Geomorphology
Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology - Roorkee

Lecture – 18
Mass Wasting

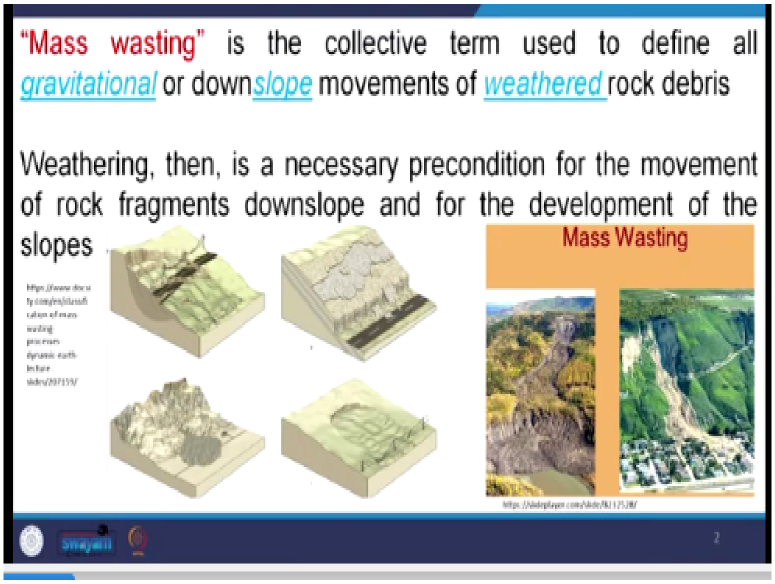
So friends, welcome again to the class of geomorphology and in this class, we are going to discuss about mass wasting. So, before moving to mass wasting, you must properly understand what does it mean; what is mass wasting and the meaning; it is hidden within this terminology mass and wasting; wasting means losing, detaching something and mass means here, we talk about the rock mass.

The rock mass, we are losing from this original position that is mass wasting, so mass wasting is a bridge between weathering and erosion. In weathering, we create some weather material, at that weather material, just to be removed from their origin and it is transported away from this in situ place, so this process is called mass wasting. So, during erosional process we have wind action, we have river action, we have glacier action like this.

But once we say it is mass wasting here those agents play a negligible role or lesser role as compared to an agent which is called gravity. So, that means in mass wasting case mostly, gravity plays major role as compared to other agents, so that means we can summarise it here by action of gravity a mass of rock or a rock mass detaching from the main body and it is sliding down under the force of gravity is called mass wasting, is not it?

So, before going to study the mass wasting, we should first know what is this different terminologies and what is the different preconditions which are responsible for mass wasting, so understanding the precondition is much important in terms of understanding the mass wasting.

(Refer Slide Time: 02:49)



So here mass wasting is the collective term used to define all gravitational downslope movement of weathered rock debris, gravitational that means, gravity play a major role, downslope; it is the downslope movement because gravity stands to tend to pull the system downward. In this weathering and erosional system, if you compare there is the only wind erosion, mass can move against gravity.

Wind can blow material to the uphill or other weathering agents, they remove material to downhill to downslope but wind is the only parameter or wind is the only agent that can move the mass uphill against gravity. So that means here gravitational downslope movement of weathered rock material; weathered rock material means that means the rock must have to be weathered.

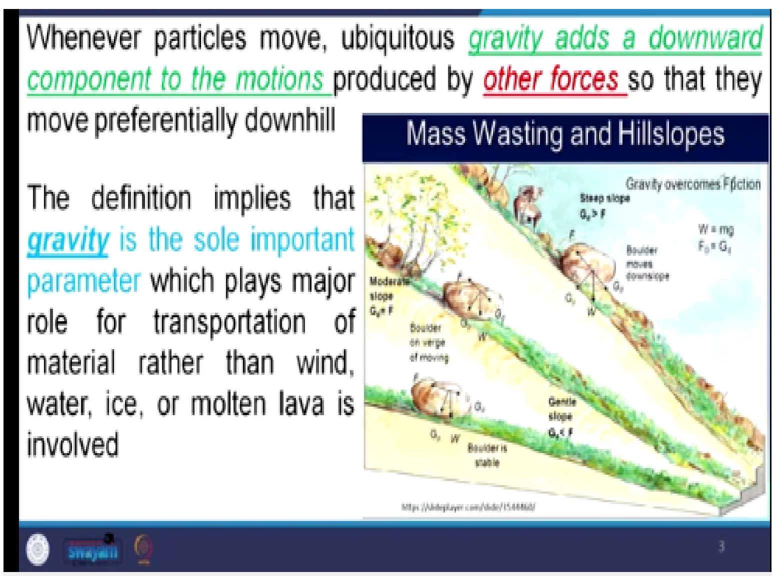
So, now the question arise is; if it is weathered to what is the degree of weathering is required, so the degree of weathering if we consider, it may be less degree, it may be higher degree even if the fresh rock, if there are joint planes are there and through the joint planes, there will be movement and due to this gravitational pulling, a block of rock, a block of fresh rock can be also be removed from the rock mass intact.

So that is also mass wasting, so the degree of weathering, once you consider more degree of weathering more the mass wasting and reverse is also true, but it is not always true because we have examples that fresh rock mass, they came has to detached along this joint planes. Weathering, then it is a necessary precondition for movement of rock fragments downslope for the development of the slope.

So, here the development of the slope is important, so development of the slope means, here once we remove the material, we are removing the material, that means we are creating slope, we are changing the slopes, so slope changes takes place due to mass wasting, sometimes the slope may be become gentler due to removal of mass, sometimes these gentle slope will be steeper due to removal of mass.

