted. Sometimes consolidation can take years. This is especially true in saturated clays because their hydraulic conductivity is extremely low, and this causes the water to take an exceptionally long time to drain out of the soil. While drainage is occurring, the pore water pressure is greater than normal because it is carrying part of the applied stress (as opposed to the soil particles).

7. **Stabilization**

Landslides can be triggered by many often concomitant causes. In addition to shallow erosion or reduction of shear strength caused by seasonal rainfall, causes triggered by anthropic activities such as adding excessive weight above the slope, digging at mid-slope or at the foot of the slope, can also be included. However, often individual phenomena join together to generate instability, also after some time has elapsed, which, other than in well-instrumented limited areas, do not allow a reconstruction of the evolution of the occurred landslide. It is therefore pointless, for the purpose of planning landslide hazard mitigation measures, to classify the work as a function of the phenomenon or of more important phenomena, renouncing any attempt to precisely describe all the causes or the conditions which, at different times, contribute to the occurrence of the landslide. Therefore, slope stabilisation methods in rock or in earth, can be collocated into three types of measure:

- Geometric methods, in which the geometry of the hillside is changed (in general the slope);
- Hydrogeological methods, in which an attempt is made to lower the groundwater level or to reduce the water content of the material;
- Chemical and mechanical methods, in which attempts are made to increase the shear strength of the unstable mass or to introduce active external forces (e.g. anchors, rock or ground nailing) or passive (e.g. structural wells, piles or reinforced ground) to contrast the destabilising forces.

The different type of material conditions the engineering solution adopted, although It always comes back, in principle, to the previously introduced classification.

8. **Soil slopes**

8.1. **Geometry modification**

The operation of re-profiling a slope with the aim of improving its stability, can be achieved through various procedures:

- Lowering the slope
- Positioning infill at the foot of the slope

8.2. **Slope re-profiling work**

Slopes can be reduced by digging out the brow of the slope. This is effective for correcting shallow forms of instability, where movement is limited to layers of ground near to the surface and when the slopes are higher than 5m. Moreover, the steps created in this way and suitably achieved also reduce surface erosion. However, caution should be exercised to avoid the onset of local breakage following the cuts made. Infill at the foot of the slope, instead, has a stabilising effect in the case of translational or deep rotational landslide, in which the landslide surface at the top submerges and describes a sub-vertical surface that re-emerges in the area at the foot of the slope. The choice of reducing the slope and infilling at the foot is rarely a problem since there are generally specific constraints to be respected at the top or at the foot of the slope.

Generally in slope stabilisation where there are no constraints (often this occurs for natural slopes) a combination of slope reduction and infilling at the foot of the slope is adopted to avoid heavy work of just one type. Included among work at the foot of the slope are the berm and some gravitational structures like gabions or reinforced ground, that is, concrete blocks. In the case of natural slopes the choice of re-profiling scheme is not so clear as in the case of artificial slopes. Often the profile is highly irregular with large areas of not recent natural creep, so that its shallow development can make some areas unserviceable as a cutting or infill point. Where the buried shape of the old landslide is complicated, depositing of infill material in one area can lead to destabilising another.

When planning this type of work the stepping effect of the cuts and infill should be taken into account: their beneficial influence on the increase in Safety Factor will be reduced in relationship to the size of the landslide under examination. Moreover, it is very important to ensure that neither the cuts nor the infill mobilise the existing or potential creep plane of the landslide. Generally, infilling at the foot of the landslide should be preferred to cutting at the top (to reduce weight at the top of the slope), since the latter solution proves to be often more expensive than the former. Moreover, in complex and compound landslides, infill at the foot of the slope, at the tip of the foot itself, has a lesser probability of interfering with the interaction of the individual landslide elements. An important aspect of stabilisation work that changes the morphology of the slope is that, in more precisely mechanical terms, effecting cuts and infill generates non-drained charge and discharge stresses. In fact, in the case of positioning infill, the safety factor SF, will be less in the short term than in the long term. In the case of effecting a cut in the slope, SF will be less in the long term rather than in the short term. therefore in both cases it is opportune to calculate the SF both in the short and the long term.

Finally, it should be remembered that the effectiveness of infill increases with time on condition that it is associated with an appropriate infill drainage system, obtained through an underlying drainage cover or appropriate shallow drainage. More generally therefore re-profiling systems are associated with and integrated by surficial protection of the slope against erosion and by regulation of meteoric waters through drainage systems made up of ditches and small channels (clad or unclad and prefabricated) to run off the water collected.

These surficial water regulation systems are obtained by modelling the land itself around the body of the landslide large ground diches in the case of incoherent material landslides) or by means of flexible suitably placed drainage pipes able to collect the water.

These provisions will serve the purpose of avoiding penetration of the landslide body by circulating water or into any cracks or fissures, further decreasing ground shear strength. A problem that could be caused by water near the surface of the hillside is the erosion of surface material due to water runoff. This proves hazardous in terms of stability since it tends to weaken the slope by removing material as well as triggering excess pressure due to the water flow. For defence against erosion, a series of solutions can be used, such as:

- Geomats
- Geogrids
- Brushwood mats

These measures share the superficial character of their installation given their low environmental impact.

Geomats: Geomats or rather anti-eroding biomats or bionets are purpose-made synthetic products for the protection and grassing of slopes subject to surface wash through two main erosion control mechanisms: the containment and reinforcement of the surficial ground; the protection from the impact of the raindrops.

Geogrids: Wicker or brushwood mats are made of vegetal material. Very long and flexible willow branches can be used, which are then covered with infill soil. Alternating stakes of different woody species are used and they are woven to form a barrier against the downward drag of the material eroded by the free water on the surface

9. **Draining techniques**

Drainage systems are adopted to reduce the neutral stresses in a potentially unstable hillside. In terms of safety for global stability, these measures translate into the lowering of the water level inside the mass, which consequently leads to reduction in pore-pressure in the ground and an increase in the shear strength available in particular along the potential creep surface. In relation to hillside morphology, the kinematism of movement predicted and to the depth of the creep surfaces, the reduction in pore-pressure by drainage can be obtained using shallow and deep drains. Usually, shallow drainage is adopted when the potential hillside movement is foreseen as shallow landslide affecting the ground to a depth of about 5-6m. When there is deeper surface slipping, deep drainage has to be introduced, but shallow drainage systems can be provided anyway with the aim of running off that aliquot of surficial water directly connected to seasonal rainfall.

9.1. **Shallow drainage**

9.2. **Deep drainage**

Deep drainage acts by modifying the filtration routes in the ground. Often they are more expensive than shallow drains, but they are usually more effective because they remove the quantity of water that induces instability in the hillside, from within the ground and diminish the neutral stresses directly where necessary. Deep drainage in earth slopes can be obtained by means of the following works: large diameter drainage wells equipped with sub-horizontal drains. These systems can have just a structural function, just a draining function or both. The draining elements are the microdrains, perforated and positioned sub-horizontally and fanned out, orientated uphill to favour water discharge by gravity.

The size of the wells is chosen with the aim of allowing the insertion and functioning of the perforation equipment for the microdrains. Generally, the minimum internal diameter to be adopted must be greater than 3.5 m, for drains with a length of 20 to 30 m. Longer drains require wells with a diameter of up to 8-10 m. To determine the network of microdrains planners have to take into consideration the makeup of the subsoil and the hydraulic regime of the slope, to provide for the correct number and distribution of the microdrains. The drainage in these wells is passive, realised by linking the bottom of adjacent wells by sub-horizontal perforations (provided with temporary sheathing pipes) in which the microdrains are placed at a gradient of about 15-20 and are equipped with microperforated PVC pipes, protected by non-filtering fabric along the draining length. Once all the drain is inserted in the hole and having embedded the latter in the ground, the temporary sheathing is completely removed and the head of the drain is cemented to the well. In this way a discharge line is created linking all the wells emerging to the surface downhill, where the water is discharged naturally without the help of raising pumps.

The wells are placed at such a distance apart that the individual collecting areas of the microdrains, appertaining to each well, are overlaid. In this way all the volume of the slope involved with the water table is drained. Medium-diameter drainage wells linked at the bottom. The technique involves the dry cutting with temporary sheathing pipes, of aligned drainage wells, with a diameter of 1200-1500 mm., positioned at an interaxis of 6-8 m., their bottoms linked together to a bottom tube for the discharge of drained water. In this way the water discharge takes place passively, due to gravity by perforated pipes with mini-tubes, positioned at the bottom of the wells themselves. The linking pipes, generally made of steel, are blind in the linking length and perforated or windowed in the length corresponding to the well. The wells have a concrete bung at the bottom and are filled, after withdrawal of the temporary sheathing pipe, with dry draining material and are closed with an impermeable clay bung.

In normal conditions, these wells reach a depth of 20-30 m, but, in especially favourable cases, a depth of even 50 m can be reached. Some of these wells have drainage functions across their whole section and others can be inspected. The latter serve for maintenance of the whole drainage screen. Such wells that can be inspected are also a support point for the creation of new drainage wells and access for the installation, also on a later occasion, for a range of sub-horizontal drains at the bottom or along the walls of the wells themselves, with the purpose of increasing the drainage capacity of the well.

- **Isolated wells fitted with drainage pumps**: This system provides for the installation of a drainage pump for each well. The distribution of the wells is established according to the permeability of the land to be drained, the lowering of the water pressure to be achieved and the area that has to be involved in this work, so that the water pressure area deriving from the depression fans generated by the single drainage points, responds to the needs of the plan. The use of isolated wells with a drainage pumps leads to high running costs and imposes a very time-consuming level of control and maintenance.

- **Deep drainage trenches**: Deep drainage trenches consist of unbroken cuts with a small cross-section that can be covered at the bottom with geofabric canvas having a primary filter function. They are filled with draining material that has a filtering function and exploits the passive drainage to carry away the drained water downhill. The effectiveness of these systems is connected to the geometry of the trench and the continuity of the draining material along the whole trench. As far as the geometry of the cut is concerned attention should be paid to the slope given to the bottom of the cut. In fact, deep drainage trenches do not have bottom piping that is inserted in the end part of the trench, downhill, where the depth of the cut is reduced until the campaign level is reached.
- **Drainage galleries fitted with microdrains**: Drainage galleries constitute a rather expensive stabilisation provision for large, deep landslide movements, to be carried out where the ground is unsuitable for cutting trenches or drainage wells and when it is impossible to work on the surface owing to a lack of space for the work machinery. Their effectiveness is due to the extensiveness of the area to be drained. Moreover, these drainage systems have to be realised on the stable part of the slope.The drainage systems are placed inside the galleries and are made up of microdrains, with lengths that can reach 5060 m and are spatially orientated in a suitable directions. The sizes of the galleries are conditioned by the need to insert the drain perforation equipment. For this reason the minimum transversal internal size of the galleries vary from a minimum of 2 m, when using special reduced size equipment, and to at least 3.5 m, when using traditional equipment.
- **Siphon drain**: This is a technique conceived and developed in France, which works like the system of isolated drainage wells but overcoming the inconvenience of installing a pump for each well. In fact, the system on the principle that once motion is triggered in the siphon tube, avoiding the entry of air into the loop, the motion is uninterrupted. For this reason, in this system, the condition that the two ends of the siphon tube are submerged in the water of the two permanent storage tanks, must always be checked.

This drain is created vertically starting from the campaign level, but can also be sub-vertical or inclined. The diameter of the well can vary from 100 to 300 mm; inside a PVC pipe is placed or a perforated or microperforated steel pipe, filled with draining material. The siphon drain in this way carries off of drainage water by gravity without the need for drainage pumps or pipes linking the bottom of each well. This system proves to be economically advantageous and relatively simple to set up even if it necessitates a programme of controls and maintenance.

- **Microdrains**: Microdrains is a simple to create drainage system with contained costs. They consist of small diameter perforations, made from surface locations, in trenches, in wells or in galleries. The microdrains are set to work in a sub-horizontal or sub-vertical position, according to the type of application.

10. **Reinforcement measure**

The stabilisation of the hillside in terms of an increase in the mechanical characteristics of the potentially unstable ground, can be effected by means of two different approaches:

- Insertion of reinforcement elements in the ground;
- The improvement of the mechanical characteristics of the ground volume affected by landslide through chemical, thermal or mechanical treatment

11. **Insertion of reinforcement elements in the ground**

This category of work uses:

- Large diameter wells supported by one or more crowns of consolidated and possibly reinforced earth columns;
- Anchors
- Networks of micropiles
- Nailing
- Geogrids for reinforced ground
- Cellular faces

Large diameter wells supported by one or more crowns of consolidated and possibly reinforced earth columns To guarantee slope stability it may be necessary to insert very rigid, strong element. These elements are large diameter full section or ring section reinforced concrete wells. The wells can have a circular or elliptical section. The depth of the static wells can reach 30-40m. Often the static stabilising action of the wells is integrated with a series of microdrains laid out radially on several levels, also to reduce pore-pressure, if it is hazardous.

The equilibrium of an unstable slope also can be achieved by increasing resistance to landsliding by means of the application of active forces to the unstable ground. These forces increase the normal stress and therefore resistance to friction along the creeping surface. Anchors can be applied for this purpose, linked at the surface to each other by a beam frame, which is generally made of reinforced concrete. Here, the anchors are installed at node points. The anchors are then fixed in a certainly stable place. They are usually realised with orthogonal axes to the slope surface and therefore, at first approximately orthogonal to the surface of the creep. The adoption of this system sometimes gives anchorage problems, as in the case of silt-clayey ground. In fact, where there is water or the anchors are embedded in a clayey sub-layer, the adherence of the anchor to the ground has to be assured. Moreover, it is opportune that the surface contained within the grid of the beam frame is protected, using geofabrics, in order to avoid erosion removing the ground underlying the beam frame.

12. **Networks of micropiles**

This solution provides for a plant of a series of micropiles that make up a three-dimensional grid, variably tilted and linked at the head by a rigid reinforced concrete mortise. This structure constitutes a reinforcement for the ground, inducing an intrinsic improvement of the ground characteristics incorporated in the micropiles. A measure of this type proves effective in cases of not very extensive landslide. The effectiveness of solutions with micropiles is linked to the possibility of inserting micropiles over the whole width of the landslide area. In the case of rotational landslides in soft clay, the piles contribute to increasing the resisting moment by friction on the upper part of the pile shaft found in the landslide. This functionality is usually valid for micropiles working using the point. In the case of suspended piles, strength is governed by the part of the pile offering the least resistance. As an operational method, those piles that destined to the most unstable area of the slope should be positioned first, subsequently those around the unstable area, in order to reduce any possible lateral ground displacements. Preliminary design methods for the micropiles, nowadays are entrusted to the use of codes that carry out numerical simulations, but which are subject to simplifications in the models that necessitate characterisations of rather precise potential landslide material.

13. **Nailing**

The soil nailing technique applied to temporarily and/or permanently stabilise natural slopes and artificial scarps, fall back on a fundamental principle in the field of construction technique: mobilising the intrinsic mechanical characteristics of the ground, such as cohesion and the angle of internal friction, so that the ground actively collaborates with the stabilisation work. Nailing, on a par with anchors, induce normal stress to the advantage of stability. One nailing solution is that of rapid response diffuse nailing: CLOUJET, where the nails are embedded in the ground by means of an expanded bulb obtained by means of injecting mortar at high pressure into the anchorage area. Drainage is an integral part of the CLOUJET project since the hydraulic regime, considered in the form of pore-pressure applied normally to the fractured surfaces, directly influences the characteristics of the system. The drained water, both through fabric and by means of pipes embedded in the ground with a pre-determined gradient, flows together at the foot of the slope where it is collected in a suitable collector parallel to the direction of the face. Another system suitable for stabilizing slopes and landslides is a soil nail and root technology (SNART). Here steel nails are inserted very rapidly into a slope by percussion, vibration or screw methods. Grid spacing is typically 0.8 to 1.5 m, nails are 25 to 50 mm in diameter and may be as long as 20 m. Nails are installed perpendicular to and through the failure plane (or potential failure plane), and as such are designed in bending and shear (rather than tension) using geotechnical engineering principles. Potential failure surfaces less than 2 m deep normally require the nails to be wider near the top, and is typically achieved with steel plates fastened at the nail heads. An effective and aesthetic facing to prevent soil loss between the nails can be designed using plant roots.

14. **Geogrids**

The geogrids are synthetic materials used to reinforce the ground. The insertion of geosynthetic reinforcements (generally in the direction in which the deformation has developed) therefore has the function of reinforcing the ground conferring greater stiffness and stability upon it and the capacity to be subjected to greater deformations without reaching fracture point.

15. **Cellular faces**

Cellular faces, also known by the name of "crib faces" are special supporting walls realised by means of head grids prefabricated in reinforced concrete or in wood (treated externally with preservatives). The heads have a length of about 1-2m and the work can also reach 5m in height. Compacted granular material is inserted in the spaces of the grid. The characteristic modularity of the system confers notable flexibility of use on its use both in terms of adaptability to the morphology of the ground and because the structure does not require any deep foundation other than a laying plane of lean concrete useful to make the support plane of the whole structure regular. This solution can also take vegetal ground into the grid spaces, to favour the camouflaging of the work into the surroundings by means of the vegetation rooting on the exposed face. Improvement in the mechanical characteristics of the soil volume affected by landslide by means of chemical, thermal or mechanical treatment Among the treatments belonging to the group of intrinsic improvements of a mechanical character in the ground, the technique of jet-grouting is often used, in particular as a substituting and/or integrating element for technologies used for the previously described structural measures. The phases of this work are:

- **PHASE I Perforation phase**: insertion, with perforation destroying the nucleus, of a set of poles into the ground up to the depth of treatment required by the project.
- **PHASE II Extraction and programmed injection phase**: injection of the mixture at very high pressure is done during the extraction phase of the set of poles. It is in this phase that through the

insistence of the jet in a certain direction for a certain interval of time, the effect is obtained by the speed of extraction and rotation of the set of poles, so that volumes of ground can be treated in the shape and size desired.

The high energy jet produces a mixture of the ground and a continuous and systematic "claquage" with only a local effect within the radius of action without provoking deformations at the surface that could induce negative consequences on the stability of adjacent constructions. The projection of the mixture at high speed through the nozzles, using the effect of the elevated energy in play, allows the modification of the natural disposition and mechanical characteristics of the ground in the desired direction and in accordance with the mixture used (cement, bentonite, water, chemical, mixtures etc.). Depending on the characteristics of the natural ground, the type of mixture used, and work parameters, compression strength from 1 to 500 kgf/cm (100 kPa to 50 MPa) can be obtained in the treated area

The realisation of massive consolidated ground elements of various shapes and sizes (buttresses and spurs) within the mass to be stabilised, is achieved by acting opportunely on the injection parameters. In this way the following can be obtained: thin diaphragms, horizontal and vertical cylinders of various diameter and generally any geometrical shapes. Another improvement system of the mechanical characteristics of the ground is that of thermal treatment of potentially unstable hillsides made up of clayey materials. Once on the railways, for the treatment of unstable slopes in clayey grounds, the lighting of wood or coal fires was used in holes dug into the slope, to harden the surrounding ground. In large diameter holes (from 200 to 400mm.), about 0.8-1.2m. apart and horizontally interconnected, burners were introduced to form cylinders of hardened clay. The temperatures reached were around 800C. These clay cylinders worked like piles giving greater shear strength to the creep surface. This system was useful for surface creep, as in the case of an embankment. In other cases the depth of the holes or the amount of fuel necessary led to either the exclusion of this technique or made the effort ineffective.

Other stabilisation attempts were made by using electro-osmotic treatment of the ground. This type of treatment is applicable only in clayey grounds. It consists of subjecting the material to the action of a continuous electrical field, introducing pairs of electrodes embedded in the ground. These electrodes, when current is introduced cause the migration of the ion charges in the clay. Therefore the inter-pore waters are collected in the cathode areas and they are dragged by the ion charges. In this way a reduction in water content is achieved. Moreover, by suitable choice of anodic electrode a structural transformation of the clay can be induced due to the ions freed by the anode triggering a series of chemo-physical reactions improving the mechanical characteristics of the unstable ground. This stabilisation method, however, is effective only in homogeneous clayey grounds. This condition is hard to find in unstable slopes, therefore electro-osmotic treatment, after some applications, has been abandoned.

16. **Soil slope stabilization With steel wire mesh**
    Steel wire mesh may be used for soil and rock slope stabilization. After leveling, the surface is covered by a steel-wire mesh, which is fastened to the slope and tensioned. It is a cost-effective approach.

- In Section 2 of this course you will cover these topics:
- Machine Equipment Power Requirements
- Dozers
- Scrapers
- Excavators
- Trucks And Hauling Equipment

Topic : Machine Equipment Power Requirements

Topic Objective:

At the end of this topic student would be able to:

- Define the term loader
- Describe the compact front end loaders
- Highlight the heavy equipment front loaders

Definition/Overview:

Loader: A loader is an engineering vehicle (often used in construction) that is primarily used to "load" material (asphalt, demolition debris, dirt, feed, gravel, logs, raw minerals, recycled material, rock, sand, wood chips, etc.) into or onto another type of machinery (dump truck, conveyor belt, feed-hooper, rail-car, etc.).

Key Points:

1. **Compact front end loaders**
   Popular additions to compact utility tractors and farm tractors are Front End Loaders, also referred to as a FEL. Compact utility tractors, also called CUTs are small tractors, typically with 18 to 50 horsepower and used primarily for grounds maintenance and landscape chores. There are 2 primary designs of compact tractor FELs, the traditional dogleg designed style and the curved arm style. John Deere Tractor manufactures a semi-curved loader design that does not feature the one piece curved arm, but also is not of the traditional two piece design. New Holland Ag introduced a compact loader with a one piece curved arm on its compact utility tractors, similar one piece curved arm loaders are now available on compact tractors on many brands including Case/Farmall, and some Montana and Kioti tractors. Kubota markets traditional loader designs on most of its compact tractors but now features a semi-curved loader design similar to the John Deere loader design on several of its small tractors. While the Front End Loaders on CUT size tractors are capable of many tasks, given their

relatively small size and low capacities when compared to commercial loaders, the compact loaders can be made more useful with some simple options. A Toothbar is commonly added to the front edge of a loader bucket to aid with digging. Some loaders are equipped with a Quick Attach (QA) system, the QA system allows the bucket to be removed easily and other tools to be added in its place. Common additions would include a set of Pallet Forks for lifting pallets of goods or a Bale Spear for lifting hay bales.

2. **Heavy equipment front loaders**

   A loader (also known as: bucket loader, front loader, front end loader, payloader, scoop loader, shovel, skip loader, and/or wheel loader) is a type of tractor, usually wheeled, sometimes on tracks, that has a front mounted square wide bucket connected to the end of two booms (arms) to scoop up loose material from the ground, such as dirt, sand or gravel, and move it from one place to another without pushing the material across the ground. A loader is commonly used to move a stockpiled material from ground level and deposit it into an awaiting dump truck or into a open trench excavation. The loader assembly may be a removable attachment or permanently mounted. Often the bucket can be replaced with other devices or tools--for example, many can mount forks to lift heavy pallets or shipping containers, and a hydraulically-opening "clamshell" bucket allows a loader to act as a light dozer or scraper. The bucket can also be augmented with devices like a bale grappler for handling large bales of hay or straw.

Large loaders, such as the Kawasaki 95ZV-2, John Deere 844J, Caterpillar 950H, Volvo L120E, Case 921E, or Hitachi ZW310 usually have only a front bucket and are called Front Loaders, whereas small loader tractors are often also equipped with a small backhoe and are called backhoe loaders or loader backhoes. The largest loader in the world is LeTourneau L-2350. Currently these large loaders are in production in the Longview, Texas facility. The L-

2350 uses a diesel electric propulsion system simlilar to that used in a locomotive. Each rubber tired wheel is driven by its own independent electric motor. Loaders are used mainly for uploading materials into trucks, laying pipe, clearing rubble, and digging. A loader is not the most efficient machine for digging as it cannot dig very deep below the level of its wheels, like a backhoe can. Their deep bucket can usually store about 3-6 cubic meters (exact number varies with the model) of earth. The front loader's bucket capacity is much bigger than a bucket capacity of a backhoe loader. Loaders are not classified as earthmoving machinery, as their primary purpose is other than earthmoving.

Unlike most bulldozers, most loaders are wheeled and not tracked, although track loaders are common. They are successful where sharp edged materials in construction debris would damage rubber wheels, or where the ground is soft and muddy. Wheels provide better mobility and speed and do not damage paved roads as much as tracks, but provide less traction. In construction areas loaders are also used to transport building materials - such as bricks, pipe, metal bars, and digging tools - over short distances. Loaders are also used for snow removal, using their bucket or a snowbasket, but usually using a snowplow attachment. They clear snow from streets, highways and parking lots. They sometimes load snow into dump trucks for transport. High-tip buckets are suitable for light materials such as chip, peat and light gravel and when the bucket is emptied from a height. Unlike backhoes or standard tractors fitted with a front bucket, many large loaders do not use automotive steering mechanisms. Instead, they steer by a hydraulically actuated pivot point set exactly between the front and rear axles. This is referred to as "articulated steering" and allows the front axle to be solid, allowing it to carry greater weight. Articulated steering provides better maneuverability for a given wheelbase. Since the front wheels and attachment rotate on the same axis, the operator is able to "steer" his load in an arc after positioning the machine, which can be useful. The tradeoff is that when the machine is "twisted" to one side and a heavy load is lifted high, it has a greater risk of turning over to the "wide" side. Front loaders gained popularity during the last two decades, especially in urban engineering projects and small earthmoving works. Many engineering vehicle manufacturers offer a wide range of loaders, the most notable are those of John Deere, Caterpillar, Case, Volvo, Komatsu, Liebherr and Kawasaki, being the longest, on-going manufacturer of articulated wheel loaders in the world. The term "loader" is also used in the debris removal field to describe the boom on a.

Topic : Dozers

Topic Objective:

At the end of this topic student would be able to:

- Define the term bulldozers
- Describe the uses of bulldozers in construction
- Highlight the uses of rippers

Definition/Overview:

Bulldozer: A **bulldozer** is a crawler (caterpillar tracked tractor), equipped with a substantial metal plate (known as a blade), used to push large quantities of soil, sand, rubble, etc, during construction work. The term "bulldozer" is often used to mean any heavy engineering vehicle, but precisely, the term refers only to a tractor (usually tracked) fitted with a dozer blade. That is the meaning used herein.

Ripper: The **ripper** is the long claw-like device on the back of the bulldozer. Rippers can come singly (single shank) or in groups of two or more (multi shank rippers). Usually, a single shank is preferred for heavy ripping. The ripper shank is fitted with a replaceable tungsten steel alloy tip.

Key Points:

1. **Bulldozer**

   Most often, bulldozers are large and powerful tracked engineering vehicles. The tracks give them excellent ground hold and mobility through very rough terrain. Wide tracks help distribute the bulldozer's weight over large area (decreasing pressure), thus preventing it from sinking in sandy or muddy ground. Extra wide tracks are known as 'swamp tracks'. Bulldozers have excellent ground hold and a torque divider designed to convert the engine's power into dragging ability , letting the bulldozer use its own weight to push very heavy things and remove obstacles that are stuck in the ground. The Caterpillar D9, for example, can easily tow tanks that weigh more than 70 tons. Because of these attributes, bulldozers are used to clear areas of obstacles, shrubbery, burnt vehicles, and remains of structures. Sometimes a bulldozer is used to push another piece of earthmoving equipment known as a "scraper". The towed Fresno Scraper, invented in 1883 by James Porteous, was the first design to enable this to be done economically, removing the soil from the cut and depositing it elsewhere on shallow ground (fill). Many dozer blades have a reinforced center section with this purpose in mind, and are called "bull blades." The bulldozer's primary tools are the blade and the ripper.

1.1. **Ripper**

Ripping rock lets the ground surface rock be broken into small rubble easy to handle and transport, which can then be removed so grading can take place. Agricultural ripping lets rocky or very hard earth be broken up so otherwise unploughable land can be farmed. For example, much of the best land in the California wine country consists of old lava flows. With heavy bulldozers such as the Caterpillar D9 and the Caterpillar D11 the lava is shattered, allowing agriculture. Also, hard earth can be ripped and decompacted to allow planting of orchards where trees could not otherwise grow.

1.2. **Blade**

The bulldozer blade is a heavy metal plate on the front of the tractor, used to push objects, and shoving sand, soil and debris. Dozer blades usually come in three varieties:

- A Straight Blade ("S-Blade") which is short and has no lateral curve, no side wings, and can be used for fine grading.
- A Universal Blade ("U-Blade") which is tall and very curved, and has large side wings to carry more material.
- A "S-U" combination blade which is shorter, has less curvature, and smaller side wings. This blade is typically used for pushing piles of large rocks, such as at a quarry.

In military use, dozer blades are fixed on combat engineering vehicles and can optionally be fitted on other vehicles, such as artillery tractors like the Type 73 or M8 Tractor. Combat applications for dozer blades include clearing battlefield obstacles and preparing fire positions.

2. **Modifications**

Bulldozers have been further modified over time to evolve into new machines which can work in ways that the original bulldozer cannot. One example is that loader tractors were created by removing the blade and substituting a large volume bucket and hydraulic arms which can raise and lower the bucket, thus making it useful for scooping up earth and loading it into trucks. Other modifications to the original bulldozer include making it smaller to let it operate in small work areas where movement is limited, such as in mining. A very small bulldozer is sometimes called a calfdozer: Some forms of bulldozers are commonly used in snow removal. Nevertheless, the original earthmoving bulldozers are still irreplaceable as their tasks are concentrated in deforestation, earthmoving, ground leveling, and road carving. Heavy bulldozers are mainly employed to level the terrain to prepare it for construction. The construction, however, is mainly done by small bulldozers and loader tractors.

Topic : Scrapers

Topic Objective:

At the end of this topic student would be able to:

- Define the term wheel tractor scraper
- Describe the history of tractor and scraper
- Highlight the purpose of hand scraper

Definition/Overview:

Wheel Tractor-Scraper: In civil engineering, a **wheel tractor-scraper** is a piece of heavy equipment used for earthmoving. The rear part has a vertically moveable hopper (also known as the bowl) with a sharp horizontal front edge. The hopper can be hydraulically lowered and raised. When the hopper is lowered, the front edge cuts into the soil or clay like a cheese plane and fills the hopper. When the hopper is full (8 to 34 m (10 to 45 yd) heaped, depending on type) it is raised, and closed with a vertical blade (known as the apron). The scraper can transport its load to the fill area where the blade is raised, the back panel of the hopper, or the ejector, is hydraulically pushed forward and the soil or clay load tumbles out. Then the empty scraper returns to the cut site and repeats the cycle.

Key Points:

1. **Wheel Tractor-Scraper**
   Scrapers can be very efficient on short hauls where the cut-and-fill areas are close together and have sufficient length to fill the hopper. The heavier scraper types have two engines ('tandem powered'), one driving the front wheels, one driving the rear wheels, with engines

up to 400 kW (550 horsepower). Scrapers were invented by LeTourneau in the 1930s. Two scrapers can work together in a push-pull fashion but this requires a long cut area.

The Fresno Scraper was invented in 1883 by the Scottish immigrant and entrepreneur James Porteous who, having worked with farmers in Fresno, California, had recognised the dependence of the Fresno Valley on irrigation and the requirement for a more efficient means of constructing canals and ditches in the sandy soil. In perfecting the design of his machine, Porteous made several revisions on his own and also traded ideas with William Deidrick, Frank Dusy, and Abijah McCall, who invented and held patents on similar scrapers. Porteous bought the patents held by Deidrick, Dusy, and McCall, gaining sole rights to the Fresno Scraper. The design of the Fresno Scraper forms the basis of most modern earthmoving scrapers, having the ability to not only scrape and move a quantity of soil, but also to discharge it at a controlled depth, thus quadrupling the volume which could be handled manually. The blade scooped up the soil, instead of merely pushing it along, and ran along a C-shaped bowl which could be adjusted in order to alter the angle of the bucket to the ground, so that the dirt could be deposited in low spots. This design was so revolutionary and economical that it has influenced the design of modern bulldozer blades and earth-movers to this day.

2. **History**

Between 1884 and 1910 thousands of Fresno scrapers were produced at the Fresno Agricultural Works which had been formed by Porteous, and used in agriculture and land levelling, as well as road and railroad grading and the general construction industry. They played a vital role in the construction of the Panama Canal and later served the US Army in World War I. It was one of the most important agricultural and civil engineering machines ever made. In 1991 the Fresno Scraper was designated as an International Historic Engineering Landmark by the American Society of Mechanical Engineers. It is featured prominently in the Fresno Metropolitan Museum.

3. **Hand Scraper**

A hand scraper is a single-edged tool used to scrape metal from a surface. This may be required where a surface needs to be trued, corrected for fit to a mating part, needs to retain oil (usually on a freshly ground surface), or even to give a decorative finish. Surface plates were traditionally made by scraping. Three raw cast surface plates, a flat scraper (as pictured at the top of the image) and a quantity of bearing blue (or Red Lead) were all that was required in the way of tools. Methodology, skill, patience and tenacity was to be supplied by the tradesman. The scraper in the center of the image is a three corner scraper and is typically used to deburr holes or the internal surface of bush type bearings. Bushes are typically made from bronze or a white metal. The scraper pictured at the bottom is a curved scraper. It has a slight curve in its profile and is also suitable for bush bearings, typically the longer ones.

The task of scraping has been the bane of most engineering apprentices, however its versatility and appropriateness far outweighs the hard work it requires, or is perceived to require. Its effective use requires skill and concentration. An often overlooked advantage of scraping is the ability to take the tool to the workpiece. When the workpiece weighs several tons and towers head and shoulders over the worker, the apprentice's solution of chucking it on the mill is impractical, if not outright impossible. A skilled craftsman can wield a scraper and turn out work that is the envy of his peers; it just takes more time than the usual methods. The man who scrapes is called a "hand". It is done by using a precision surface such as a surface plate or a straight edge as a standard (a straight edge in this context is not a ruler it is a miniature surface plate of extreme accuracy). A professional scraping tool will be a special made tool, not an old file. The standard is coated with a very thin coating of some material such as Prussian blue. The work piece and standard are touched together by gravity alone and the high spots on the work piece will be colored by the dye on the standard. These high spots are scraped off and the process repeated until there is an even spread of high spots which total about 60% or more of the surface area. If desired the surface can then be Frosted. A surface prepared in this way is superior to any prepared by machining or grinding operations, although lapping can equal it. Grinding and machining stresses the metal thermally and mechanically, scraping and lapping do not.

Scraping is the only method for producing an original set of flat surfaces from which one can transfer that accuracy through to other surfaces by means of grinding. Lapping and grinding do not achieve the long distance flatness scraping can, as they act on the entire surface rather than local high or low spots. Although well done scraping provides an extra measure of accuracy, for most applications it does not matter. A ground lathe bed or milling machine ways are perfectly adequate for almost all types of work. With precision ground surfaces, any oil film applied to the surface will lack the means to adhere to the surface, especially between two mating parts of exceptional finish. The oil film will be swept away leaving nothing but bare metal and the risk of seizure. Carefully scraping the surface will leave the original high quality surface intact, but provide many shallow depressions where the oil film can maintain its depth and surface tension. When scraping is used for this purpose it is more accurately called "frosting", "spotting" or "flaking" as opposed to actually fully scraping an accurate surface. Typically a scraped surface is scraped to highly accurate flatness and then "frosting" is applied over it for oil retention. The advantage of this oil retention "frosting" is debatable. It is claimed to stop the so called "stick-slip" phenomenon where a machine member might move in a jerky fashion rather than moving smoothly. Such frosting will definitely increase oil retention but will also drastically reduce bearing area and capacity. There is no possibility of achieving hydrodynamic bearing performance on normal sliding machine ways. The velocity is far too low. Most of the time the ways will run under boundary lubrication conditions while at the highest speeds it might achieve mixed lubrication. This makes oil additives important in ways lubrication. Scraping leaves a distinctive pattern on the surface. The marks of scraped ways are an indicator of precision in the ways. Absence of these markings, on some classes of machine, indicate an inferior product. Many manufacturers add "frosting" to machine ways on lower-cost models, which is a superficial surface treatment designed to give the impression of a scraped machine way.

Topic : Excavators

Topic Objective:

At the end of this topic student would be able to:

- Define the term excavators
- Describe the usage of excavators
- Highlight the operations and size of excavators.

Definition/Overview:

Excavators: An **excavator** is an engineering vehicle consisting of an articulated arm (boom, stick), bucket and cab mounted on a pivot (a rotating platform, like a Lazy Susan) atop an undercarriage with tracks or wheels. Their design is a natural progression from the steam shovel.

Key Points:

1. **Excavator**

2. **Usage of Excavator**

   Excavators are used in many roles:

- Digging of trenches, holes, foundations
- Material handling
- Brush cutting with hydraulic attachments

- Demolition
- General grading/landscaping
- Heavy lift, e.g. lifting and placing of pipes
- Mining, especially, but not only open-pit mining
- River dredging

3. **Configurations**
   Excavators come in a wide variety of sizes. The smaller ones are called a mini-excavator or compact excavator. One manufacturer's largest model weighs 84,980 kg (187,360 lb) and has a maximum bucket size of 4.5 m (5.9 yd). The same manufacturer's smallest mini-excavator weighs 1470 kg (3240 lb), has a maximum bucket size of 0.036 m (0.048 yd) and the width of its tracks can be adjusted to 89 cm (35 inches). Another company makes a mini excavator that will fit through a doorway with tracks that can be adjusted to only 70 cm (28 inches) wide.