So, it is constantly modifying the slope; hill slope, river slope, any type of slope, it is constantly modifying, so the mass wasting is plays an important role in modifying the hill slopes, so that is why it is called mass wasting and hill slope evolution.

(Refer Slide Time: 05:52)



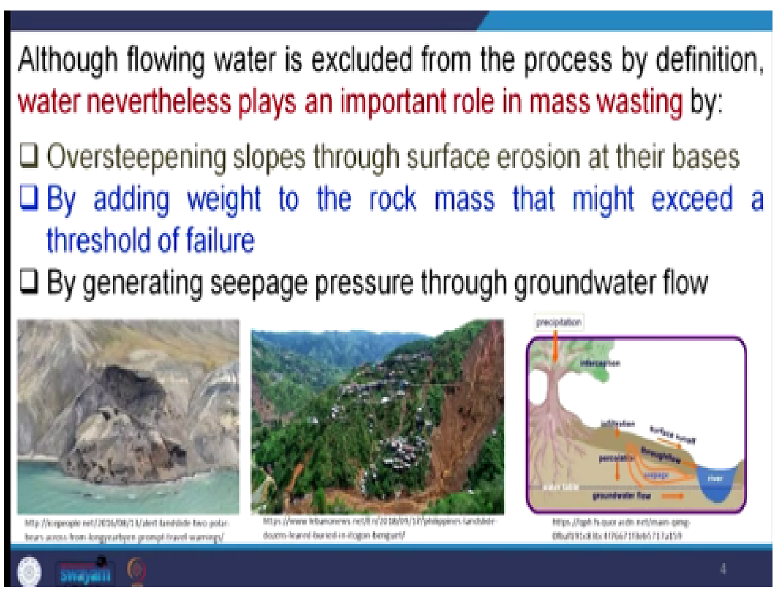
So, whenever a particle is moving that is gravity adds to downslope component of the motion produced by other forces that is other forces means, suppose, it is the sloping surface, on the sloping surface, a particle or a mass of rock it is moving downward, so once it is moving downward, other forces also accelerating in the movement or influencing the movement, what are the other forces?

One is the slope itself, larger the slope the rate of movement will be more, similarly, mass of the material, it is a small particle, it can stable here or this is the higher slope or the steeper slope, even a small particle can be stable but the same particle, it is in lower slope, it is not stable that means, it is in the further higher slope, it will fall down, a mass of particular mass, it may stable here, in this slope, if it is lower slope, it is stable.

But here it is relatively stable, but here it is unstable, so slope is playing another role here, then water, if water is there, so water in which form it is, that also depends upon, if water is flowing that means, it is increasing seepage pressure, so material will be easily removed from the slopes, so that means, except gravity, some other factors do work together with the gravity to change the hill slope from time and space.

So, this definition implies gravity is the sole important parameters which play a major role for transportation of material rather than wind, water, ice and molten lava itself. So, whenever we talk about this term mass wasting, we always and always keep in our mind that gravity here plays important role or major role as compared to other parameters.

(Refer Slide Time: 08:00)



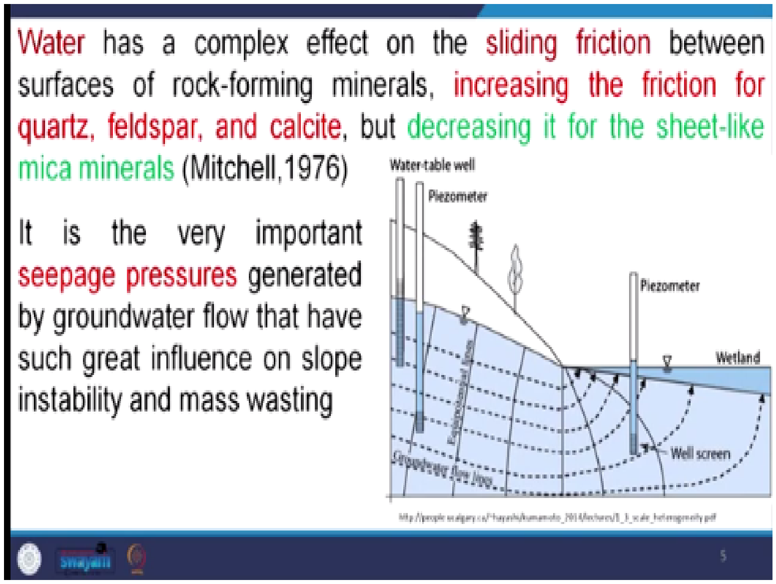
So, flowing water is excluded here, definition; but water nevertheless plays an important role in mass wasting, how? Water has 3 types of role; first is it is oversteepening of slopes through surface erosion at their basis for example, we have a sloping surface and at the slope, at the base of the slope, a river is flowing. For example, in this figure, here is a sloping surface and a river is flowing.

So, once the river is flowing, it is cutting its base, the toe of the slope, here it is cutting so, once it is cutting the toe, so that means, these part of the slope become unstable, so river has direct effect on the slope instability. Second thing is by adding weight to the rock mass, it might exceed the threshold of failure, so once it is a sloping surface, for example the second figure here, if you confine, it is a sloping surface and the rocks are highly weathered.

So, during running, what happens; this weathered material they absorbs water, so its mass increases, so once the mass of a sloping surface increases, it adds, it promotes mass wasting, it is promotes, it is removal because it is own weight increase, so once its own weight increases, the mass will easily pull down, so that is why by increasing or by adding weight of the rock mass that might exceed the threshold failure.

Then, third point is by generating seepage pressure through downward flow, ground water flow by seepage pressure, once the water is flowing within the medium, it is seepage pressure is increasing, so seepage pressure, it behaves as the buoyancy system; buoyant system, so that means, it will remove the material, easily create cracks, so easily create cracks that means, there is possibility that this cracked portion or this detached portion, they can easily detached from this main body.

(Refer Slide Time: 10:17)

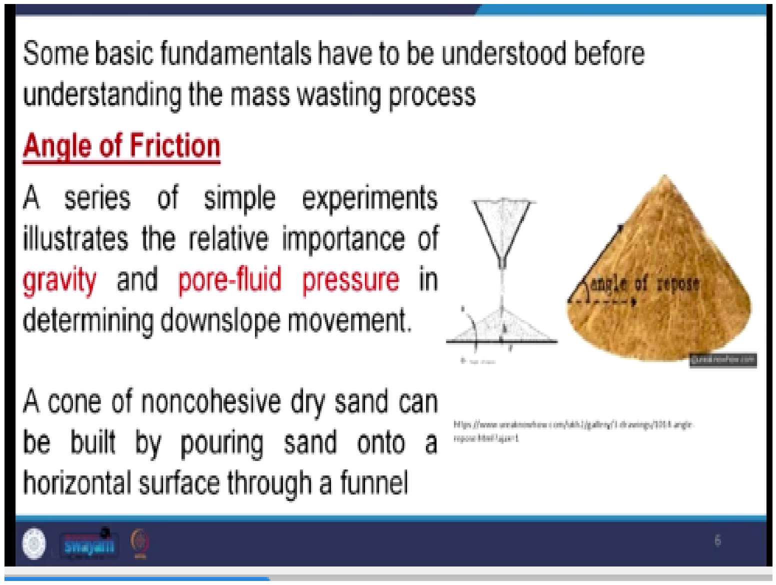


So, water has 3 types of role play in this mass wasting in addition to gravity, water has a complex effect on the sliding friction between surface of the rock forming mineral, some minerals, the sliding friction increases with the presence of water and for some mineral, the sliding friction decreases, for example if we can confine our self; quartz, feldspar, calcite in the presence of water, the sliding friction among these different mineral that increases.

That means, the rock become more stable, the minerals they are bounded which is the due to the sliding friction however, some other minerals like the clay's minerals, the sheet structure, if water remains there within their surfaces, it behaves as a lubricant, so once it behaves like a lubricant, there is a chance of failure increases, so that is why water has dual effect.

For some minerals, it is increasing the friction and for some certain minerals, it is decreasing the friction, so it is very important the seepage pressure generated by groundwater flow that have such great influence on slope instability and mass wasting, okay. So, seepage pressure plays an important role, the more the seepage pressure is the easy for the system to pull down, easy for the rock mass to pull down the gravity.

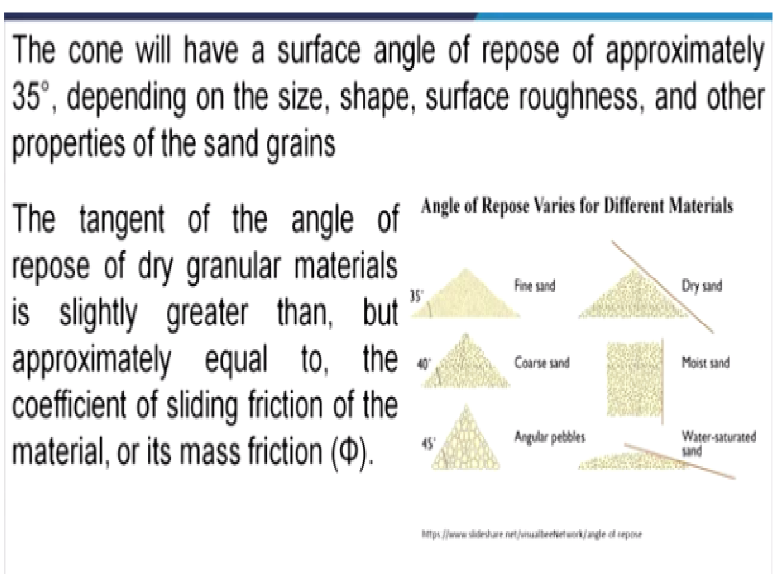
(Refer Slide Time: 11:47)



So, before going to study the mass wasting, its effect, its mechanism, its agents which are responsible and the type of mass wasting, we must understand certain basic parameters, basic understanding what is science behind it, why the mass wasting takes place? So, first is; first parameter is the angle of friction, so angle of friction that is otherwise called the angle of repose, so a series of simple experiments has been carried out to understand what is the angle of repose and how this angle of repose is defined or is changes with the material property.

For example, if we allow free fall of sand particles through a cone; through a funnel, it will create a cone and this angle of repose if you see here; it is around 30 to 35 degree.

(Refer Slide Time: 12:53)