4. **Excavator attachments**
   In recent years, hydraulic excavator capabilities have expanded far beyond excavation tasks with buckets. With the advent of hydraulic powered attachments such as a breaker, a grapple or an auger, the excavator is frequently used in many applications other than excavation. Many excavators feature quick-attach mounting systems for simplified attachment mounting, dramatically increasing the machine's utilization on the jobsite. Excavators are usually employed together with loaders and bulldozers. Most wheeled versions, and smaller, compact excavators have a small backfill (or dozer-) blade. This is a horizontal bulldozer-like blade attached to the undercarriage and is used for pushing removed material back into a hole. Bucket-wheel excavators are heavy equipment used in surface mining and civil engineering. They are among the largest vehicles ever constructed, and the biggest bucket-wheel excavator ever built, the MAN Takraf RB293, is the largest terrestrial vehicle in human history.

5. **Operation**

   The excavation component itself is a large rotating wheel mounted on an arm or boom. On the outer edge of the wheel is a series of scoops or buckets. As the wheel turns, the buckets remove soil or rock from the target area and carry it around to the backside of the wheel, where it falls onto a conveyor, which carries it up the arm toward the main body of the excavator. Additional conveyors then may carry it further; in some cases, several long conveyors are placed end-to-end, each supported by a large vehicular base (usually with caterpillar tracks).

6. **Size**

   Especially large bucket-wheel excavators, over 200 meters long and up to 100 meters in height, are used in German strip-mining operations, and are the largest earth-movers in the world. These tremendous machines can cost over $100 million, take 5 years to assemble, require 5 people to operate, weigh more than 13,000 tons, and have a theoretical capacity of more than 12,000 m/h. Specifically, the RB293 bucket wheel excavator manufactured by MAN Takraf is recognised by Guinness World Records as the largest land vehicle.

Topic : Trucks And Hauling Equipment

Topic Objective:

At the end of this topic student would be able to:

- Define the term trucks
- Describe the purpose of truck, engine and drive train
- Highlight the uses of hauling equipment in construction process

Definition/Overview:

Truck: A truck is a vehicle for carrying goods and materials. The word "truck" possibly derives ultimately from the Greek "trochos", meaning "wheel." In North America, the big wheels of wagons were called trucks

Key Points:

1. **Truck**
   The word "truck" possibly derives from the Greek "trochos" (τροχός = wheel). In North America, certain kinds of big wheels were called trucks. When the gasoline-engine driven trucks came into fashion, these were called "motor trucks." Lorry is a term from the United Kingdom and Ireland, but is only used for the medium and heavy types (see below), i.e. a van, a pickup or a Jeep would never be regarded as a "lorry." Other languages have loanwords based on these terms, such as the Malay language and the Spanish language in northern Mexico. In Australia and New Zealand a small vehicle with an open back is called a ute (short for "utility vehicle") or a pick-up and the word "truck" is reserved for larger vehicles. In the United States a commercial driver's license is required to drive any type of vehicle weighing more than 26,001 lb.

2. **Engine**
   Trucks can use all sorts of engines. Small trucks such as SUVs or pickups, and even light medium-duty trucks in North America and Russia will use gasoline engines. Most heavier trucks use four stroke turbo intercooler diesel engines, although there are alternatives. Huge off-highway trucks use locomotive-type engines such as a V12 Detroit Diesel two stroke engine. North American manufactured highway trucks almost always use an engine built by a third party, such as CAT, Cummins, or Detroit Diesel. The only exceptions to this are Volvo and its subsidiary Mack Trucks, which are available with own engines. Freightliner, Sterling Trucks and Western Star, subsidaries of DaimlerChrysler, are available with Mercedes-Benz

and Detroit Diesel engines. Trucks and buses built by the Navistar International can also contain International engines. The Swedish truckmaker Scania claims they stay away from the U.S.-market because of this third party tradition. In the European union all truck engines must comply with Euro 4 regulations, the regulations will become more restrictive in 2008 with the introduction of Euro 5. Formerly in Britain some lorries were coal-fired steam-powered: for more information see Traction engine.

3. **Drive-train**

Small trucks use the same type of transmissions as almost all cars which have either an automatic transmission or a manual transmission with synchronisers. Bigger trucks often use manual transmissions without synchronisers which have less bulk and weight although synchromesh transmissions are used in larger trucks as well. Transmissions without synchronisers known as "crash boxes" require double clutching for each shift, (which can lead to repetitive motion injuries), or a technique known colloquially as "floating," a method of changing gears which doesn't use the clutch, except for starts and stops, due to the physical effort of double clutching especially with non power assisted clutches, faster shifts, and less clutch wear. Double clutching allows the driver to control the engine and transmission revolutions to synchronize, so that a smooth shift can be made e.g. when upshifting, accelerator pedal is released and the clutch pedal is depressed while the gear lever is moved in to neutral, clutch pedal is then released and quickly pushed down again while the gear lever is moved to the next highest gear. Finally, the clutch pedal is released and accelerator pedal pushed down to obtain required engine rpms. Although this is a relatively fast movement perhaps a second or so while transmission is in neutral it allows the engine speed to drop and synchronize engine and transmission revolutions relative to the road speed. Downshifting is performed in a similar fashion except the engine speed is now required to increase (while transmission is in neutral) just a right amount in order to achieve the synchronisation for the smooth non-crunching gearchange. The so called skip changing is also widely used, in principle operation is the same but it requires neutral be held slightly longer than single gearchange. Common North American setups include 9, 10, 13, 15, and 18 speeds. Automatic and semi-automatic transmissions for heavy trucks are becoming more and more common, due to advances both in transmission and engine power. In Europe 8, 10 and 12 gears are common on larger trucks with manual transmission, while automatic or semiautomatic transmission would have anything from 5 to 12 gears. Almost all heavy trucks transmissions are of a "range (double H shift pattern) and split" type where range change and so called half gears or splits are air operated and always preselected before the main gears selection. In Europe more new trucks are being bought with automatic or semi-automatic transmission. This may be due the fuel consumption can be lowered and truck durability improved. The primary reason perhaps is the fact that such transmissions give a driver more time to concentrate on the road and traffic conditions.

4. **Chassis**

The chassis or frame of a truck is commonly constructed mainly of two beams, and several crossmembers. A truck chassis consists of two parallel straight C-shaped beams, or in some cases stepped or tapered beams, these held together by crossmembers. In most instances, gussets help attach the crossmembers to the beams. The "C-shape" of the beams has a middle vertical and longer side, and a short horizontal flange at each end; the length of the beams is variable. The chassis is usually made of steel, but can be made (whole or in part) of aluminium for a lighter weight. The integrity of the chemical composition (carbon, molybdenum, etc.) and structure of the beams is of uttermost importance to its strength, and to help prevent cracking or breaking of beams, and to help maintain rigidity and flexibility of the frame, welding, drilling and other types of modifications should not be performed by unlicenced persons. The chassis is the main structure of the truck, and the other parts attach to it. A tow bar may be found attached at one or both ends.

- In Section 3 of this course you will cover these topics:
- Finishing Equipment
- Drilling Rock And Earth
- Blasting Rock

- Aggregate Production

Topic Objective:

At the end of this topic student would be able to:

- Define the term concrete finisher
- Describe the uses and purpose of concrete finisher

Definition/Overview:

Concrete Finisher: A **concrete finisher**, also known as a cement mason, is a tradesman who works with concrete. The job entails placing, finishing, protecting and repairing concrete in engineering and construction projects.

Key Points:

1. **Concrete Finisher**
   Concrete finishers are often responsible for setting the concrete forms, ensuring they have the correct depth and pitch. Concrete finishers place the concrete either directly from the concrete wagon chute, concrete pump, concrete skip or wheelbarrow. They spread the concrete using shovels and rakes, sometimes using a straightedge back and forth across the top of the forms to screed, or level, the freshly placed concrete. After levelling the concrete, they smooth the surface using either a hand masonry trowel, a long handed bull float or powered floats. After the concrete has been leveled and floated, concrete finishers press an edger between the forms and the concrete to give a chamfered edge that is less likely to chip.

Topic : Drilling Rock And Earth

Topic Objective:

At the end of this topic student would be able to:

- Define the term drilling rig
- Describe the uses of cable tool rigs
- Highlight the process of auger drilling.

Definition/Overview:

Drilling Rig: A drilling rig is a machine which creates holes (usually called boreholes) and/or shafts in the ground. Drilling rigs can be massive structures housing equipment used to drill water wells, oil wells, or natural gas extraction wells or they can be small enough to be moved manually by one person. They sample sub-surface mineral deposits, test rock, soil and groundwater physical properties, and to install sub-surface fabrications, such as underground utilities, instrumentation, tunnels or wells. Drilling rigs can be mobile equipment mounted on trucks, tracks or trailers, or more permanent land or marine-based structures (such as oil platforms, commonly called 'offshore oil rigs'). The term "rig" therefore generally refers to the complex of equipment that is used to penetrate the surface of the earth's crust.

Cable tool Rigs: Cable tool rigs are a traditional way of drilling water wells internationally and in the United States. The majority of large diameter water supply wells, especially deep wells completed in bedrock aquifers, were completed using this drilling method. Although this drilling method has largely been supplanted in recent years by other, faster drilling techniques, it is still the most practicable drilling method for large diameter, deep bedrock wells, and in widespread use for small rural water supply wells.

Auger Drilling: Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the borehole by the blade of the screw.

RC Drilling; RC drilling is similar to air core drilling, in that the drill cuttings are returned to surface inside the rods. The drilling mechanism is a pneumatic reciprocating piston known as a hammer driving a tungsten-steel drill bit.

Diamond Core Drilling: Diamond core drilling (Exploration diamond drilling) utilises an annular diamond-impregnated drill bit attached to the end of hollow drill rods to cut a cylindrical core of solid rock.

Direct Push Technology: Direct push technology includes several types of drilling rigs and drilling equipment which advances a drill string by pushing or hammering without rotating the drill string. This should perhaps not properly be called drilling, however the same basic results (i.e. a borehole) are achieved. Direct push rigs include both cone penetration testing (CPT) rigs and direct push sampling rigs such as a Geoprobe. Direct push rigs typically are limited to drilling in unconsolidated soil materials and very soft rock.

Key Points:

1. **Drilling Rigs**

   Drilling rigs can be:

- Small and portable, such as those used in mineral exploration drilling, water wells and environmental investigations.
- Huge, capable of drilling through thousands of meters of the Earth's crust. Large "mud pumps" circulate drilling mud (slurry) through the drill bit and the casing, for cooling and removing the

"cuttings" while a well is drilled. Hoists in the rig can lift hundreds of tons of pipe. Other equipment can force acid or sand into reservoirs to facilitate extraction of the oil or mineral sample; and permanent living accommodation and catering for crews which may be more than a hundred. Marine rigs may operate many hundreds of miles or kilometres offshore with infrequent crew rotation.

2. **Drilling rig classification**

There are many types and designs of drilling rigs, with many drilling rigs capable of switching or combining different drilling technologies as needed. Drilling rigs can be described using any of the following attributes:

by power used

- Human: percussion is performed by pulling a rope over a pulley or a lever and rotary action (if any) by one or more workers, in manual well drilling.
- Electric: the rig is connected to a power grid usually produced by its own generators and uses electric motors to drive individual components such as drawworks, mud pumps and rotary tables.
- Mechanical: the rig uses torque converters, clutches, and transmissions powered by its own engines, often diesel
- Hydraulic: the rig primarily uses hydraulic power
- Pneumatic: the rig is primarily powered by pressurized air

by pipe used

- Cable: a cable is used to raise and drop the drill bit or drill string
- Conventional: uses metal or plastic drill pipe of varying types
- coil tubing: uses a giant coil of tube and a downhole drilling motor

by height

- single: can drill only single drill pipes, has no vertical pipe racks (most small drilling rigs)
- double: can store double pipe stands in pipe racks
- triple: can store stands composed of three pipes in the pipe rack (most large drilling rigs)
- quad: can store stands composed of four pipes in the pipe rack

by method of rotation or drilling method

- no rotation includes direct push rigs and most service rigs
- rotary table - rotation is achieved by turning a square or hexagonal pipe (the kelly) at drill floor level.
- top-drive - rotation and circulation is done at the top of the drillstring, on a motor that moves along the derrick.
- sonic - uses primarily vibratory energy to advance the drill string

by position of derrick

- conventional - derrick is vertical
- slant - derrick is at an angle (this is used to achieve deviation without an expensive downhole motor)

3. **Drill types**

There are a variety of drill mechanisms which can be used to sink a borehole into the ground. Each has its advantages and disadvantages, in terms of the depth to which it can drill, the type of sample returned, the costs involved and penetration rates achieved. There are two basic types of drills: drills which produce rock chips, and drills which produce core samples.

3.1. **Auger drilling**

Hollow stem Auger drilling is used for environmental drilling,geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits. Solid flight augers/bucket augers are used in construction drilling. In some cases, mine shafts are dug with auger drills. Small augers can be mounted on the back of a utility truck, with large augers used for sinking piles for bridge foundations. Auger drilling is restricted to generally soft unconsolidated material or weak weathered rock. It is cheap and fast.

3.2. **Percussion rotary air blast drilling (RAB)**

RAB drilling is used most frequently in the mineral exploration industry. The drill uses a pneumatic reciprocating piston-driven 'hammer' to energetically drive a heavy drill bit into the rock. The drill bit is hollow, solid steel and has ~20 mm thick tungsten rods protruding from the steel matrix as 'buttons'. The tungsten buttons are the cutting face of the bit. The cuttings are blown up the outside of the rods and collected at surface. Air or a combination of air and foam lift the cuttings. RAB drilling is used primarily for mineral exploration, water bore drilling and blast-hole drilling in mines, as well as for other applications such as engineering, etc. RAB produces lower quality samples because the cuttings are blown up the outside of the rods and can be contaminated from contact with other rocks. RAB drilling rarely achieves more than 150 metres depth as encountering water rapidly clogs the outside of the hole with debris, precluding removal of drill cuttings from the hole. This can be counteracted, however, with the use of 'stabilisers' also known as 'reamers', which are large cylindrical pieces of steel attached to the drill string, and made to perfectly fit the size of the hole being drilled. These have sets of rollers on the side, usually with tungsten buttons, that constantly break down cuttings being pushed upwards. The use of multiple high-powered air compressors, which push 900-1150cfm of air at 300-350psi down the hole also ensures drilling of a deeper hole up to ~1250m due to higher air pressure which pushes all rock cuttings and any water to the surface. This, of course, is all dependent on the density and weight of the rock being drilled, and on how worn the drill bit is.

3.3. **Air core drilling**

Air core drilling and related methods use hardened steel or tungsten blades to bore a hole into unconsolidated ground. The drill bit has three blades arranged around the bit head, which cut the unconsolidated ground. The rods are hollow and contain an inner tube which sits inside the hollow outer rod barrel. The drill cuttings are removed by injection of compressed air into the hole via the annular area between the innertube and the drill rod. The cuttings are then blown back to surface up the inner tube where they pass through the sample separating system and are collected if needed. Drilling continues with the addition of rods to the top of the drill string. Air core drilling can occasionally produce small chunks of cored rock. This method of drilling is used to drill the weathered regolith, as the drill rig and steel or tungsten blades cannot penetrate fresh rock. Where possible, air core drilling is preferred over RAB drilling as it provides a more representative sample. Air core drilling can achieve depths approaching 300 meters in good conditions. As the cuttings are removed inside the rods and are less prone to contamination compared to conventional drilling where the cuttings pass to the surface via outside return between the outside of the drill rob and the walls of the hole. This method is more costly and slower than RAB.

3.4. **Cable tool drilling**

Also sometimes called "spudders", these rigs raise and drop a drill string to finely pulverize the subsurface materials. The drill string is comprised of the upper drill rods, a set of "jars" (inter-locking "sliders" that help transmit additional energy to the drill bit and assist in removing the bit if it is stuck) and a drill bit. During the drilling process, the drill string is periodically removed from the borehole and a bailer is lowered to collect the drill cuttings (rock fragments, soil, etc.). The bailer is a bucket-like tool with a trapdoor in the base. If the borehole is dry, water is added so that the drill cuttings will flow into the bailer. When lifted, the bailer closes and the cuttings are then raised and removed. Since the drill string must be raised and lowered to advance the boring, casing (larger diameter outer piping) is typically used to hold back upper soil materials and stabilize the borehole. Cable tool rigs are simpler and cheaper than similarly sized rotary rigs, although loud and very slow to operate. The world record Cable Tool Well was drilled in New York to a depth of almost 12,000 feet. The common Bucyrus Erie 22 can drill down to about 1,100 feet. Since cable tool drilling does not use air to eject the drilling chips like a rotary, instead using a cable strung bailer, technically there is no limitation on depth.

3.5. **Reverse circulation (RC) drilling**

RC drilling utilises much larger rigs and machinery and depths of up to 500 metres are routinely achieved. RC drilling ideally produces dry rock chips, as large air compressors dry the rock out ahead of the advancing drill bit. RC drilling is slower and costlier but achieves better penetration than RAB or air core drilling; it is cheaper than diamond coring and is thus preferred for most mineral exploration work. Reverse circulation is achieved by blowing air down the rods, the differential pressure creating air lift of the water and cuttings up the inner tube which is inside each rod. It reaches the bell at the top of the hole, then moves through a sample hose which is attached to the top of the cyclone. The drill cuttings travel around the inside of the cyclone until they fall through an opening at the bottom and are collected in a sample bag. The most commonly used RC drill bits are 5-8 inches (12.720.32 cm) in diameter and have round metal 'buttons' that protrude from the bit, which are required to drill through rock and shale. As the buttons wear down, drilling becomes slower and the rod string can potentially become bogged in the hole. This is a problem as trying to recover the rods may take hours and in some cases weeks. The rods and drill bits themselves are very expensive, often resulting in great cost to drilling companies when equipment is lost down the bore hole. Most companies will regularly 'sharpen' the buttons on their drill bits in order to prevent this, and to speed up progress. Usually, when something is lost (breaks off) in the hole, it is not the drill string, but rather from the bit, hammer, or stabiliser to the bottom of the drill string (bit). This is usually caused by a blunt bit getting stuck in fresh rock, over-stressed metal, or a fresh drill bit getting stuck in a part of the hole that is too small, due to having used a bit that has worn to smaller than the desired hole diameter.