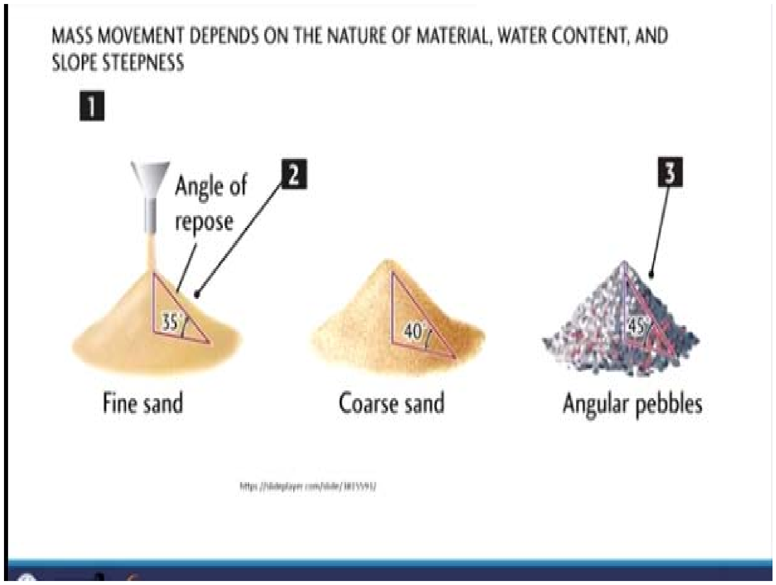


But this 30 to 35 degree, it is not same as the material changes, the angle of repose changes, for example if you see here for fine sand, it is about 35 degree, for coarse sand, it is about 40 degree, for gravels, it is 45 degree, for dry sand, dry coarse sand, it is more than that and it is moist sand, it is also 90 degree or so and if it is water saturated sand, it is like that. So, that means, I want to say depending upon the property of the material, depending upon the water saturation, the angle of repose varies.

The tangent to the angle of repose of a dry granular material is slightly greater than what approximately equal to the coefficient of sliding friction of this material of the mass friction that is the angle that is called phi. So, here the material changes, the angle of repose changes, the water content changes, this is an angle of repose changes, that means if we apply these knowledge in hill slope.

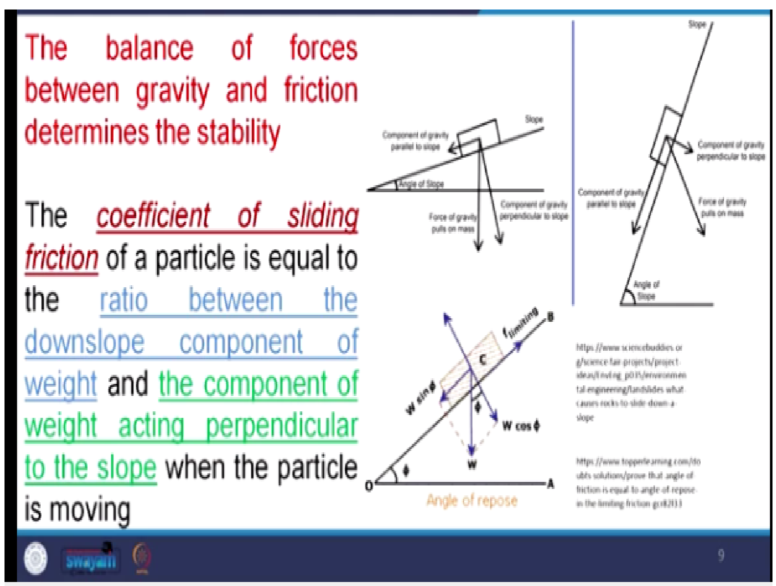
Hill slope composed of fine material will be different degree of sliding, different degree of a repose or different angle required for failure similarly, the hill slope, composed of gravels that will fail at different angle, it is saturated, it is fail at different angle, water seepage is going on, it will fail at different angle, so that means by those simple experiments in the laboratory, we can apply those knowledge in natural environment to understand the basic properties of this mass movement or a particular topography or particular angle of the slope and particular material involved.

(Refer Slide Time: 14:45)



The same thing here; the fine sand 35 degree, coarse sand 40 degree, angular pebbles like 45 degree and if it is so angular or rounded pebble, it is less than 45 degree, so that means the texture, this material, this size that defines the angle of repose.

(Refer Slide Time: 15:04)

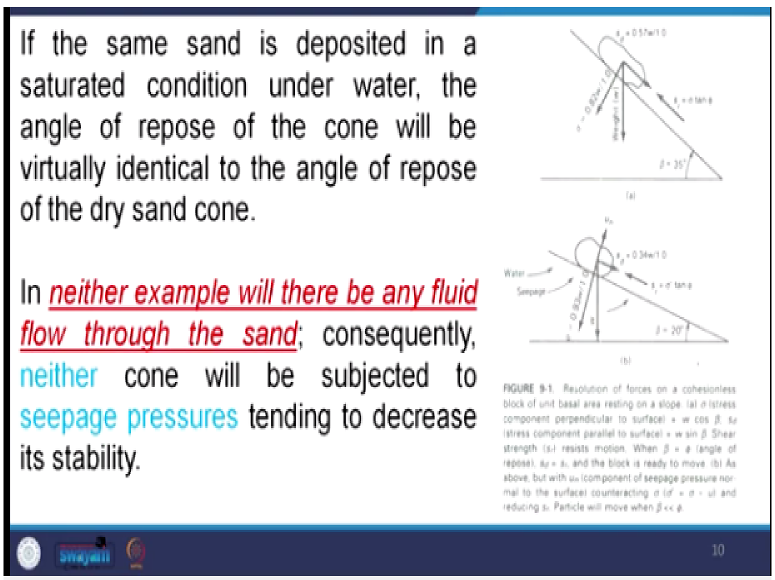


The balance of force between gravity and friction determines the stability because once a block is placed in a sloping surface, there will be an angle of friction there will be a friction between the surface and the material. Gravity always wants to pull it down and the frictional force, it try to make it intact to the slope, so it is a tussle between the gravitational pull and the frictional force, so whichever is more that will affect and that is totally governed by the type of material and the angle of the slope; slope angle.

If the slope angle is less, here the frictional force will dominant and gravity will fail here but it is the angle of repose or the angle of slope is more, here the gravity will play a major role as compared to the frictional force and the block will move down. So, the coefficient of sliding friction of a particle is equal to the ratio between the down slope component of weight and the component of weight acting perpendicular to the slope.

Then the particle is moving, so this tussle between the 2 that define whether this particle will move downward or it will be remain as it is at the surface of intact.

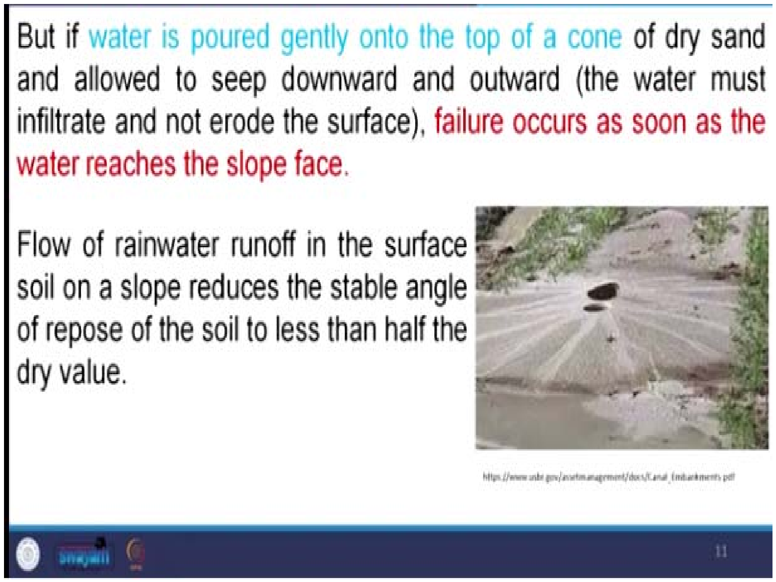
(Refer Slide Time: 16:28)



If the same sand is deposited in a saturated condition under water, the angle of repose of the cone will be virtually identical of this angle of repose at the dry condition, provided that the water seepage is not there but once the water seepage starts and the water suppose, we pour water at the tip of this cone and is allow it flow at the base. So, once the water flow at the base of this cone, the water of the sand starts failing.

So, the failure occur at the sand cone, once the water is percolating down because due to the seepage pressure.

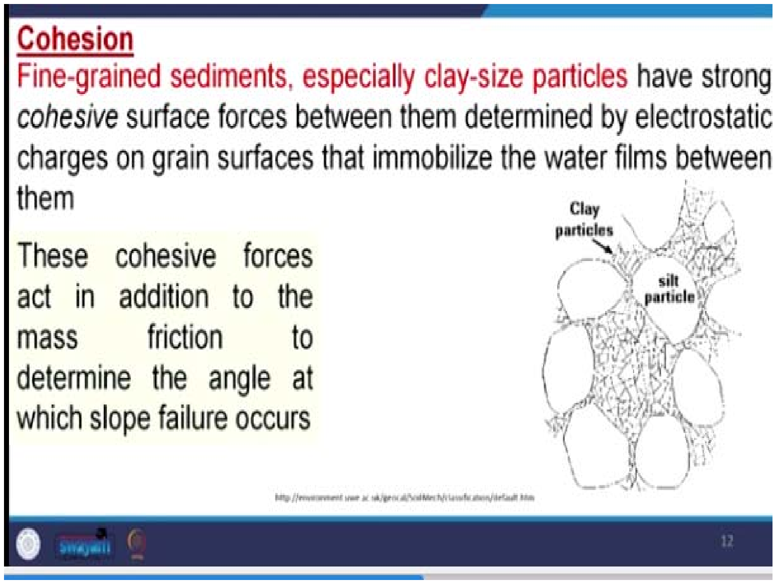
(Refer Slide Time: 17:10)



But water is poured gently on the top of this cone, the dry sand and allowed to seep downward and outward, so failure occurs as soon as the water reaches the slope face, flow of rain water runoff in the surface soil of the slope reduces the stable angle of repose of the soil to less than half of the dry value, it is very sensitive to understand here. That means, once we have a system, we have a slope surface, weathered surface or it is composed of sand or any material which can absorb water, until unless water getting seepage through that, water is flowing out of the system.

So, that means, up to that that maybe some stability will be there, once water seepage start at the base, that means seepage pressure increases, so seepage pressure increases that means, this part of this material, part of the slope will be slide down, so seepage pressure in addition to gravity also plays important role for defining the stability of the slope.

(Refer Slide Time: 18:23)

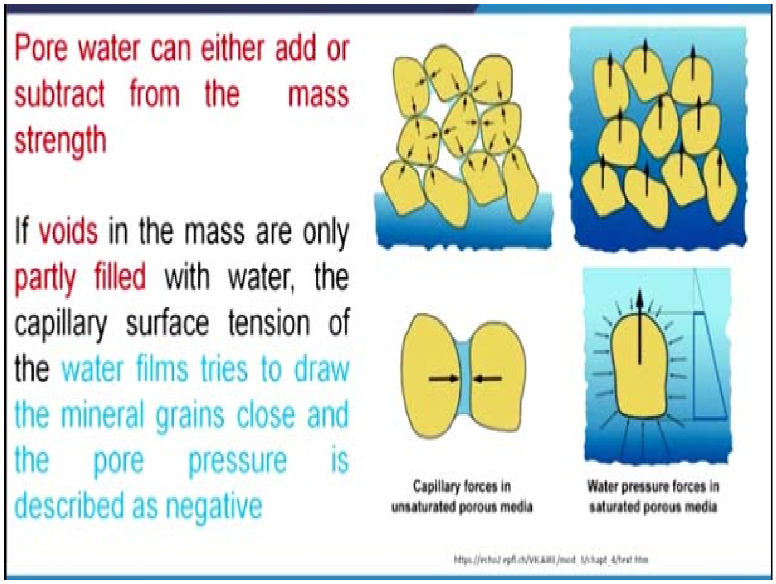


So, another point to understand here is the cohesion; is the fine-grained sediment especially, clay sized particles have strong cohesive surface force between them determined the electrostatic charges of grain structure that immobilise the water film between them, so here due to the cohesion, the particles they remain intact with each other. So, seepage pressure is not here, seepage pressure because water is not flowing here.