Although RC drilling is air-powered, water is also used, to reduce dust, keep the drill bit cool, and assist in pushing cutting back upwards, but also when collaring a new hole. A mud called liqui-pol is mixed with water and pumped into the rod string, down the hole. This helps to bring up the sample to the surface by making the sand stick together. Occasionally, 'super-foam' (AKA 'quik-foam') is also used, to bring all the very fine cuttings to the surface, and to clean the hole. When the drill reaches hard rock, a collar is put down the hole around the rods which is normally PVC piping. Occasionally the collar may be made from metal casing. Collaring a hole is needed to stop the walls from caving in and bogging the rod string at the top of the hole. Collars may be up to 60 metres deep, depending on the ground, although if drilling through hard rock a collar may not be necessary. Reverse circulation rig setups usually consist of a support vehicle, an auxiliary vehicle, as well as the rig itself. The support vehicle, normally a truck, holds diesel and water tanks for resupplying the rig. It also holds other supplies needed for maintenance on the rig. The auxiliary is a vehicle, carrying an auxiliary engine and a booster engine. These engines are connected to the rig by high pressure air hoses. Although RC rigs have their own booster and compressor to generate air pressure, extra power is needed which usually isn't supplied by the rig due to lack of space for these large engines. Instead, the engines are mounted on the auxiliary vehicle. Compressors on an RC rig have an output of around 1000 cfm at 500 psi (500 Ls-1 at 3.4 MPa). Alternatively, stand-alone air compressors which have an output of 900-1150cfm at 300-350 psi each are used in sets of 2, 3, or 4, which are all routed to the rig through a multi-valve manifold.

3.6. **Diamond core drilling**

The diamonds used are fine to microfine industrial grade diamonds. They are set within a matrix of varying hardness, from brass to high-grade steel. Matrix hardness, diamond size and dosing can be varied according to the rock which must be cut. Holes within the bit allow water to be delivered to the cutting face. This provides three essential functions; lubrication, cooling, and removal of drill cuttings from the hole. Diamond drilling is much slower than reverse circulation (RC) drilling due to the hardness of the ground being drilled. Drilling of 1200 to 1800 metres is common and at these depths, ground is mainly hard rock. Diamond rigs need to drill slowly to lengthen the life of drill bits and rods, which are very expensive. Core samples are retrieved via the use of a lifter tube, a hollow tube lowered inside the rod string by a winch cable until it stops inside the core barrel. As the core is drilled, the core lifter slides over the core as it is cut. An overshot attached to the end of the winch cable is lowered inside the rod string and locks on to the backend, located on the top end of the lifter tube. The winch is retracted, pulling the lifter tube to the surface. The core does not drop out the inside of the lifter tube when lifted because a "core lifter spring," located at the bottom of the tube allows the core to move inside the tube but not fall out.

Once a rod is removed from the hole, the core sample is then removed from the rod and catalogued. The Driller's offsider screws the rod apart using tube clamps, then each part of the rod is taken and the core is shaken out into core trays. The core is washed, measured and broken into smaller pieces using a hammer to make it fit into the sample trays. Once catalogued, the core trays are retrieved by geologists who then analyse the core and determine if the drill site is a good location to expand future mining operations. Diamond rigs can also be part of a multi-combination rig. Multi-combination rigs are a dual setup rig capable of operating in either a reverse circulation (RC) and diamond drilling role (though not at the same time). This is a common scenario where exploration drilling is being performed in a very isolated location. The rig is first set up to drill as an RC rig and once the desired metres are drilled, the rig is set up for diamond drilling. This way the deeper metres of the hole can be drilled without moving the rig and waiting for a diamond rig to set up on the pad

3.7. **Direct Push Rigs**

CPT rigs advance specialized testing equipment (such as electronic cones), and soil samplers using large hydraulic rams. Most CPT rigs are heavily ballasted (20 metric tons is typical) as a counter force against the pushing force of the hydraulic rams which are often rated up to 20kn. Alternatively, small, light CPT rigs and offshore CPT rigs will use anchors such as screwed-in ground anchors to create the reactive force. In ideal conditions, CPT rigs can achieve production rates of up to 250-300 meters per day. Geoprobe rigs use hydraulic cylinders and a hydraulic hammer in advancing a hollow core sampler to gather soil and groundwater samples. The speed and depth of penetration is largely dependent on the soil type, the size of the sampler, and the weight and power the rig. Direct push techniques are generally limited to shallow soil sample recovery in unconsolidated soil materials. The advantage of direct push technology is that in the right soil type it can produce a large number of high quality samples quickly and cheaply, generally from 50 to 75 meters per day. Rather than hammering, direct push can also be combined with sonic (vibratory) methods to increase drill efficiency.

3.8. **Hydraulic-rotary drilling**

Oil well drilling utilises tri-cone roller, carbide embedded, fixed-cutter diamond, or diamond-impregnated drill bits to wear away at the cutting face. This is preferred because there is no need to return intact samples to surface for assay as the objective is to strike a formation containing oil or natural gas. Sizable machinery is used, enabling depths of several kilometres to be penetrated. Rotating hollow drill pipes carry down bentonite and barite infused drilling muds to lubricate, cool, and clean the drilling bit, control downhole pressures, stabilize the wall of the borehole and remove drill cuttings. The mud travels back to the surface around the outside of the drill pipe, called the annulus. Examining rock chips extracted from the mud is known as mud logging. Another form of well logging is electronic and is frequently employed to evaluate the existence of possible oil and gas deposits in the borehole. This can take place while the well is being drilled, using Measurement While Drilling tools, or after drilling, by lowering measurement tools into the newly-drilled hole. The rotary system of drilling was in general use in Texas in the early 1900s. It is a modification of one invented by Fauvelle in 1845, and used in the early years of the oil industry in some of the oil-producing countries in Europe. Originally pressurized water was used instead of mud, and was almost useless in hard rock before the diamond cutting bit. The drilling and production of oil and gas pose a safety risk and a hazard to the environment from the ignition of the entrained gas causing dangerous fires and also from the risk of oil leakage polluting water, land and groundwater. For these reasons, redundant safety systems and highly trained personnel are required by law in all countries with significant production.

3.9. **Sonic (Vibratory) Drilling**

A sonic drill head works by sending high frequency resonant vibrations down the drill string to the drill bit, while the operator controls these frequencies to suit the specific conditions of the soil/rock geology. Resonance magnifies the amplitude of the drill bit, which fluidizes the soil particles at the bit face, allowing for fast and easy penetration through most geological formations. An internal spring system isolates these vibrational forces from the rest of the drill rig. **Drilling mud**, more formally known as drilling fluid, also known as spud mud (when beginning the drilling process), is a fluid used in operations to drill boreholes into the earth. Often used while drilling oil and natural gas wells and on exploration drilling rigs but can also be used for much simpler holes, such as water wells. The main classification scheme used broadly separates the mud into 3 categories based on the main component that makes up the mud:

- Water Based Mud (WBM). This can be sub divided into Dispersed and Non-Dispersed
- Non Aqueous or more commonly Oil Based Mud (OBM) this also includes synthetic oils (SBM).
- Gaseous or Pneumatic mud.

On a drilling rig, mud is pumped from the mud pits through the drill string where it sprays out of nozzles on the drill bit, cleaning and cooling the drill bit in the process. The mud then carries the crushed rock ("cuttings") up the annular space ("annulus") between the drill string and the sides of the hole being drilled, up through the surface casing, and emerges back at the surface. Cuttings are then filtered out at the shale shakers and the mud returns to the mud pits. The returning mud can contain natural gases or other flammable materials. These can collect in and around the shale shakers area or in other work areas. There is a potential risk of a fire, an explosion or a detonation occurring if they ignite. In order to prevent this safety measures have to be taken. Safety procedures, special monitoring sensors and explosion-proof certified equipment has to be installed, e.g. explosion-proof certified electrical wiring or control panels. The mud is then pumped back down and is continuously recirculated. After testing, the mud is treated periodically in the mud pits to give it properties that optimize and improve drilling efficiency.

4. **Function**

The main functions of a Drilling Mud can be summarised as follows:

4.1. **Remove cuttings from well**

Drilling fluid carries the rock excavated by the drill bit up to the surface. Its ability to do so depends on cutting size, shape, and density, and speed of fluid traveling up the well (annular velocity). These considerations are analogous to the ability of a stream to carry sediment; large sand grains in a slow-moving stream settle to the stream bed, while small sand grains in a fast-moving stream are carried along with the water. The mud viscosity is another important property, as cuttings will settle to the bottom of the well if the viscosity is too low.

4.2. **Other properties include:**

- Most drilling muds are thixotropic (i.e. they gel under static condition). This characteristic keeps the cuttings suspended when the mud is not moving during, for example, maintenance.
- Fluids that have shear thinning and elevated viscosities are efficient for hole cleaning.
- Higher annular velocity improves cutting transport. Transport ratio (transport velocity / lowest annular velocity) should be at least 50%.
- High density fluids may clean hole adequately even with lower annular velocities (by increasing the buoyancy force acting on cuttings). But may have a negative impact if mud weight is in excess of that needed to balance the pressure of surrounding rock (formation pressure), so mud weight is not usually increased for hole cleaning purposes.
- Higher rotary drill-string speeds introduce a circular component to annular flow path. This helical flow around the drill-string causes drill cuttings near the wall, where poor hole cleaning conditions occur, to move into higher transport regions of the annulus. Increased rotations are the best methods in high angle and horizontal beds.

4.3. **Suspend and release cuttings**

- Must suspend drill cuttings, weight materials and additives under a wide range of conditions.
- Drill cuttings that settle can causes bridges and fill, which can cause stuck-pipe and lost circulation.
- Weight material that settles is referred to as sag; this causes a wide variation in the density of well fluid. More frequently occurs in high angle and hot wells.
- high concentrations of drill solids are detrimental to;
  - drilling efficiency (it causes increased mud weight & viscosity which in turn increases maintenance costs and increased dilution)
  - Rate of Penetration (ROP) (increases horsepower required to circulate)
  - Mud properties that suspended must balanced with properties in cutting removal by solid control equipment.

- For effective solids controls, drill solids must be removed from mud on the 1st circulation from the well. If re-circulated, cuttings break into smaller pieces and are more difficult to remove.
- Conduct a test to compare the sand content of mud at flow line and suction pit (to determine whether cuttings are being removed).

4.4. **Control formation pressures**

- If formation pressure increases, mud density should also be increased, often with barite (or other weighting materials) to balance pressure and keep the wellbore stable. Unbalanced formation pressures will cause a blowout from pressured formation fluids.
- Hydrostatic pressure depends on mud weight and True Vertical Depth. If hydrostatic pressure is greater than or equal to formation pressure, formation fluid will not flow into the wellbore.
- Well control means no uncontrollable flow of formation fluids into the wellbore.
- Hydrostatic pressure also controls the stresses caused by tectonic forces, these may make wellbores unstable even when formation fluid pressure is balanced.
- If formation pressure is subnormal, air, gas, mist, stiff foam or low density mud (oil base) can be used.
- In practice, mud weight should be limited to the minimum necessary for well control and wellbore stability. If too great it may fracture the formation.

4.5. **Seal permeable formations**

- When mud column pressure exceeds formation pressure, mud filtrate invades the formation, and a filter cake of mud is deposited on the wellbore wall.
- Mud is designed to deposit thin, low permeability filter cake to limit the invasion.
- Problems occur if a thick filter cake is formed; tight hole conditions, poor log quality, stuck pipe, lost circulation and formation damage.
- in highly permeable formations with large pore throats, whole mud may invade the formation, depending on mud solids size;

- use bridging agents to block large opening, than mud solids can form seal.
- for effectiveness, bridging agents must be over the half size of pore spaces / fractures.
- Bridging agents (i.e calcium carbonate, ground cellulose).

o Depending on the mud system in use, a number of additives can improve the filter cake (i.e bentonite, natural & synthetic polymer, asphalt and gilsonite).

4.6. **Maintain wellbore stability**

o Chemical composition and mud properties must combine to provide a stable wellbore. Weight of mud must be within the necessary range to balance the mechanical forces.

o wellbore instability = sloughing formations can cause tight hole conditions, bridges and fill on trips (same symptoms indicate hole cleaning problems).

o wellbore stability = hole maintains size and cylindrical shape.

o if the hole is enlarged, it becomes weak and difficult to stabilize, causes problems (low annular velocities, poor hole cleaning, solids loading and poor formation evaluation)

o In sand and sandstones formations, hole enlargement can be accomplished by mechanical actions (hydraulic forces & nozzles velocities). Reduced by conservative hydraulics system. Good qualities filter cake containing bentonite to limit the enlargement.

o In shales, mud weight is usually sufficient to balance formation stress, and wells are usually stable. With water base mud, chemical differences cause interactions between mud & shale and can lead to softening. Highly fractured, dry, brittle shales can be extremely unstable (leading to mechanical problems).

o various chemical inhibitors can control mud / shale interactions (calcium, potassium, salt, polymers, asphalt, glycols and oil best for water sensitive formations)

o Oil (and synthetic oil) based drilling fluids are used to drill most water sensitive Shales in areas with difficult drilling conditions.

- To add inhibition, emulsified brine phase (calcium chloride) drilling fluids are used to reduce water activity and creates osmotic forces prevent adsorption of water by Shales.

4.7. **Minimizing formation damage**

- skin damage or any reduction in producing formation natural porosity and permeability (washout)
- most common damage;
  - mud or drill solid invade formation matrix
  - swelling of formation clays within reservoir, reduce permeability
  - precipitation of solids of mud filtrate to formations fluids or to the other fluids forming insoluble salts
  - mud filtrate & formation fluids forming an emulsion (blocking reservoir pores)
- Specially designed drill-in fluids or workover and completion fluids minimize formation damage.

4.8. **Cool, lubricate & support the bit and drilling assembly**

- Heat is generated from mechanical and hydraulic forces at the bit and when drill-string rotates and rubs against casing and wellbore.
- Cool and transfer heat away from source and lower to temperature than bottom hole.
- if not, bit, drillstring and mud motors would fail more rapidly.
- Lubricity base on Coefficient of friction. Oil and synthetic bases lubricate better than water based mud (but can be improved by the addition of lubricants).
- Amount of lubrication provided by drilling fluid depends on type & quantity of drill solids and weight materials + chemical composition of system.
- poor lubrication causes high torque and drag, heat checking of drillstring but aware these problem also caused by key seating, poor hole cleaning and incorrect bottom hole assemblies design.

- Drilling fluids also support portion of drill-string or casing through buoyancy. Suspend in drilling fluid, buoyed by force equal to weight (or density) of mud, so reducing hook load at derrick.
- Weight that derrick can support limited by mechanical capacity, increase depth so weight of drill-string and casing increase.
- when running long, heavy string or casing, buoyancy possible to run casing strings whose weight exceed a rigs hook load capacity.

4.9. **Transmit hydraulic energy to tools and bit**

- Hydraulic energy provides power to mud motor for bit rotation and for MWD (measurement while drilling) and LWD (logging while drilling) tools. Hydraulic programs base on bit nozzles sizing for available mud pump horsepower to optimize jet impact at bottom well.
- limited to;
  - pump horsepower
  - pressure loss inside drillstring
  - maximum allowable surface pressure
  - optimum flow rate
  - drillstring pressure loses higher in fluids higher densities, plastic viscosities and solids.
- low solids, shear thinning drilling fluids such as polymer fluids, more efficient in transmit hydraulic energy.
- depth can be extended by controlling mud properties.
- transfer information from MWD & LWD to surface by pressure pulse.

5. **Minimize impact on environment**

Mud is, with varying degree, toxic. It is also difficult and expensive to dispose of in an environmentally-friendly manner. A Vanity Fair article described the conditions at Lago Agrio, a large oil field in Ecuador where drillers were effectively unregulated. Texaco, the drilling company, left the used mud (and associated cuttings and crude oil) in unlined open-air pits, allowing it to contaminate both surface and underground waters. Storing mud properly is very expensive. After a decade of drilling, Texaco considered transferring the mud waste at Lago Agrio to concrete-lined pits, but estimated that it would cost over 4 billion dollars (US).

Topic : Blasting Rock

Topic Objective:

At the end of this topic student would be able to:

- Define the term rock blasting
- Describe the process of explosions

Definition/Overview:

Rock blasting: Rock Blasting is the controlled use of explosives to excavate or remove rock. It is a technique used most often in mining and civil engineering such as dam construction.

Key Points:

1. **Explosions**

   Explosions used to break up a rock formation and aid in the collection of ore is called blasting. There are two types of blasting: high velocity and low velocity. High velocity blasting uses explosives that have high rates of reactions and produce high pressures (i.e. high explosives). Low velocity blasting is done with explosives which have a low rate of reaction and thus low pressures (i.e. low explosives). Blasting is done in selected regions where the ore is available. The size of the ore after blasting varies. In 1990, 2.1 Tg of commercial explosives was consumed in the USA, representing an estimated expenditure of 3.5 to 4 billion 1993 dollars on blasting. Australia had the highest explosives consumption that year at 500 Tg, and the Scandinavian countries are also big blasters. It is an object of the present invention, at least in preferred embodiments, to provide a method of blasting rock that reduces the environmental impact of the blasting event. It is another object of the present invention, at least in preferred embodiments, to provide a method of blasting rock that results in improved rock fragmentation.

2. **Method for Blasting Rock**

The inventors have developed a method for blasting rock that significantly improves the quality and efficiency of a blasting event. These improvements have in part been realised from detailed research of the interference of subterranean stressfields propagated following actuation of groups of explosive charges in pre-drilled blastholes. The timing of initiation of the explosive charges, the grouping of the explosive charges, and the resulting patterns of stressfields interaction have profound effects upon the blasting event and the efficiency of rock fragmentation. In this way, the invention provides dramatic improvements to the methods of blasting of the prior art. Electronic detonators are preferably used with the method of the present invention because of their capacity for accurate timing with delay differences as low as 1 millisecond. However, the methods are not limited in this regard. In fact, any type of initiator system may be used in accordance with the invention, including traditional non-electric, electric, and electronic detonator systems.

According to the present invention there is provided a method of blasting a section of rock to cause fragmentation of the rock without excessive ground vibrations, the method comprising the steps of: providing two or more groups of blastholes in the rock, each group comprising from 2 to 7 blastholes each of which is adjacent to another of said blastholes within the group; loading each blasthole with an explosive charge; providing blast initiation means associated with each explosive charge; and inducing timed actuation of each explosive charge via the associated blast initiation means to propagate stressfields from each blasthole; wherein the explosive charges in adjacent blastholes within any group of blastholes are actuated within 5 ms of one another, whereby the stressfields from the blastholes within each group combine prior to dissipation to enhance fragmentation of the rock, and wherein a delay of at least 8 ms occurs between completion of actuation of explosive charges in any group of blastholes and commencement of actuation of explosive charges in any adjacent group of blastholes, whereby the combined stressfields that propagate from blastholes within any group of blastholes at least substantially dissipate prior to actuation of explosive charges within blastholes of any adjacent group of blastholes. By the present invention, it is possible in at least some embodiments to reduce the quantity of explosive material required for the blasting event as well as to reduce the environmental impact of the blast.

The determination of the number of holes, and as a result the total explosive charge to be used in any group of holes, has been achieved by detailed analysis of and research into blast vibration control techniques. The control of excessive rock vibration from lasting may be achieved through a number of means. Conventional charge weight scaling laws may be derived for the particular blasting site and applied to determine the maximum charge weight permissible to control vibration at the points of concern in the vicinity of the blast. Preferably, more sophisticated approaches can be used. A particularly effective approach is the use of statistical vibration models based on waveform superposition (for example, Blair, D. P., 1999. Statistical models for ground vibration and airblast, FRAGBLAST-Int. J. Blasting and Fragmentation 3:335-364 ("Blair 1999")). Blast waveforms from typical blastholes may be obtained experimentally for the blasting site and applied to the region of concern. The statistical vibration model may then be used to determine the appropriate charge weights to be used within each group within the blast field. Charge weights and the number of holes per group or per array within groups (as described hereinafter) may be varied across the blast field as vibration requirements change over the blast field. Thus, different blasting techniques within the scope of the invention may be used across a single blast field.

The way in which the present invention is implemented across a blast field may be consistent over the various groups of blastholes in the blast field. Alternatively, the way in which the invention is implemented may vary between groups of blastholes across the blast field, as may be required. This may be useful where the material (rock) being blasted varies across the blast field and/or where it is desired to provide different effects (or blast outcomes) across the blast field. In another embodiment, a blast in accordance with the invention may be combined with a blast of one or more sections of rock in the blast field that are not in accordance with the invention. This may be particularly advantageous adjacent the edges of the blast field where less fragmentation of the rock may be desired. In this embodiment it will be appreciated that at least two groups of blastholes in the rock are blasted in accordance with the method of the present invention. The inventors' detailed research into the use of such vibration control approaches has established that the most practical range of blastholes per group is between 2 and 7. Similarly, 8 ms has been found to be the minimum practical time delay between groups of holes that are initiated as described by this invention in order to achieve some control of blast vibration. Note that the actual initiation delays both within and between groups of holes may vary across the blast field as vibration requirements change over the blast field. Models such as that of Blair (1999) can be used to set these delay times to meet the specific blasting site requirements.

Preferably each group of blastholes comprises from 3 to 5 blastholes. In many blasting events 3 blastholes per group will be found to be satisfactory, but the particular number may vary as described. The group of blastholes may extend linearly along a single row or across rows, or they may be in adjacent rows with two or more blastholes in at least one of the rows. In the following embodiments the various blast designs are described with reference to at least one group of the two or more groups of blastholes referred to in the general definition of the present invention. As mentioned above, the blast design may be uniform across an entire blast field in which case each group of blastholes of the two or more groups of blastholes will have the same blast design. Alternatively, without departing from the spirit of the present invention, the blast design may vary across the blast field as between different groups of blastholes of the two or more groups of blastholes blasted in accordance with the present invention. In this case the blast design of one or more groups of blastholes may be different from one or more other groups of blastholes provided at other areas of the blast field. It is also possible that a section of the blast field may be blasted using conventional blasting techniques. In this case however the blast field will still include at least two groups of blastholes that are blasted in accordance with the method of the present invention. In this case the at least two groups of blastholes may be the same or different in blast design, as described above. The delay between completion of actuation of explosive charges in any group of blastholes and commencement of actuation of explosive charges in any adjacent group of blastholes may be longer than 8 ms, for example 25 ms or more.

The explosive charges in adjacent blastholes within any group of blastholes may be actuated at different times within 5 ms of each other or at substantially the same time. By "substantially the same time" as used throughout this specification is meant within 1 ms. preferably, the explosive charges in adjacent blastholes within any group of lastholes are actuated within about 1 to 3 ms of one another. In one embodiment the explosive charges in all blastholes within any group of blastholes are actuated within 5 ms of one another, preferably within about 1 to 3 ms of one another. A variety of different arrangements of explosive charge may be used in blastholes across a blast field. Commonly the explosive charge comprises a column of explosive material, and different embodiments of methods of blasting in accordance with the invention will be described hereinafter using columns of blasting material. In one embodiment, each blasthole in at least one group of the two or more groups of blastholes is loaded with an explosive charge that comprises a column of explosive material and that is associated with an initiation means comprising a single initiation device positioned in the column to produce a detonation head within the column such that the detonation head burns away from the initiation device, thereby to propagate the stressfields from the column.

In this embodiment, the at least one group of blastholes may comprise two or more arrays of one or more blastholes, the explosive material in different arrays within the same group being actuated at different times but the explosive material in two or more blastholes of any selected array being actuated at substantially the same time, with each blasthole from any selected array being adjacent to a blasthole of another array in the group. Thus, if two arrays of blastholes are provided in a group, these will alternate in a group of three or more blastholes. In this embodiment, the single initiation devices may be positioned at or adjacent (usually within 1 m of) the same or different ends of the columns in the different arrays. Thus, in one arrangement the initiation devices are positioned at or adjacent the same end of the columns of explosive material in the at least one group of blastholes, thereby to stagger progression of the detonation heads within at least two adjacent blastholes of the same group of blastholes. The initiation devices may be positioned in this arrangement adjacent the collar end of the columns, but preferably they are positioned at or adjacent the toe end of the columns of explosive material in the at least one group of blastholes.

In another arrangement, the at least one group of blastholes comprises two or more arrays of one or more blastholes, in at least one of the arrays the initiation device being positioned at a first end of each column for unidirectional actuation of each column in the at least one array in a first direction and in at least one other of the arrays the initiation device being located at a second end of each column in the at least one other array for unidirectional actuation thereof in a second direction, with each blasthole from any selected array being adjacent to a blasthole of any other array in the group. In a variation of this embodiment, the single initiation device in each column of the at least one group of blastholes may be positioned remote from the ends of the column. The initiation devices may be positioned about midway between the ends of the columns, but in one arrangement the initiation devices in adjacent columns of the at least one group of blastholes are offset relative to each other. This may stagger progression of the detonation heads within adjacent blastholes of the group. In another embodiment, each blasthole in at least one group of the two or more groups of blastholes is loaded with an explosive charge that comprises a column of explosive material and that is associated with an initiation means comprising a first and a second initiation device positioned at or adjacent opposite ends of the column to produce two detonation heads within the column such that the detonation heads burn away from each initiation device towards each other, thereby to propagate opposed stressfields from the column in the at least one group of blastholes that combine both with one another and with stressfields propagating from at least one adjacent blasthole in said group to enhance said fragmentation of the rock.

In this embodiment, advantageously in one arrangement the at least one group of blastholes comprises two or more arrays of one or more blastholes, the columns of explosive material in blastholes of different arrays within the same group being actuated by the first initiation devices at different times and by the second initiation devices at different times but the columns of explosive material in two or more blastholes of any selected array being actuated by the first initiation devices thereof at substantially the same time and by the second initiation devices thereof at substantially the same time, and wherein each blasthole from any selected array is adjacent to a blasthole in any other array in the group thereby to stagger progressive bidirectional actuation of said columns of explosive material in the blastholes within the at least one group of blastholes. In this arrangement the columns of explosive material in the blasthole or each blasthole of any selected array within the at least one group of blastholes is actuated by the first and second initiating devices at substantially the same time or at different times. If at different times, preferably the columns of explosive material in the blasthole or in each blasthole or each blasthole within the array is actuated by the second initiation device at a time when the detonation head from the actuation of the column by the first initiation device has travelled between about 51 and 95%, preferably between about 60 and 90% more preferably between about 75 and 85%, for example about 80% of the length of the column towards the second initiation device.

In a possible further embodiment, each blasthole in at least one group of the two or more groups of blastholes is loaded with an explosive charge that comprises a column of explosive material and the at least one group of blastholes comprises two or more arrays of one or more blastholes, wherein in at least one of the arrays the initiation means comprises a first and a second initiation device positioned at or adjacent opposite ends of each column of the array to produce two detonation heads within the column such that the detonation heads burn away from each initiation device towards each other, thereby to propagate opposed stressfields from the column that combine with one another, wherein in at least one other of the arrays the initiation means comprises a single initiation device positioned remote from the opposite ends of each column of the array to produce a single detonation head within the column that burns in opposite directions away from the initiation device, and wherein each blasthole from any selected array is adjacent to a blasthole in any other array in the at least one group of blastholes thereby to propagate stressfields from adjacent blastholes within the at least one group of blastholes that combine to enhance fracture. In this embodiment, preferably the single initiation device in each column of said at least one other array is disposed about midway along the column. The explosive material in each column of said at least one array is actuated by the first and second initiation devices at substantially the same time or at different times, for example as described above.

In yet another embodiment using first and second initiation devices in each column of explosive material within the at least one group of blastholes, the group need not be arranged in arrays. Thus, in this embodiment, the columns of explosive material in all of the blastholes within the at least one group of blastholes are actuated by the first initiation devices at different times to each other and by the second initiation devices at different times to each other. In this embodiment each column of explosive material may be actuated by the first initiation device at substantially the same time as it is actuated by the second initiation device or at different times, for example as described above. In another aspect of the present invention there is provided a blasting system for conducting the method according to the invention, the blasting system comprising: a plurality of explosive charges, each charge positioned in a corresponding blasthole; initiation means associated with each explosive charge for actuation thereof in response to appropriate signals; timing means to time actuation of each explosive charge in accordance with the requirements of the method; at least one blasting machine to provide control signals to each initiation means in the system.

Topic : Aggregate Production

Topic Objective:

At the end of this topic student would be able to:

- Define the term construction aggregate
- Describe the formation of aggregates
- Highlight the purpose and uses of aggregates

Definition/Overview:

Construction aggregate: Construction aggregate, or simply "aggregate", is a broad category of coarse particulate material used in construction, including sand, gravel, crushed stone, slag, and recycled concrete.

Key Points:

1. **Aggregates**
   Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Aggregates are also used as base material under foundations, roads, and railroads. To put it another way, aggregates are used as a stable foundation or road/rail base with predictable, uniform properties (e.g. to help prevent differential settling under the road or building), or as a low-cost extender that binds with more expensive cement or asphalt to form concrete. The American Society for Testing and Materials publishes an exhaustive listing of specifications for various construction aggregate products, which, by their individual design, are suitable for specific construction purposes. These products include specific types of coarse and fine aggregate designed for such uses as additives to asphalt and concrete mixes, as well as other construction uses. State transportation departments further refine aggregate material

specifications in order to tailor aggregate use to the needs and available supply in their particular locations.

Sources for these basic materials can be grouped into three main areas: Mining of mineral aggregate deposits, including sand, gravel, and stone; use of waste slag from the manufacture of iron and steel; and recycling of concrete, which is itself chiefly manufactured from mineral aggregates. In addition, there are some (minor) materials that are used as specialty lightweight aggregates: clay, pumice, perlite, and vermiculite. The advent of modern blasting methods enabled the development of quarries, which are now used throughout the world, wherever competent bedrock deposits of aggregate quality exist. In many places, good limestone, granite, marble or other quality stone bedrock deposits do not exist. In these areas, natural sand and gravel are mined for use as aggregate. Where neither stone, nor sand and gravel, are available, construction demand is usually satisfied by shipping in aggregate by rail, barge or truck. Additionally, demand for aggregates can be partially satisfied through the use of slag and recycled concrete. However, the available tonnages and lesser quality of these materials prevent them from being a viable replacement for mined aggregates on a large scale.

2. **Large Stone Quarry**

   Large stone quarry and sand and gravel operations exist near virtually all population centers. These are capital-intensive operations, utilizing large earth-moving equipment, belt conveyors, and machines specifically designed for crushing and separating various sizes of aggregate, to create distinct product stockpiles. Aggregate is needed for any kind of construction. Mineral aggregates will be used in ever-increasing quantities as long as economies remain stable. Roads, including these used to transport aggregate, require continual maintenance and rebuilding. Homes, offices, warehouses, shopping centers, and workplaces all require foundations composed of aggregate, as well as concrete footers, asphalt parking lots, manufactured bricks, blocks and poured walls. Corporations which specialize in mining and processing aggregates are likely to grow and consolidate. In fact, the purchase of small aggregate companies by large, global corporations is the dominant trend in the industry. As less-developed countries build their infrastructure, the worldwide demand for construction aggregates will continue to grow. This demand will increasingly be met by global aggregate companies such as Hanson Aggregates, Polaris Minerals, Martin Marietta Aggregates, Vulcan Materials Company, Lafarge, Oldcastle, Cemex, Samscreen and Perforated Screen Surfaces, Inc (PSSI).

According to the USGS, 2005 U.S. crushed stone production was 1.69 billion tonnes valued at $12.1 billion, of which limestone was 1,090 million tonnes valued at $7.49 billion from 1,904 quarries, granite was 263 million tonnes valued at $2.16 billion from 339 quarries, traprock was 130 million tonnes valued at $1.04 billion from 348 quarries, and the balance other kinds of stone from 597 quarries. Limestone and granite are also produced in large amounts as dimension stone. The great majority of the crushed stone moved by heavy truck from the quarry/plant to the first point of sale or use. According to the USGS, 2005 U.S. sand and gravel production was 1.27 billion tonnes valued at $7.46 billion, of which 294 million tonnes valued at $1.98 billion was used as concrete aggregates. The great majority of this was again moved by truck, instead of by electric train. Currently, total U.S. aggregate demand by final market sector was 30%-35% for non-residential building (offices, hotels, stores, manufacturing plants, government and institutional buildings, and others), 25% for highways, and 25% for housing.

- In Section 4 of this course you will cover these topics:

Asphalt Mix Produciton And Placement

Concrete And Concrete Equipment

Cranes

Draglines And Clamshells

Topic : Asphalt Mix Produciton And Placement

Topic Objective:

At the end of this topic student would be able to:

- Define the term asphalt
- Describe the uses of asphalt and rolled asphalt concrete
- Highlight the types of asphalt

Definition/Overview:

Asphalt: Asphalt is a sticky, black and highly viscous liquid or semi-solid that is present in most crude petroleums and in some natural deposits sometimes termed asphaltum. It is most commonly modeled as a colloid, with asphaltenes as the dispersed phase and maltenes as the continuous phase (though there is some disagreement amongst chemists regarding its structure). In U.S. terminology, asphalt (or asphalt cement) is the carefully refined residue from the distillation process of selected crude oils. Outside North America, the product is called bitumen.

Key Points:

1. **Uses of Asphalt**
   The primary use of asphalt (Bitumen) is in road construction, where it is used as the glue or binder for the aggregate particles. The road surfacing material is usually called 'asphalt concrete' in North America or simply 'asphalt' elsewhere. The apparent interchangeability of the words 'asphalt' and 'bitumen' causes confusion outside of the road construction industry despite quite clear definitions within industry circles.

2. **Rolled asphalt concrete**

   The largest use of asphalt is for making asphalt concrete for road surfaces and accounts for approximately 80% of the asphalt consumed in the United States. Roofing shingles account for most of the remaining asphalt consumption. Other uses include cattle sprays, fence post treatments, and waterproofing for fabrics. Asphalt road surface is the most widely recycled material in the US, both by gross tonnage and by percentage. According to a report issued by the Federal Highway Administration and the United States Environmental Protection Agency, 80% of the asphalt from road surfaces' that is removed each year during widening and resurfacing projects is reused as part of new roads, roadbeds, shoulders and embankments.

3. **Mastic asphalt**

   Mastic asphalt is a type of asphalt which differs from dense graded asphalt (asphalt concrete) in that it has a higher bitumen (binder) content, usually around 7-10% of the whole aggregate mix, as opposed to roller asphalt, which has only around 5% added bitumen. Another asphalt which is fast gaining global popularity is stone mastic asphalt (SMA). SMA's advantages over rolled asphalt is its high anti skid qualities due to its high aggregate density and the lack of void content (air pockets). Another advantage of SMA is its longer durability over alternative road asphalt surfaces, but its manufacture and application, if not controlled closely, can result in slippery road surfaces due to excess bitumen pooling (bleeding) onto the surface.

4. **Asphalt emulsion**

   A number of technologies allow asphalt to be mixed at much lower temperatures. These involve mixing the asphalt with petroleum solvents to form "cutbacks" with reduced melting point or mixtures with water to turn the asphalt into an emulsion. Asphalt emulsions contain up to 70% asphalt and typically less than 1.5% chemical additives. There are two main types of emulsions with different affinity for aggregates, cationic and anionic. Asphalt emulsions are used in a wide variety of applications. Chipseal involves spraying the road surface with asphalt emulsion followed by a layer of crushed rock or gravel. Slurry Seal involves the creation of a mixture of asphalt emulsion and fine crushed aggregate that is spread on the surface of a road. Cold mixed asphalt can also be made from asphalt emulsion to create pavements similar to hot-mixed asphalt, several inches in depth and asphalt emulsions are also blended into recycled hot-mix asphalt to create low cost pavements.

5. **Mixing with petroleum-contaminated soil**
   Sometimes asphalt can be mixed with the output from low-temperature thermal desorption.

6. **Alternatives**
   The world has become increasingly concerned over the global climate change problem in recent years due to the pollution that is released into the atmosphere. Most of the emissions are derived primarily from burning fossil fuels. This has led to the introduction of bitumen alternatives that are more environmentally friendly and non toxic. Bitumen can now be made from non-petroleum based renewable resources such as sugar, molasses and rice, corn and potato starches etc. To further help the environment bitumen can also be made from the waste material vacuum tower bottoms produced in the process of cleaning used motor oils which helps the recycling industries, this waste is normally disposed by burning or dumping into land fills. These new non-petroleum based bitumen binders can be colored, which thereby help reduce the temperatures of road surfaces which contribute to the Urban heat island which in turn contributes to global climate change. For millions of people living in and around cities, heat islands are of growing concern. This phenomenon describes urban and suburban temperatures that are 2 to 10F (1 to 6C) hotter than nearby rural areas Elevated temperatures can impact communities by increasing peak energy demand, air conditioning costs, air pollution levels, and heat-related illness and mortality. Fortunately, there are common-sense measures that communities can take to reduce the negative effects of heat islands, such as replacing conventional black asphalt road surfaces with the new pigmentable bitumen that gives lighter colors. Asphalt made with vegetable oil based binders was

patented by Colas SA in France in 2004 (Vegecol), Colas was originally owned by the Royal Dutch Shell.