Then the cohesive force act in addition to the mass friction to determine the angle at which the slope failure occur, that is why in clay surfaces, we can cut it vertically but it will remain stable. why? due to the cohesive forces but the non-cohesive system like the sand, if we cut it in vertical faces that can removed, there will be sliding, so that is also another field ways to understand the silt deposit and this sand deposit.

In loesses that is windblown, dust particle mostly, silt and clay, if you cut it vertically, the vertical surface will remain there for considerable time but the sand surface, if you cut it vertically, it will not remain vertical for a considerable or this same for the same time because there will be sliding of sand due to the non-cohesive nature but this clays, the slits, they have cohesive forces between them, so they remain it intact that it is the field way, that the field device or the field phenomena, how you can distinguish whether you are dealing with a sand deposit, you are dealing with a silt deposits.

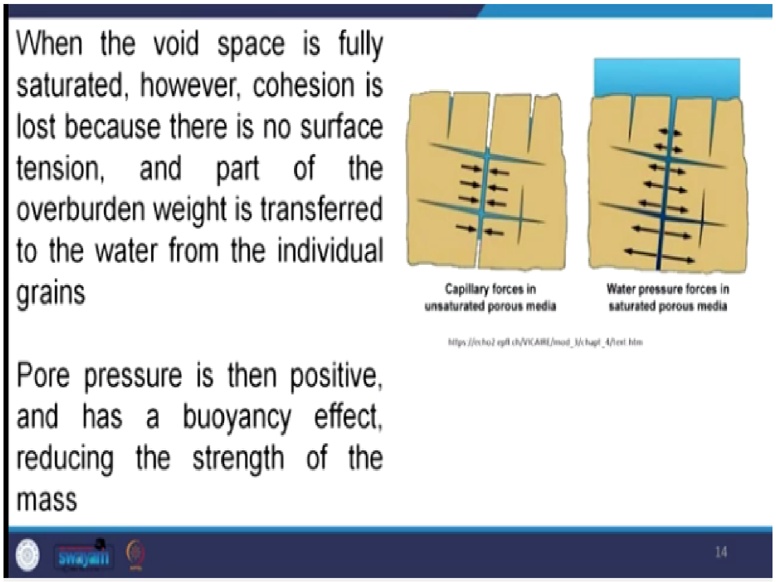
(Refer Slide Time: 20:10)



So, pore water, so when we talk about the water seepage or water absorption of a system; this pore water can either add or subtract from mass strength for example, suppose the voids of the mass are only partially filled, for example, this figure you see, the voids are partially filled, so once it is partially filled, the capillary surface tension of this water filled that will draw the mineral grains close to each other.

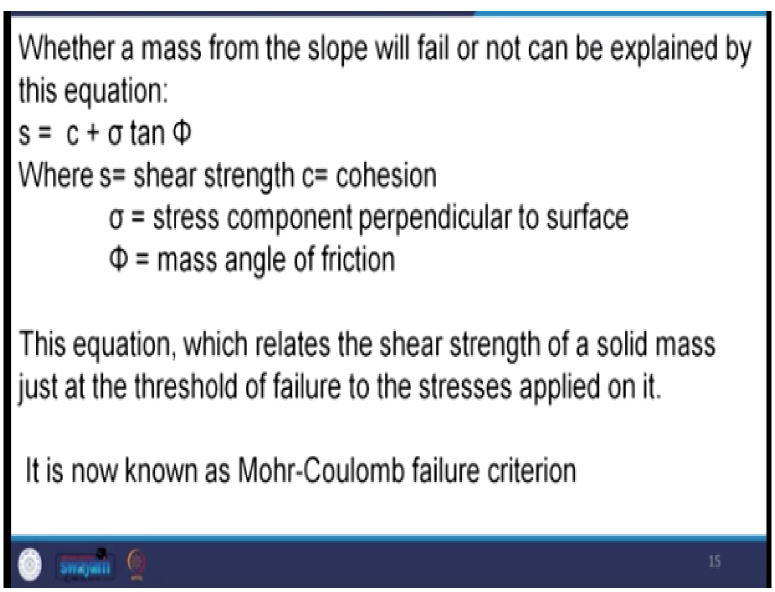
So, the pores pressure is a described negative because inward; it is intacting, it is bounding, it is binding this particle system; particles with each other, so here the pore pressure is negative, so this means once the pore pressure is negative, it is adding to the frictional force, so making the grains stable.

(Refer Slide Time: 20:59)



But in the latter case, if this totally filled, when the void space is fully saturated however, cohesion is lost because there is no surface tension and part of this overburden weight is transferred to the water from the individual grains. Pore pressure is then positive and has a buoyancy effect reducing the strength of the mass then the failure occurs. So, if the system is half filled, the system is partially filled that will be more stable as compared to the system which is total filled with water.

(Refer Slide Time: 21:37)



Whenever a mass from the slope will fall or not that will explained by this equation that is ($s = c + \sigma \tan \varphi$), where s is the shear strength, c is the cohesion, σ is the stress component perpendicular to the surface, φ is the mass angle of friction, this equation which relates the shear strength of a solid mass just at the threshold of failure and a stress applied on it, it is now known as Mohr-Coulomb failure criterion.