A number of homeowners seeking an environmentally-friendly alternative to asphalt for paving have experimented with waste vegetable oil as a binder for driveways and parking areas in single-family applications. The earliest known test occurred in 2002 in Ohio, where the homeowner combined waste vegetable oil with dry aggregate to create a low-cost and non-polluting paving material for his 200-foot driveway. After five years, he reports the driveway is performing as well or better than petroleum-based materials.

7. **Sand**

One key ingredient of most roadstones is sand. Sand generally has a high water content. Boiling off this water is a large part of the energy cost of heating the aggregate, in turn a significant part of the overall cost of operation. The water content of sand also varies considerably, especially when stored outdoors, being typically of the order of some tens of percent of the overall mass of wet sand. Since sand takes the form of small grains, with a high surface area per unit volume, and binder attaches to the surface of the aggregates, the amount of dry sand in the mix is particularly critical to the overall blend; the moisture content must be measured and the equivalent dry weight calculated.

8. **Binder**

Binder comes in different grades known as "penetration" or "pen" grades, with values varying between around 30 and 300. The pen value is an expression of the depth to which a standard needle will penetrate the surface of the binder at a specified temperature (the higher the value, the softer the binder). This has an effect on the workability of hot asphalt and the stiffness of the asphalt when cooled. Lower pen values give harder wearing. Asphalt wearing courses are typically 35-50 pen, base courses will be higher, typically 200 or 300 pen. The coating plant may combine binder of different grades to achieve a grade between those held on site.

9. **Filler**

   Filler, as the name implies, fills the voids between aggregate grains and improves the wearing capabilities of the overall mix. It is stored and fed dry into the mix, during or after addition of binder. A common source of filler is fines from the heating process recovered by bag filters or wet filtration ponds from the exhaust of the heating drum.

Topic : Concrete And Concrete Equipment

Topic Objective:

At the end of this topic student would be able to:

- Define the term concrete
- Describe the composition of concrete
- Highlight the uses of concrete in construction

Definition/Overview:

Concrete: Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel limestone or granite, plus a fine aggregate such as sand), water, and chemical admixtures. The word concrete comes from the Latin word "concretus", which means "hardened" or "hard".

Key Points:

1. **Concrete**

   Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. The reactions are highly exothermic and care must be taken that the build-up in heat does not affect the integrity of the structure. Concrete is used to make pavements, architectural structures, foundations, motorways/roads, bridges/overpasses, parking structures, brick/block walls and footings for gates, fences and poles. More concrete is used than any other man-made material in the world. As of 2006, about seven billion cubic meters of concrete are made each yearmore than one cubic meter for every person on Earth. Concrete powers a $US 35-billion industry which employs more than two million workers in the United States alone. More than 55,000 miles of highways in America are paved with this material. The People's Republic of China currently consumes 40% of the world's cement/concrete production.

2. **Composition**

   There are many types of concrete available, created by varying the proportions of the main ingredients below. The mix design depends on the type of structure being built, how the concrete will be mixed and delivered, and how it will be placed to form this structure.

2.1. **Cement**

Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. English engineer Joseph Aspdin patented Portland cement in 1824; it was named because of its similarity in colour to Portland limestone, quarried from the English Isle of Portland and used extensively in London architecture. It consists of a mixture of oxides of calcium, silicon and aluminium. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay, and grinding this product (called clinker) with a source of sulfate (most commonly gypsum). High-temperature applications, such as masonry ovens and the like, generally require the use of a refractory cement; concretes based on Portland cement can be damaged or destroyed by elevated temperatures, but refractory concretes are better able to withstand such conditions.

2.2. **Water**

Combining water with a cementitious material forms a cement paste. The cement paste glues the aggregate together, fills voids within it, and allows it to flow more easily. Less water in the cement paste will yield a stronger, more durable concrete; more water will give an easier-flowing concrete with a higher slump. Impure water used to make concrete can cause problems, either when setting, or later on.

2.3. **Aggregates**

Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel and crushed stone are mainly used for this purpose. Recycled aggregates (from construction, demolition and excavation waste) are increasingly used as partial replacements of natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted. Decorative stones such as quartzite, small river stones or crushed glass are sometimes added to the surface of concrete for a decorative "exposed aggregate" finish, popular among landscape designers.

2.4. **Reinforcement**

Concrete is strong in compression, as the aggregate efficiently carries the compression load. However, it is weak in tension as the cement holding the aggregate in place can crack, allowing the structure to fail. Reinforced concrete solves these problems by adding metal reinforcing bars, glass fiber, or plastic fiber to carry tensile loads.

2.5. **Chemical admixtures**

Chemical admixtures are materials in the form of powder or fluids that are added to the concrete to give it certain characteristics not obtainable with plain concrete mixes. In normal use, admixture dosages are less than 5% by mass of cement, and are added to the concrete at the time of batching/mixing. The most common types of admixtures are:

- Accelerators speed up the hydration (hardening) of the concrete.
- Retarders slow the hydration of concrete, and are used in large or difficult pours where partial setting before the pour is complete is undesirable.
- Air-entrainers add and distribute tiny air bubbles in the concrete, which will reduce damage during freeze-thaw cycles thereby increasing the concrete's durability. However, entrained air is a trade-off with strength, as each 1% of air may result in 5% decrease in compressive strength.
- Plasticizers (water-reducing admixtures) increase the workability of plastic or "fresh" concrete, allowing it be placed more easily, with less consolidating effort. Superplasticizers (high-range water-reducing admixtures) are a class of plasticizers which have fewer deleterious effects when used to significantly increase workability. Alternatively, plasticizers can be used to reduce the water content of a concrete (and have been called water reducers due to this application) while maintaining workability. This improves its strength and durability characteristics.
- Pigments can be used to change the color of concrete, for aesthetics.
- Corrosion inhibitors are used to minimize the corrosion of steel and steel bars in concrete.
- Bonding agents are used to create a bond between old and new concrete.
- Pumping aids improve pumpability, thicken the paste, and reduce dewatering the tendency for the water to separate out of the paste.

3. **Mineral admixtures and blended cements**

   There are inorganic materials that also have pozzolanic or latent hydraulic properties. These very fine-grained materials are added to the concrete mix to improve the properties of concrete (mineral admixtures), or as a replacement for Portland cement (blended cements).

- **Fly ash:** A by product of coal fired electric generating plants, it is used to partially replace Portland cement (by up to 60% by mass). The properties of fly ash depend on the type of coal burnt. In general, silicious fly ash is pozzolanic, while calcareous fly ash has latent hydraulic properties.
- **Ground granulated blast furnace slag (GGBFS or GGBS):** A by product of steel production, is used to partially replace Portland cement (by up to 80% by mass). It has latent hydraulic properties.
- **Silica fume:** A by-product of the production of silicon and ferrosilicon alloys. Silica fume is similar to fly ash, but has a particle size 100 times smaller. This results in a higher surface to volume ratio and a much faster pozzolanic reaction. Silica fume is used to increase strength and durability of concrete, but generally requires the use of superplasticizers for workability.
- **High Reactivity Metakaolin (HRM):** Metakaolin produces concrete with strength and durability similar to concrete made with silica fume. While silica fume is usually dark gray or black in color, high reactivity metakaolin is usually bright white in color, making it the preferred choice for architectural concrete where appearance is important.

Topic : Cranes

Topic Objective:

At the end of this topic student would be able to:

- Define the term crane
- Describe the mechanical principle of working of crane
- Highlight the stability of crane

Definition/Overview:

Crane: A crane is a lifting machine equipped with a winder, wire ropes or chains and sheaves that can be used both to lift and lower materials and to move them horizontally. It uses one or more simple machines to create mechanical advantage and thus move loads beyond the normal capability of a human. Cranes are commonly employed in the transport industry for the loading and unloading of freight; in the construction industry for the movement of materials; and in the manufacturing industry for the assembling of heavy equipment.

Key Points:

1. **Crane: Mechanical principles**
   There are two major considerations that are taken into account in the design of cranes. The first is that the crane must be able to lift a load of a specified weight and the second is that the crane must remain stable and not topple over when the load is lifted and moved to another location.

2. **Lifting capacity**
   Cranes illustrate the use of one or more simple machines to create mechanical advantage.

- **The lever**. A balance crane contains a horizontal beam (the lever) pivoted about a point called the fulcrum. The principle of the lever allows a heavy load attached to the shorter end of the beam to be lifted by a smaller force applied in the opposite direction to the longer end of the beam. The ratio of the load's weight to the applied force is equal to the ratio of the lengths of the longer arm and the shorter arm, and is called the mechanical advantage.

- **The pulley**. A jib crane contains a tilted strut (the jib) that supports a fixed pulley block. Cables are wrapped multiple times round the fixed block and round another block attached to the load. When the free end of the cable is pulled by hand or by a winding machine, the pulley system delivers a force to the load that is equal to the applied force multiplied by the number of lengths of cable passing between the two blocks. This number is the mechanical advantage.
- **The hydraulic cylinder**. This can be used directly to lift the load or indirectly to move the jib or beam that carries another lifting device.

Cranes, like all machines, obey the principle of conservation of energy. This means that the energy delivered to the load cannot exceed the energy put into the machine. For example, if a pulley system multiplies the applied force by ten, then the load moves only one tenth as far as the applied force. Since energy is proportional to force multiplied by distance, the output energy is kept roughly equal to the input energy (in practice slightly less, because some energy is lost to friction and other inefficiencies).

3. **Stability of crane**

In order for a crane to be stable, the sum of all moments about any point such as the base of the crane must equate to zero. In practice, the magnitude of load that is permitted to be lifted (called the "rated load" in the US) is some value less than the load that will cause the crane to tip. Under US standards for mobile cranes, the stability-limited rated load for a crawler crane is 75% of the tipping load. The stability-limited rated load for a mobile crane supported on outriggers is 85% of the tipping load. Standards for cranes mounted on ships or offshore platforms are somewhat stricter due to the dynamic load on the crane due to vessel motion. Additionally, the stability of the vessel or platform must be considered. For stationary pedestal or kingpost mounted cranes, the moment created by the boom, jib, and load is resisted by the pedestal base or kingpost. Stress within the base must be less than the yield stress of the material or the crane will fail.

4. **Types of cranes**

4.1. **Railroad cranes**

A railroad crane is a crane with flanged wheels, used by railroads. The simplest form is just a crane mounted on a railroad car or on a flatcar. More capable devices are purpose-built. Different types of crane are used for maintenance work, recovery operations and freight loading in goods yards.

4.2. **Mobile crane**

The most basic type of mobile crane consists of a steel truss or telescopic boom mounted on a mobile platform, which may be rail, wheeled (including "truck" carriers) or caterpillar tracks. The boom is hinged at the bottom, and can be raised and lowered by cables or by hydraulic cylinders. A hook is suspended from the top of the boom by wire rope and sheaves. The wire ropes are operated by whatever prime movers the designers have available, operating through a variety of transmissions. Steam engines, electric motors and internal combustion engines (IC) have all been used. Older cranes' transmissions tended to be clutches. This was later modified when using IC engines to match the steam engines "max torque at zero speed" characteristic by the addition of a hydrokinetic element culminating in controlled torque converters. The operational advantages of this arrangement can now be achieved by electronic control of hydrostatic drives, which for size and other considerations is becoming standard. Some examples of this type of crane can be converted to a demolition crane by adding a demolition ball, or to an earthmover by adding a clamshell bucket or a dragline and scoop, although design details can limit their effectiveness. To increase the horizontal reach of the hoist, the boom may be extended by adding a jib to the top. The jib can be fixed or, in more complex cranes, luffing (that is, able to be raised and lowered).

4.3. **Telescopic crane**

A telescopic crane has a boom that consists of a number of tubes fitted one inside the other. A hydraulic or other powered mechanism extends or retracts the tubes to increase or decrease the total length of the boom. These types of booms are often used for short term construction projects, rescue jobs, lifting boats in and out of the water, etc. The relative compactness of telescopic booms make them adaptable for many mobile applications.

4.4. **Tower crane**

The tower crane is a modern form of balance crane. Fixed to the ground (or "jacked up" and supported by the structure as the structure is being built), tower cranes often give the best combination of height and lifting capacity and are used in the construction of tall buildings. To save space and to provide stability the vertical part of the crane is often braced onto the completed structure which is normally the concrete lift shaft in the center of the building. A horizontal boom is balanced asymmetrically across the top of the tower. Its short arm carries a counterweight of concrete blocks, and its long arm carries the lifting gear. The crane operator either sits in a cabin at the top of the tower or controls the crane by radio remote control from the ground, usually standing near the load. In the first case the operator's cabin is located at the top of the tower just below the horizontal boom. The boom is mounted on a slewing bearing and is rotated by means of a slewing motor. The lifting hook is operated by a system of sheaves.

A tower crane is usually assembled by a telescopic jib crane of smaller lifting capacity but greater height and in the case of tower cranes that have risen while constructing very tall skyscrapers, a smaller crane (or derrick) will sometimes be lifted to the roof of the completed tower to dismantle the tower crane afterwards. A self-assembling tower crane lifts itself off the ground using jacks, allowing the next section of the tower to be inserted at ground level. It is often claimed that a large fraction of the tower cranes in the world are in use in Dubai. The exact percentage remains an open question.

4.5. **Hammerhead crane**

The hammerhead, or giant cantilever, crane is a fixed-jib crane consisting of a steel-braced tower on which revolves a large, horizontal, double cantilever; the forward part of this cantilever or jib carries the lifting trolley, the jib is extended backwards in order to form a support for the machinery and counter-balancing weight. In addition to the motions of lifting and revolving, there is provided a so-called "racking" motion, by which the lifting trolley, with the load suspended, can be moved in and out along the jib without altering the level of the load. Such horizontal movement of the load is a marked feature of later crane design. Hammerhead cranes are generally constructed in large sizes, up to 350 tons.

The design evolved first in Germany around the turn of the 19th century and was adopted for use in British shipyards to support the battleship construction program from 1904-1914. The ability of the hammerhead crane to lift heavy weights was useful for installing large pieces of battleships such as armour plate and gun barrels. Hammerhead cranes were also installed in naval shipyards in Japan and in the USA. The British Government also installed a hammerhead crane at the Singapore Naval Base (1938) and later a copy of the crane was installed at Garden Island Naval Dockyard in Sydney (1951). These cranes provided repair support for the battle fleet operating far from Great Britain.

4.6. **Truck-mounted crane**

A crane mounted on a truck carrier provides the mobility for this type of crane. Generally, these cranes are designed to be able to travel on streets and highways, eliminating the need for special equipment to transport a crane to the jobsite. When working on the jobsite, outriggers are extended horizontally from the chassis then down vertically to level and stabilize the crane while stationary and hoisting. Many truck cranes possess limited slow-travelling capability (just a few miles per hour) while suspending a load. Great care must be taken not to swing the load sideways from the direction of travel, as most of the anti-tipping stability then lies in the strength and stiffness of the chassis suspension. Most cranes of this type also have moving counterweights for stabilization beyond that of the outriggers. Loads suspended directly over the rear remain more stable, as most of the weight of the truck crane itself then acts as a counterweight to the load. Factory-calculated charts (or electronic safeguards) are used by the crane operator to determine the maximum safe loads for stationary (outriggered) work as well as (on-rubber) loads and travelling speeds. Truck cranes range in lifting capacity from about 14.5 US tons to about 1300 US tons.

4.7. **Rough terrain crane**

A crane mounted on an undercarriage with four rubber tires that is designed for pick-and-carry operations and for off-road and "rough terrain" applications. Outriggers that extend horizontally and vertically are used to level and stabilize the crane for hoisting. These telescopic cranes are single-engine machines where the same engine is used for powering the undercarriage as is used for powering the crane, similar to a crawler crane. However, in a rough terrain crane, the engine is usually mounted in the undercarriage rather than in the upper, like the crawler crane.

4.8. **All Terrain Crane (AT's)**

A mobile crane which has the necessary equipment to travel with high speed on public roads/highways and on the job site in rough terrain with all wheel and crab steering. ATs combine the roadability of Truck-mounted Crane and the manoeuvrability of a Rough Terrain Crane. ATs have 2-9 axles and are designed for lifting loads up to 1200 metric tons.

4.9. **Crawler crane**

A crawler is a crane mounted on an undercarriage with a set of tracks (also called crawlers)that provide for the stability and mobility of the crane. Crawler cranes have both advantages and disadvantages depending on their intended use. The main advantage of a crawler is that they can move on site and perform lifts with very little set-up, as the crane is stable on its tracks with no outriggers. In addition, a crawler crane is capable of traveling with a load. The main disadvantage of a crawler crane is that they are very heavy, and cannot easily be moved from one job site to the next without significant expense. Typically, a large crawler must be disassembled and moved by trucks, rail cars or ships to be transported to its next location.

4.10. **Gantry crane**

A gantry crane has a hoist in a trolley which runs horizontally along gantry rails, usually fitted underneath a beam spanning between uprights which themselves have wheels so that the whole crane can move at right angles to the direction of the gantry rails. These cranes come in all sizes, and some can move very heavy loads, particularly the extremely large examples used in shipyards or industrial installations. A special version is the container crane (or "Portainer" crane, named after the first manufacturer), designed for loading and unloading ship-borne containers at a port.

4.11. **Overhead crane**

Also known as a "suspended crane", this type of crane works in the same way as a gantry crane but without uprights. The hoist is on a trolley which moves in one direction along one or two beams, which move at right angles to that direction along elevated tracks, often mounted along the side walls of an assembly area in a factory. Some of them can lift very heavy loads.

4.12. **Floating crane**

Floating cranes are used mainly in bridge building and port construction, but they are also used for occasional loading and unloading of especially heavy or awkward loads on and off ships. Some floating cranes are mounted on a pontoon, others are specialized crane barges with a lifting capacity exceeding 10,000 tons and have been used to transport entire bridge sections. Floating cranes have also been used to salvage sunken ships. Crane vessels are often used in offshore construction. The largest revolving cranes can be found on SSCV Thialf, which has two cranes with a capacity of 7,100 metric tons each.

4.13. **Aerial crane**

Aerial cranes usually extend from helicopters to lift large loads. Helicopters are able to travel to and lift in areas that are more difficult to reach by a conventional crane. Aerial helicopter cranes are most commonly used to lift units/loads onto shopping centers, multi-story buildings, highrises, etc. However, they can lift basically anything within their lifting capacity, (i.e. cars, boats, swimming pools, etc.). They also work as disaster relief after natural disasters for clean-up, and during wild-fires they are able to carry huge buckets of water over fires to put them out.

Examples include:

- Sikorsky S-64 Skycrane/Erickson Air Crane - civilian version
- CH-54 Tarhe - military version
- Mi-26 - Russian flying crane helicopter
- 234 Chinook - Boeing Helicopters/Columbia Helicopters tandem rotor heavy lift

4.14. **Jib crane**

A jib crane is a type of crane where a horizontal member (jib or boom), supporting a moveable hoist, is fixed to a wall or to a floor-mounted pillar. Jib cranes are used in industrial premises and on military vehicles. The jib may swing through an arc, to give additional lateral movement, or be fixed. Similar cranes, often known simply as hoists, were fitted on the top floor of warehouse buildings to enable goods to be lifted to all floors.

Topic : Draglines And Clamshells

Topic Objective:

At the end of this topic student would be able to:

- Define the term dragline excavation systems
- Describe the components of dragline excavation systems
- Highlight the uses and importance of dragline excavation systems

Definition/Overview:

Dragline excavation systems: Dragline excavation systems are heavy equipment used in civil engineering and surface mining. In civil engineering the smaller types are used for road and port construction. The larger types are used in strip-mining operations to move overburden above coal, and for tar-sand mining. Draglines are amongst the largest mobile equipment (not water-borne), and weigh in the vicinity of 2000 metric tonnes, though specimens weighing up to 13,000 metric tonnes have also been constructed.

Key Points:

1. **Dragline Bucket System**
   A dragline bucket system consists of a large bucket which is suspended from a boom (a large truss-like structure) with wire ropes. The bucket is maneuvered by means of a number of ropes and chains. The hoistrope, powered by large diesel or electric motors, supports the bucket and hoist-coupler assembly from the boom. The dragrope is used to draw the bucket assembly horizontally. By skillful maneuver of the hoist and the dragropes the bucket is controlled for various operations.

2. **Operation**
   In a typical cycle of excavation, the bucket is positioned above the material to be excavated. The bucket is then lowered and the dragrope is then drawn so that the bucket is dragged along the surface of the material. The bucket is then lifted by using the hoist rope. A swing operation is then performed to move the bucket to the place where the material is to be dumped. The dragrope is then released causing the bucket to tilt and empty. This is called a dump operation. The bucket can also be 'thrown' by winding up to the jib and then releasing a clutch on the drag cable. This would then swing the bucket like a pendulum. Once the bucket had passed the vertical, the hoist cable would be released thus throwing the bucket. On smaller draglines, a skilled operator could make the bucket land about one-half the length of the jib further away than if it had just been dropped. On larger draglines, only a few extra metres may be reached.

3. **Draglines in mining**

A large dragline system used in the open pit mining industry costs approximately US$50-100 million. A typical bucket has a volume ranging from 30 to 60 cubic metres, though extremely large buckets have ranged up to 168 cubic metres. The length of the boom ranges from 45 to 100 metres. In a single cycle it can move up to 450 metric tonnes of material. Most mining draglines are not fuel powered like most other mining equipment. Their power consumption is so great that they have a direct connection to the high-voltage grid at voltages of between 6.6 to 22 kV. A typical dragline, with a 55 cubic metre bucket, can use up to 6 megawatts during normal digging operations. Because of this, many (possibly apocryphal) stories have been told about the blackout-causing effects of mining draglines. For instance, there is a long-lived story that, back in the 1970s, if all seven of the Peak Downs (a very large coal mine in central Queensland, Australia) draglines turned simultaneously, they would black out all of North Queensland.

In all but the smallest of draglines, movement is accomplished by "walking" using feet or pontoons, as caterpillar tracks place too much pressure on the ground, and have great difficultly under the immense weight of the dragline. Maximum speed is only at most a few hundred metres per hour since the feet must be repositioned for each step. If travelling medium distances, (about 30-100 km), a special dragline carrier can be brought in to transport the dragline. Above this distance, disassembly is generally required. Researchers at CSIRO in Australia have a long-term research project into automating draglines and have moved over 250,000 tonnes of overburden under computer control.

4. **Limitations**

The primary limitations of draglines are their boom height and boom length, which limits where the dragline can dump the waste material. Another primary limitation is their dig depth, which is limited by the length of rope the dragline can utilize. Inherent with their construction, a dragline is most efficient excavating material below the level of their base. While a dragline can dig above itself, it does so inefficiently and is not suitable to load piled up material (like a rope shovel can). Despite their limitations, and their extremely high capital cost, draglines remain popular with many mines, due to their reliability, and extremely low waste removal cost. Draglines have different cutting sequences. The first is the side cast method using offset benches; this involves throwing the overburden sideways onto blasted material to make a bench. The second is a key pass. This pass cuts a key at the toe of the new highwall and also shifts the bench further towards the low-wall. This may also require a chop pass if the wall is blocky. A chop pass involves the bucket being dropped down onto an angled highwall to scale the surface. The next sequence is the slowest operation, the blocks pass. However, this pass moves most of the material. It involves using the key to access to bottom of the material to lift it up to spoil or to an elevated bench level. The final cut if required is a pull back, pulling material back further to the low-wall side.

- In Section 5 of this course you will cover these topics:
- Piles And Pile-Driving Equipment
- Air Compressors And Pumps
- Planning For Building Construction
- Forming Systems

Topic : Piles And Pile-Driving Equipment

Topic Objective:

At the end of this topic student would be able to:

- Define the term pile driver and diesel pile hammer
- Describe the uses of pile driver
- Highlight the types of pile driver and their uses.

Definition/Overview:

Pile Driver: A pile driver is a mechanical device used to drive piles into soil to provide foundation support for buildings or other structures. The term is also used in reference to members of the construction crew that work with pile-driving rigs.

Diesel Pile Hammer: A modern diesel pile hammer is a very large two-stroke diesel engine. The weight is the piston, and the apparatus which connects to the top of the pile is the cylinder.

Hydraulic Hammer: A hydraulic hammer is a modern type of piling hammer used in place of diesel and air hammers for driving steel pipe, precast concrete, and timber piles.

Vibratory Pile Hammers: Vibratory pile hammers contain a system of counter-rotating eccentric weights, powered by hydraulic motors, and designed in such a way that horizontal vibrations cancel out, while vertical vibrations are transmitted into the pile.

Key Points:

1. **Pile Driver**
   One traditional type of Pile driver includes a heavy weight placed between guides so that it is able to freely slide up and down in a single line. It is placed upon a pile. The weight is raised, which may involve the use of hydraulics, steam, diesel, or manual labour. As the weight reaches its highest point. The weight is then released and smashes on to the pile in order to drive it into the ground.

2. **Types**

   Ancient pile driving equipment used manual or animal labor to lift heavy weights, usually by means of pulleys, to drop the weight onto the end of the pile. Modern piledriving equipment uses various methods to raise the weight and guide the pile.

3. **Diesel hammer**

   Piledriving is started by having the weight raised by auxiliary means - usually a cable from the crane holding the pile driver - which draws air into the cylinder. The weight is dropped, using a quick-release. The weight of the piston compresses the air, heating it to the ignition point of diesel fuel. Diesel fuel is added/injected into the cylinder. The mixture detonates, transferring the energy of the falling weight to the pile head, and driving the weight back up. The rising weight draws in more fuel-air mixture, and the cycle starts over until the fuel runs out or is stopped by the pile crew. From an army manual on pile driving hammers:

   The initial start up of the hammer requires the piston (ram) to be raised to a point where the trip automatically releases the piston, allowing it to fall by gravity. As the piston falls, it activates the fuel pump, which discharges a metered amount of fuel into the ball pan of the impact block. The falling piston also blocks the exhaust ports, and compression of fuel trapped in the cylinder begins. The compressed air exerts a pre-load force (approx. 44,000 lbs. or 20,000 kg.) to hold the impact block firmly against the drive cap and pile. At the bottom of the compression stroke, the piston strikes the impact block, atomizing the fuel and starting the pile on its downward movement. In the instant after the piston strikes, the atomized fuel ignites, and the resulting explosion exerts an even greater force on the already moving pile, driving it further into the ground. The reaction of the explosion rebounding from the resistance of the pile drives the piston upward. As the piston rises, the exhaust ports open, releasing the gases and force of the explosion into the atmosphere. After the piston stops its upward movement, it again falls by gravity to start another cycle.

4. **Hydraulic hammer**

   Hydraulic hammers are more environmentally acceptable than the older, less efficient, hammers as they generate less noise and pollutants.

5. **Hydraulic Press-in**

   Specialty equipment which installs piles using hydraulic rams to press piles into the ground. This system is preferred where vibration is a concern. There are Press attachments that can adapt to conventional pile driving rigs to press 2 pairs of sheet piles at a time. Additional types of Press equipment sit on top of existing sheet piles and grip onto previously driven piles. This system allows for greater press-in and extraction force to be used since more reaction force is developed. The reaction based machines operate at only 69dB at 23ft allowing for installation and extraction of piles in very close proximity to noise and vibration sensitive areas where traditional methods may threaten the stability of existing structures. Such equipment and methods are specified into portions of the internal drainage system in the New Orleans area after Hurricane Katrina as well as many projects around the world where noise, vibrations and limited access are a concern during the engineering design and construction phases of the project.

6. **Vibratory Pile Driver/Extractor**

   The pile driving machine is lifted and positioned over the pile by means of a crane, and is fastened to the pile by a clamp and/or bolts. Vibratory hammers can either drive in or extract a pile - extraction is commonly used to recover steel "H" piles used in temporary foundation shoring. Hydraulic fluid is typically supplied to the driver by a diesel engine powered pump mounted in a trailer or van and connected to the driver head through a set of long hoses. Vibratory pile hammers are often chosen to mitigate noise, as when the construction is very close to residence or office buildings, or when there is not enough vertical clearance above the foundation to permit use of a conventional pile hammer (for example when retrofitting additional piles to a bridge column or abutment footing). Hammers are available with several different vibration rates, ranging from about 1200 vibrations per minute to about 2400 VPM;

the vibration rate chosen is influenced by soil conditions at the site and other factors such as power requirements and purchase price of the equipment.

Topic : Air Compressors And Pumps

Topic Objective:

At the end of this topic student would be able to:

- Define the term pump and gas compression
- Describe the uses and purpose of pumps
- Highlight the types of compressors.

Definition/Overview:

Pump: A pump is a device used to move gases, liquids or slurries. A pump moves liquids or gases from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system (such as a water system). A gas pump is generally called a compressor, except in very low pressure-rise applications, such as in heating, ventilating, and air-conditioning, where the operative equipment consists of fans or blowers.

Gas Compressor: A gas compressor is a mechanical device that increases the pressure of a gas by reducing its volume.

Key Points:

1. **Pumps**
   Pumps work by using mechanical forces to push the material, either by physically lifting, or by the force of compression. The earliest type of pump was the Archimedes screw, first used by Sennacherib, King of Assyria, for the water systems at the Hanging Gardens of Babylon and Nineveh in the 7th century BC, and later described in more detail by Archimedes in the 3rd century BC. In the 13th century AD, al-Jazari described and illustrated different types of pumps, including a reciprocating pump, double-action pump with suction pipes, water pump, and piston pump. Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible, so the main action of a pump is to transport liquids.

2. **Types of compressors**
   The main types of gas compressors are illustrated and discussed below:

3. **Centrifugal compressors**
   Centrifugal compressors use a rotating disk or impeller in a shaped housing to force the gas to the rim of the impeller, increasing the velocity of the gas. A diffuser (divergent duct) section converts the velocity energy to pressure energy. They are primarily used for continuous, stationary service in industries such as oil refineries, chemical and petrochemical plants and natural gas processing plants. Their application can be from 100 hp (75 kW) to thousands of horsepower. With multiple staging, they can achieve extremely high output pressures greater than 10,000 psi (69 MPa). Many large snow-making operations (like ski resorts) use this type of compressor. They are also used in internal combustion engines as superchargers and turbochargers. Centrifugal compressors are used in small gas turbine engines or as the final compression stage of medium sized gas turbines.

4. **Diagonal or mixed-flow compressors**

   Diagonal or mixed-flow compressors are similar to centrifugal compressors, but have a radial and axial velocity component at the exit from the rotor. The diffuser is often used to turn diagonal flow to the axial direction. The diagonal compressor has a lower diameter diffuser than the equivalent centrifugal compressor.

5. **Axial-flow compressors**

   Axial-flow compressors are dynamic rotating compressors that use arrays of fan-like aerofoils to progressively compress the working fluid. They are used where there is a requirement for a high flow rate or a compact design. The arrays of aerofoils are set in rows, usually as pairs: one rotating and one stationary. The rotating aerofoils, also known as blades or rotors, accelerate the fluid. The stationary aerofoils, also known as a stators or vanes, turn and decelerate the fluid; preparing and redirecting the flow for the rotor blades of the next stage. Axial compressors are almost always multi-staged, with the cross-sectional area of the gas passage diminishing along the compressor to maintain an optimum axial Mach number. Beyond about 5 stages or a 4:1 design pressure ratio, variable geometry is normally used to improve operation. Axial compressors can have high efficiencies; around 90% polytropic at their design conditions. However, they are relatively expensive, requiring a large number of components, tight tolerances and high quality materials. Axial-flow compressors can be found in medium to large gas turbine engines, in natural gas pumping stations, and within certain chemical plants.

6. **Reciprocating compressors**

   Reciprocating compressors use pistons driven by a crankshaft. They can be either stationary or portable, can be single or multi-staged, and can be driven by electric motors or internal combustion engines. Small reciprocating compressors from 5 to 30 horsepower (hp) are commonly seen in automotive applications and are typically for intermittent duty. Larger reciprocating compressors well over 1,000 hp (750 kW) are still commonly found in large industrial and petroleum applications. Discharge pressures can range from low pressure to very high pressure (>6000 psi or 41.4 MPa). In certain applications, such as air compression, multi-stage double-acting compressors are said to be the most efficient compressors available, and are typically larger, noisier, and more costly than comparable rotary units

7. **Rotary screw compressors**

   Rotary screw compressors use two meshed rotating positive-displacement helical screws to force the gas into a smaller space. These are usually used for continuous operation in commercial and industrial applications and may be either stationary or portable. Their application can be from 3 hp (2.24 kW) to over 500 hp (375 kW) and from low pressure to very high pressure (>1200 psi or 8.3 MPa).

8. **Rotary vane compressors**

   Rotary vane compressors consist of a rotor with a number of blades inserted in radial slots in the rotor. The rotor is mounted offset in a larger housing which can be circular or a more complex shape. As the rotor turns, blades slide in and out of the slots keeping contact with the outer wall of the housing. Thus, a series of decreasing volumes is created by the rotating blades. Rotary Vane compressors are, with piston compressors one of the oldest of compressor technologies. With suitable port connections, the devices may be either a compressor or a vacuum pump. They can be either stationary or portable, can be single or multi-staged, and can be driven by electric motors or internal combustion engines. Dry vane machines are used at relatively low pressures (e.g., 2 bar) for bulk material movement whilst oil-injected machines have the necessary volumetric efficiency to achieve pressures up to about 13 bar in a single stage. A rotary vane compressor is well suited to electric motor drive and is significantly quieter in operation than the equivalent piston compressor.

9. **Scroll compressors**

   A scroll compressor, also known as scroll pump and scroll vacuum pump, uses two interleaved spiral-like vanes to pump or compress fluids such as liquids and gases. The vane geometry may be involute, archimedean spiral, or hybrid curves. They operate more smoothly, quietly, and reliably than other types of compressors in the lower volume range Often, one of the scrolls is fixed, while the other orbits eccentrically without rotating, thereby trapping and pumping or compressing pockets of fluid or gas between the scrolls.

10. **Diaphragm compressors**

   A diaphragm compressor (also known as a membrane compressor) is a variant of the conventional reciprocating compressor. The compression of gas occurs by the movement of a flexible membrane, instead of an intake element. The back and forth movement of the membrane is driven by a rod and a crankshaft mechanism. Only the membrane and the compressor box come in touch with the gas being compressed. Diaphragm compressors are used for hydrogen and compressed natural gas (CNG) as well as in a number of other applications. The photograph included in this section depicts a three-stage diaphragm compressor used to compress hydrogen gas to 6,000 psi (41 MPa) for use in a prototype compressed hydrogen and compressed natural gas (CNG) fueling station built in downtown Phoenix, Arizona by the Arizona Public Service company (an electric utilities company). Reciprocating compressors were used to compress the natural gas. The prototype alternative fueling station was built in compliance with all of the prevailing safety, environmental and building codes in Phoenix to demonstrate that such fueling stations could be built in urban areas.

Topic : Planning For Building Construction

Topic Objective:

At the end of this topic student would be able to:

- Define the term building construction

- Describe the planning of building construction
- Highlight the process and importance of building construction

Definition/Overview:

Building Construction: In the fields of architecture and civil engineering, **construction** is a process that consists of the building or assembling of infrastructure. Far from being a single activity, large scale construction is a feat of multitasking. Normally the job is managed by the project manager and supervised by the construction manager, design engineer, construction engineer or project architect.

Key Points:

1. **Planning**
   For the successful execution of a project, effective planning is essential. Those involved with the design and execution of the infrastructure in question must consider the environmental impact of the job, the successful scheduling, budgeting, site safety, availability of materials, logistics, inconvenience to the public caused by construction delays, preparing tender documents, etc. Building construction is the process of adding structure to real property. The vast majority of building construction projects are small renovations, such as addition of a room, or renovation of a bathroom. Often, the owner of the property acts as laborer, paymaster, and design team for the entire project. However, all building construction projects include some elements in common - design, financial, and legal considerations. Many projects of varying sizes reach undesirable end results, such as structural collapse, cost overruns, and/or litigation reason, those with experience in the field make detailed plans and maintain careful oversight during the project to ensure a positive outcome. Building construction is procured privately or publicly utilizing various delivery methodologies,

including hard bid, negotiated price, traditional, management contracting, construction management-at-risk, design & build and design-build bridging.

2. **Authority having jurisdiction**
   In construction, the authority having jurisdiction (AHJ) is the governmental agency or sub-agency which regulates the construction process. In most cases, this is the municipality in which the building is located. However, construction performed for supra-municipal authorities are usually regulated directly by the owning authority, which becomes the AHJ. During the planning of a building, the zoning and planning boards of the AHJ will review the overall compliance of the proposed building with the municipal General Plan and zoning regulations. Once the proposed building has been approved, detailed civil, architectural, and structural plans must be submitted to the municipal building department (and sometimes the public works department) to determine compliance with the building code and sometimes for fit with existing infrastructure. Often, the municipal fire department will review the plans for compliance with fire-safety ordinances and regulations. Before the foundation can be dug, contractors are typically required to notify utility companies, either directly or through a company such as Dig Safe to ensure that underground utility lines can be marked. This lessens the likelihood of damage to the existing electrical, water, sewage, phone, and cable facilities, which could cause outages and potentially hazardous situations. During the construction of a building, the municipal building inspector inspects the building periodically to ensure that the construction adheres to the approved plans and the local building code. Once construction is complete and a final inspection has been passed, an occupancy permit may be issued. An operating building must remain in compliance with the fire code. The fire code is enforced by the local fire department. Any changes made to a building including its use, expansion, its structural integrity, and fire protection items, require acceptance by the AHJ. Anything affecting basic safety functions, no matter how small they may appear, may require the owner to apply for a building permit, to ensure proper review of the contemplated changes against the building code.