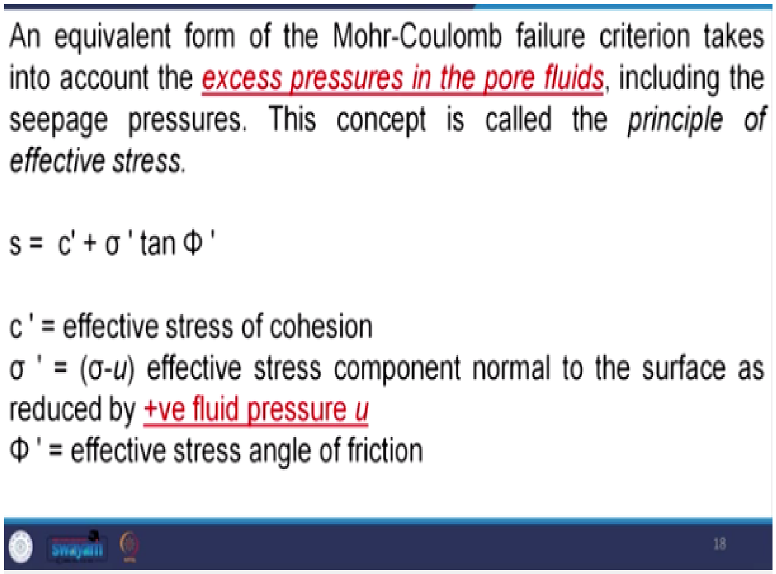
So, this Mohr-Coulomb failure criterion that defines whether a particular mass, a particular block of rock that will remain stable on the sloping surface or it will fell down, in cohesion less sand and larger gravels, this cohesion is 0, so c = 0 and mud and clay c is maximum or it is significant role and hence cohesion increases shear strength, many moist clays hold vertical faces modest height without failure which non-cohesive material can never do.

So that is the reason, silt surface can be or clay surface can be cut vertically and they remain vertical for considerable time however, the sand surface cannot.

(Refer Slide Time: 23:13)

Here, 2 figures are given or this 2 paragraphs; one here you see the sand, it is cutting into vertical surface but failure is there but silt and clay, this relatively become stable due to this cohesive forces between them.

(Refer Slide Time: 23:27)

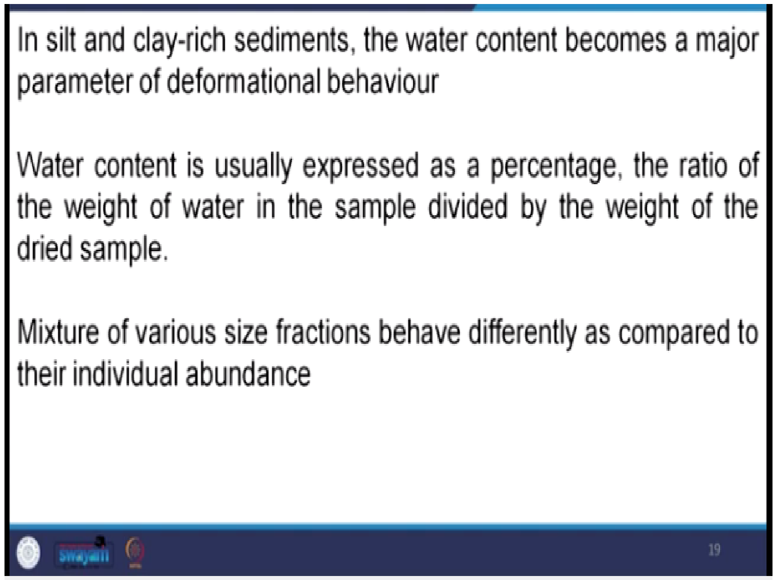


So, an equivalent form of Mohr-Coulomb failure criterion takes into account the excess pressure of pore fluid, so whatever we are talking something few minutes back, we are talking Mohr-Coulomb failure criterion, we are talking something about the dry system but suppose, we introduce this seepage pressure in this, pore fluid pressure within the system including the seepage pressure, this concept is called principle of effective stress.

Here, ($s = c' + \sigma' + \tan \varphi'$), c’ is the effective stress of cohesion, σ’; σ-u, u is effective stress component normal to the surface as reduced by positive fluid pressure u; positive fluid pressure means, fluid pressure is outward, that means it is totally filled, the system is totally filled. If the system is not totally filled, then the fluid pressure is negative and positive fluid pressure means, it is outward, the pressure is outward.

σ', it is the effective stress angle of friction, so these 2 equations; one is for the filled system, water filled system, another for the dry system that indicates or they define whether a slope will fail or will remain intact.

(Refer Slide Time: 24:52)

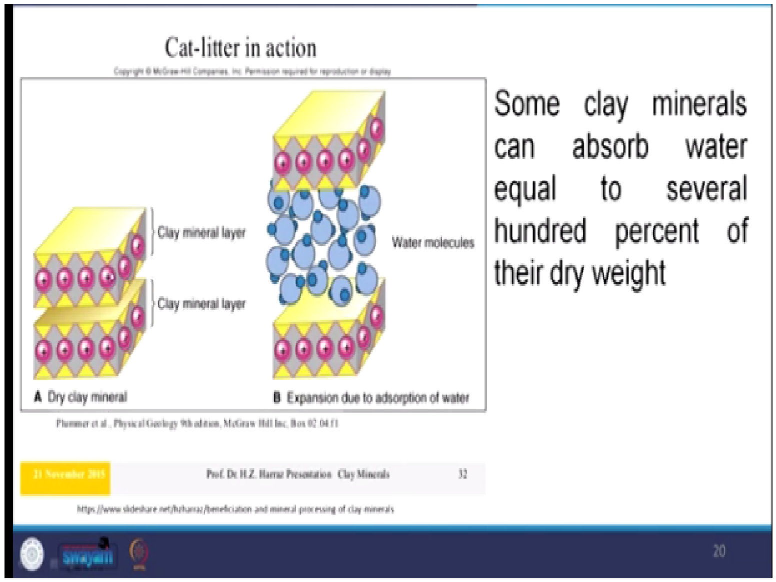


In silt and clay rich sediments, the water content becomes a major parameter for deformational behaviour, water content is usually accessed as a percentage, the ratio of weight of water in sample divided by the weight of the dry sample, mixture of various size fractions behave differently as compared to the individual abundance, it is also very important to understand here. If we have a mixture of sand, silt, clay, it will or gravel, so the system will behave differently.