Topic : Forming Systems

Topic Objective:

At the end of this topic student would be able to:

- Define the term framing
- Describe the types and uses of framing
- Highlight the importance of framing

Definition/Overview:

Framing: Framing in construction known as light frame construction, is a building technique based around structural members, usually called studs, which provide a stable frame to which interior and exterior wall coverings are attached, and covered by a roof comprising horizontal ceiling joists and sloping rafters (together forming a truss structure) or manufactured pre-fabricated roof trussesall of which are covered by various sheathing materials to give weather resistance.

Key Points:

1. **Framing**
   Modern light-frame structures usually gain strength from rigid panels (plywood and other plywood like composites such as particle-board) used to form all or part of wall sections, but until recently carpenters employed various forms of diagonal bracing (called "wind braces") to stabilize walls. Diagonal bracing remains a vital interior part of many roof systems, and in-wall wind braces are required by building codes in many municipalities or by individual state

laws in the United States. Light frame construction using standardized dimensional lumber has become the dominant construction method in North America and Australasia because of its economy. Use of minimal structural materials allows builders to enclose a large area with minimal cost, while achieving a wide variety of architectural styles. The ubiquitous platform framing and the older balloon framing are the two different light frame construction systems used in North America.

2. **Walls**

Wall framing in house construction includes the vertical and horizontal members of exterior walls and interior partitions, both of bearing walls and non-bearing walls. These "stick" members, referred to as studs, wall plates and lintels (headers), serve as a nailing base for all covering material and support the upper floor platforms, which provide the lateral strength along a wall. The platforms may be the boxed structure of a ceiling and roof, or the ceiling and floor joists of the story above. The technique is variously referred to colloquially in the building trades as "stick and frame" or "stick and platform", or "stick and box" as the sticks (studs) give the structure its vertical support, and the box shaped floor sections with joists contained within length-long post and lintels (more commonly called 'Headers'), supports the weight of whatever is above, including the next wall up and the roof above the top story. The platform, also provides the lateral support against wind and holds the stick walls true and square. Any lower platform supports the weight of the platforms and walls above the level of its component headers and joists.

Framing lumber should be grade-stamped, and have a moisture content not exceeding 19%. There are three historically common methods of framing a house. Post and Beam, which is now used predominately in barn construction. Balloon framing using a technique suspending floors from the walls was common until the late 1940s, but since that time, platform framing has become the predominant form of house construction. Platform framing often forms wall sections horizontally on the sub-floor prior to erection, easing positioning of studs and increasing accuracy while cutting the necessary manpower. The top and bottom plates are end-nailed to each stud with two nails at least 3 1/4 in. (82 mm) in length (16d or 16 penny nails). Studs are at least doubled (creating posts) at openings, the jack stud being cut to receive the lintels(headers) that are placed and end-nailed through the outer studs.

Wall sheathing, usually a plywood or other laminate, is usually applied to the framing prior to erection, thus eliminating the need to scaffold, and again increasing speed and cutting manpower needs and expenses. Some types of exterior sheathing, such as asphalt-impregnated fibreboard, plywood, oriented strand board and waferboard, will provide adequate bracing to resist lateral loads and keep the wall square, but construction codes in most jurisdictions will require a stiff plywood sheathing. Others, such as rigid glass-fibre, asphalt-coated fibreboard, polystyrene or polyurethane board, will not. In this latter case, the wall should be reinforced with a diagonal wood or metal bracing inset into the studs. In jurisdictions subject to strong wind storms (Hurricane country, tornado alleys) local codes or state law will generally require both the diagonal wind braces and the stiff exterior sheathing regardless of the type and kind of outer weather resistant coverings.

3. **Corners**
   A multiple-stud post made up of at least three studs, or the equivalent, is generally used at exterior corners and intersections to secure a good tie between adjoining walls and to provide nailing support for the interior finish and exterior sheathing. Corners and intersections, however, must be framed with at least two studs. Nailing support for the edges of the ceiling is required at the junction of the wall and ceiling where partitions run parallel to the ceiling joists. This material is commonly referred to as 'dead wood'.

4. **Exterior wall studs**
   Wall framing in house construction includes the vertical and horizontal members of exterior walls and interior partitions. These members, referred to as studs, wall plates and lintels, serve as a nailing base for all covering material and support the upper floors, ceiling and roof.

Exterior wall studs are the vertical members to which the wall sheathing and cladding are attached. They are supported on a bottom plate or foundation sill and in turn support the top plate. Studs usually consist of 2 x 4 in. (38 x 89 mm) or 2 x 6 in. (38 x 140 mm) lumber and are commonly spaced at 16 in. (400 mm) on centre. This spacing may be changed to 12 in. (300 mm) or 24 in. (600 mm) on centre depending on the load and the limitations imposed by the type and thickness of the wall covering used. Wider 2 x 6 in. (38 x 140 mm) studs may be used to provide space for more insulation. Insulation beyond that which can be accommodated within a 3 1/2 in. (89 mm) stud space can also be provided by other means, such as rigid or semi-rigid insulation or batts between 2 x 2 in. (38 x 38 mm) horizontal furring strips, or rigid or semi-rigid insulation sheathing to the outside of the studs. The studs are attached to horizontal top and bottom wall plates of 2 in. (nominal) (38 mm) lumber that are the same width as the studs.

5. **Interior partitions**

Interior partitions supporting floor, ceiling or roof loads are called loadbearing walls; others are called non-loadbearing or simply partitions. Interior loadbearing walls are framed in the same way as exterior walls. Studs are usually 2 x 4 in. (38 x 89 mm) lumber spaced at 16 in. (400 mm) on centre. This spacing may be changed to 12 in. (300 mm) or 24 in. (600 mm) depending on the loads supported and the type and thickness of the wall finish used. Partitions can be built with 2 x 3 in. (38 x 64 mm) or 2 x 4 in. (38 x 89 mm) studs spaced at 16 or 24 in. (400 or 600 mm) on center depending on the type and thickness of the wall finish used. Where a partition does not contain a swinging door, 2 x 4 in. (38 x 89 mm) studs at 16 in. (400 mm) on centre are sometimes used with the wide face of the stud parallel to the wall. This is usually done only for partitions enclosing clothes closets or cupboards to save space. Since there is no vertical load to be supported by partitions, single studs may be used at door openings. The top of the opening may be bridged with a single piece of 2 in. (nominal) (38 mm) lumber the same width as the studs. These members provide a nailing support for wall finish, door frames and trim.

6. **Lintels (headers)**

   Lintels (aka headers) are the horizontal members placed over window, door and other openings to carry loads to the adjoining studs. Lintels are usually constructed of two pieces of 2 in. (nominal) (38 mm) lumber separated with spacers to the width of the studs and nailed together to form a single unit. The preferable spacer material is rigid insulation. The depth of a lintel is determined by the width of the opening and vertical loads supported.

7. **Wall Sections**

   The complete wall sections are then raised and put in place, temporary braces added and the bottom plates nailed through the subfloor to the floor framing members. The braces should have their larger dimension on the vertical and should permit adjustment of the vertical position of the wall. Once the assembled sections are plumbed, they are nailed together at the corners and intersections. A strip of polyethylene is often placed between the interior walls and the exterior wall, and above the first top plate of interior walls before the second top plate is applied to attain continuity of the air barrier when polyethylene is serving this function. A second top plate, with joints offset at least one stud space away from the joints in the plate beneath, is then added. This second top plate usually laps the first plate at the corners and partition intersections and, when nailed in place, provides an additional tie to the framed walls. Where the second top plate does not lap the plate immediately underneath at corner and partition intersections, these may be tied with 0.036 in. (0.91 mm) galvanized steel plates at least 3 in. (75 mm) wide and 6 in. (150 mm) long, nailed with at least three 2 1/2 in. (63 mm) nails to each wall.

8. **Balloon framing**

   Balloon framing is a method of wood construction used primarily in Scandinavia, Canada and the United States (up until the mid-1950s). It utilizes long continuous framing members (studs) that run from sill plate to eave line with intermediate floor structures nailed to them, with the heights of window sills, headers and next floor height marked out on the studs with a storey pole. Once popular when long lumber was plentiful, balloon framing has been largely replaced by platform framing. While no one is sure who introduced balloon framing in the U.S., the first building using balloon framing was probably a warehouse constructed in 1832 in Chicago by George Washington Snow. The following year, Augustine Taylor (1796-1891) constructed St. Mary's Catholic Church in Chicago using the balloon framing method. The curious name of this framing technique was originally a derisive one. As Taylor was constructing his first such building, St. Mary's Church, in 1833, skilled carpenters looked on at the comparatively thin framing members, all held together with nails, and declared this method of construction to be no more substantial than a balloon. It would surely blow over in the next wind! Though the criticism proved baseless, the name stuck.

Although lumber was plentiful in 19th century America, skilled labor was not. The advent of cheap machine-made nails, along with water-powered sawmills in the early 19th century made balloon framing highly attractive, because it did not require highly-skilled carpenters, as did the dovetail joints, mortises and tenons required by post-and-beam construction. For the first time, any farmer could build his own buildings without a time-consuming learning curve. It has been said that balloon framing populated the western United States and the western provinces of Canada. Without it, western boomtowns certainly could not have blossomed overnight. It is also a fair certainty that, by radically reducing construction costs, balloon framing improved the shelter options of poorer North Americans. For example, many 19th century New England working neighborhoods consist of balloon-constructed three-story apartment buildings referred to as triple deckers. The main difference between platform and balloon framing is at the floor lines. The balloon wall studs extend from the sill of the first story all the way to the top plate or end rafter of the second story. The platform-framed wall, on the other hand, is independent for each floor.

Balloon framing has several disadvantages as a construction method:

- The creation of a path for fire to readily travel from floor to floor. This is mitigated with the use of firestops at each floor level.

- The lack of a working platform for work on upper floors. Whereas workers can readily reach the top of the walls being erected with platform framing, balloon construction requires scaffolding to reach the tops of the walls (which are often two or three stories above the working platform).
- The requirement for long framing members.
- In certain larger buildings, a noticeable down-slope of floors towards central walls, caused by the differential shrinkage of the wood framing members at the perimeter versus central walls. Larger balloon-framed buildings will have central bearing walls which are actually platform framed and thus will have horizontal sill and top plates at each floor level, plus the intervening floor joists, at these central walls. Wood will shrink much more across its grain than along the grain. Therefore, the cumulative shrinkage in the center of such a building is considerably more than the shrinkage at the perimeter where there are much fewer horizontal members. Of course, this problem, unlike the first three, takes time to develop and become noticeable.

Balloon framing has been outlawed by building codes in many areas because of the fire danger that it poses. Since steel is generally more fire-resistant than wood, and steel framing members can be made to arbitrary lengths, balloon framing is growing in popularity again in light gauge steel stud construction. Balloon framing provides a more direct load path down to the foundation. Additionally, balloon framing allows more flexibility for trade workers in that it is significantly easier to pull wire, piping and ducting without having to bore through or work around framing members.

9. **Platform framing**

In Canada and the United States, the most common method of light-frame construction for houses and small apartment buildings as well as some small commercial buildings is Platform framing. The framed structure sits atop a concrete (most common) or treated wood foundation. A sill plate is anchored, usually with 'J' bolts to the foundation wall. Generally these plates must be pressure treated to keep from rotting. The bottom of the sill plate is raised a minimum 6 inches (150 mm) above the finished grade by the foundation. This again is to prevent the sill-plate from rotting as well as providing a termite barrier. The floors, walls and roof of a framed structure are created by assembling (using nails) consistently sized framing elements of dimensional lumber (24, 26, etc.) at regular spacings (12″, 16″, and 24″ on center), forming stud-bays (wall) or joist-bays (floor). The floors, walls and roof are typically made torsionally stable with the installation of a plywood or composite wood skin referred to as sheathing. Sheathing has very specific nailing requirements (such as size and spacing); these measures allow a known amount of shear force to be resisted by the element. Spacing the framing members properly allows them to align with the edges of standard sheathing. In the past, tongue and groove planks installed diagonally were used as sheathing. Occasionally, wooden or galvanized steel braces are used instead of sheathing. There are also engineered wood panels made for shear and bracing.

The floor, or the platform of the name, is made up of joists (usually 2x6, 28, 210 or 212, depending on the span) that sit on supporting walls, beams or girders. The floor joists are spaced at (12″, 16″, and 24″ on center) and covered with a plywood subfloor. In the past, 1x planks set at 45-degrees to the joists were used for the subfloor. Where the design calls for a framed floor, the resulting platform is where the framer will construct and stand that floors walls (interior and exterior load bearing walls and space-dividing, non-load bearing partitions). Additional framed floors and their walls may then be erected to a general maximum of four in wood framed construction. There will be no framed floor in the case of a single-level structure with a concrete floor known as a slab on grade. Stairs between floors are framed by installing stepped stringers and then placing the horizontal treads and vertical risers. A framed roof is an assembly of rafters and wall-ties supported by the top storys walls. Prefabricated and site-built trussed rafters are also used along with the more common stick framing method. Trusses are engineered to redistribute tension away from wall-tie members and the ceiling members. The roof members are covered with sheathing or strapping to form the roof deck for the finish roofing material.

Floor joists can be engineered lumber (trussed, I-beam, etc.), conserving resources with increased rigidity and value. They allow access for runs of plumbing, HVAC, etc. and some forms are pre-manufactured. Double Framing is a style of framing used to reduce heat loss and air infiltration. Two walls are built around the perimeter of the building with a small gap in between. The inner wall carries the structural load of the building and is constructed as described above. The exterior wall is not load bearing and can be constructed using lighter materials. Insulation is installed in the entire space between the outside edge of the exterior wall and the inside edge of the interior wall. The size of the gap depends upon how much insulation is desired. The vapour barrier is installed on the outside of the inner wall, rather than between the studs and drywall of a standard framed structure. This increases its effectiveness as it is not perforated by electrical and plumbing connections.

10. **Materials**

Light-frame materials are most often wood or rectangular steel tubes or C-channels. Wood pieces are typically connected with nails or screws; steel pieces are connected by screws. Preferred species for linear structural members are softwoods such as spruce, pine and fir. Light frame material dimensions range from 38 mm by 89 mm (1.5 by 3.5 inches (89 mm) i.e. a two-by-four) to 5 cm by 30 cm (two-by-twelve inches) at the cross-section, and lengths ranging from 2.5 m (8 ft) for walls to 7 m (20 ft) or more for joists and rafters. Recently, architects have begun experimenting with pre-cut modular aluminum framing to reduce on-site construction costs.

Wall panels built of studs are interrupted by sections that provide rough openings for doors and windows. Openings are typically spanned by a header or lintel that bears the weight of structure above the opening. Headers are usually built to rest on trimmers, also called jacks. Areas around windows are defined by a sill beneath the window, and cripples, which are shorter studs that span the area from the bottom plate to the sill and sometimes from the top of the window to a header, or from a header to a top plate. Diagonal bracings made of wood or steel provide shear (horizontal strength) as do panels of sheeting nailed to studs, sills and headers. Wall sections usually include a bottom plate which is secured to the structure of a floor, and one, or more often two top plates that tie walls together and provide a bearing for structures above the wall. Wood or steel floor frames usually include a rim joist around the perimeter of a system of floor joists, and often include bridging material near the center of a span to prevent lateral buckling of the spanning members. In two-story construction, openings are left in the floor system for a stairwell, in which stair risers and treads are most often attached to squared faces cut into sloping stair stringers.

Interior wall coverings in light-frame construction typically include wallboard, lath and plaster or decorative wood paneling. Exterior finishes for walls and ceilings often include plywood or composite sheathing, brick or stone veneers, and various stucco finishes. Cavities between studs, usually placed 40-60 cm (16-24 inches) apart, are usually filled with insulation materials, such as fiberglass batting, or cellulose filling sometimes made of recycled newsprint treated with boron additives for fire prevention and vermin control. In natural building, straw bales, cob and adobe may be used for both exterior and interior walls. The part of a structural building that goes diagonly across a wall is called a T-bar it stops the walls collapsing in gusty winds.

11. **Roofs**

Roofs are usually built to provide a sloping surface intended to shed rain or snow, with slopes ranging from 1 cm of rise per 15 cm (less than an inch per linear foot) of rafter length, to steep slopes of more than 2 cm per cm (two feet per foot) of rafter length. A light-frame structure built mostly inside sloping walls comprising a roof is called an A-frame. Roofs are most often covered with shingles made of asphalt, fiberglass and small gravel coating, but a wide range of materials are used. Molten tar is often used to waterproof flatter roofs, but newer materials include rubber and synthetic materials. Steel panels are popular roof coverings in some areas, preferred for their durability. Slate or tile roofs offer more historic coverings for light-frame roofs. Light-frame methods allow easy construction of unique roof designs. Hip roofs, which slope toward walls on all sides and are joined at hip rafters that span from corners to a ridge. Valleys are formed when two sloping roof sections drain toward each other. Dormers are small areas in which vertical walls interrupt a roof line, and which are topped off by slopes at usually right angles to a main roof section. Gables are formed when a length-wise section of sloping roof ends to form a triangular wall section. Clerestories are formed by an interruption along the slope of a roof where a short vertical wall connects it to another roof section. Flat roofs, which usually include at least a nominal slope to shed water, are often surrounded by parapet walls with openings (called scuppers) to allow water to drain out. Sloping crickets are built into roofs to direct water away from areas of poor drainage, such as behind a chimney at the bottom of a sloping section.

12. **Structure**

Light-frame buildings are often erected on monolithic concrete slab foundations that serve both as a floor and as a support for the structure. Other light-frame buildings are built over a crawlspace or a basement, with wood or steel joists used to span between foundation walls, usually constructed of poured concrete or concrete blocks. Engineered components are commonly used to form floor, ceiling and roof structures in place of solid wood. I-beam (closed web trussed) joists are often made from laminated woods, most often chipped poplar wood, in panels as thin as 1 cm (3/8ths of an inch), glued between horizontally laminated members of less than 5 cm by 5 cm (two-by-two inches), to span distances of as much as 9 m (30 ft). Open web trussed joists and rafters are often formed of 5 cm by 10 cm (two-by-four inch) wood members to provide support for floors, roofing systems and ceiling finishes.