Because different particle size behave differently rather than we have a particle size of a rock; rock particle size in a rock which is uniform that will show uniform behaviour but a rock composed of different type of the particle, different size of particle, that will behave differently. So, in a slope failure we have to understand what is the angle; what is the degree of saturation, what type of material it is composed of.

So, all those things take; all those things should be taken combinely to define whether the slope will going to fail to or it will be remain stable.

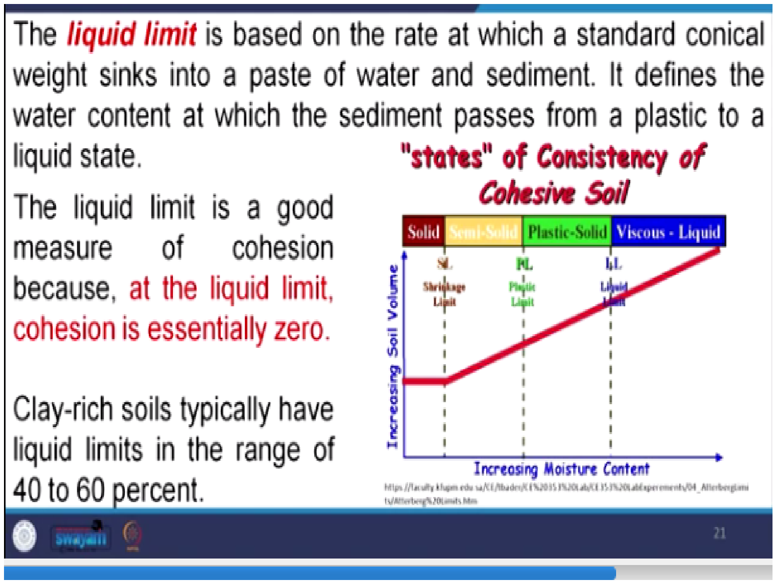
(Refer Slide Time: 26:05)



Some clay minerals can absorb water equal to several hundred percent of their dry weight, so here some clay minerals are given, those clay minerals now you can say here, it can absorb water here, the water compared to this dry clay, here dry clay mineral and here wet clay mineral water molecules, there is some clay minerals they can absorb water some hundreds of time or their own way.

So, we have to define, we have to know, what type of clay is there, what type of clay is present in the slope material, so that is why before going to any major construction, so we must analyse the rock material, whether it is composed of that type of clay, which can absorb, which can swell, which can hydrate and dehydrate seasonally, so that has to be removed, that place; the sides should be avoided.

(Refer Slide Time: 27:03)

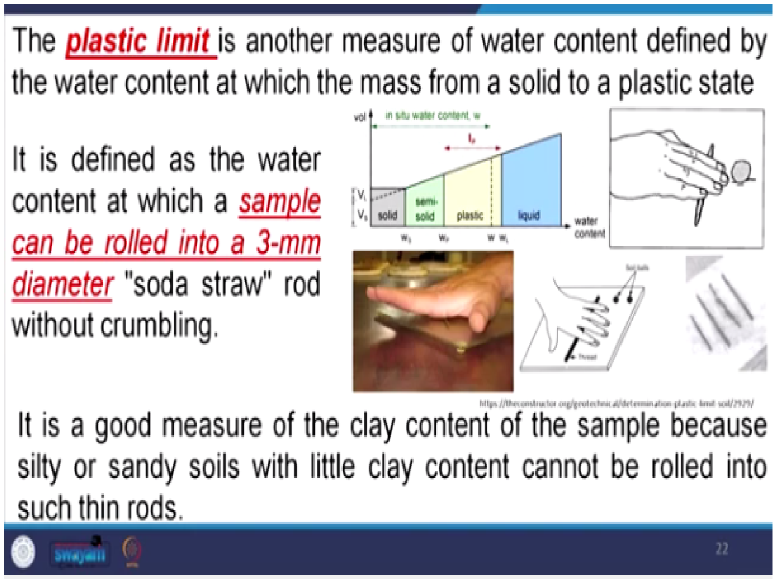


Because these are the potential site for future failure, then another point is called liquid limit, plastic limit and plasticity index. So, liquid limit is based on the rate at which the standard conical weight sinks into a paste of water and sediment. It defines the water content at which the sediment passed from plastic to liquid state. Here, a graph is given, this increasing moisture content and increasing soil volume.

So, here if you see this is liquid limit; liquid limit means, it is a plastic, this side is plastic, this side is liquid or viscous liquid, so it is the amount of water which is absorbed by the soil or absorbed by the material by which that behaves like liquid that is the liquid limit. The liquid limit; it is good measure of cohesion between the liquid limit, cohesion essentially 0. So, once we are reaching at this liquid limit that means, the system try to flow, the system starts flowing.

So that means, here cohesion is 0, so before liquid limit, this some cohesion is there, some cohesive force is there but once it reach it, that means the material if it absorbs particular amount of water, the cohesion decreases, cohesion becomes 0 at the liquid limit. Clay rich soil; typically have liquid limit ranges from 40 to 60% so that means, we have a clay in a slope, the clay can absorb water 40 to 60%, so beyond that that will start flowing.

(Refer Slide Time: 28:52)



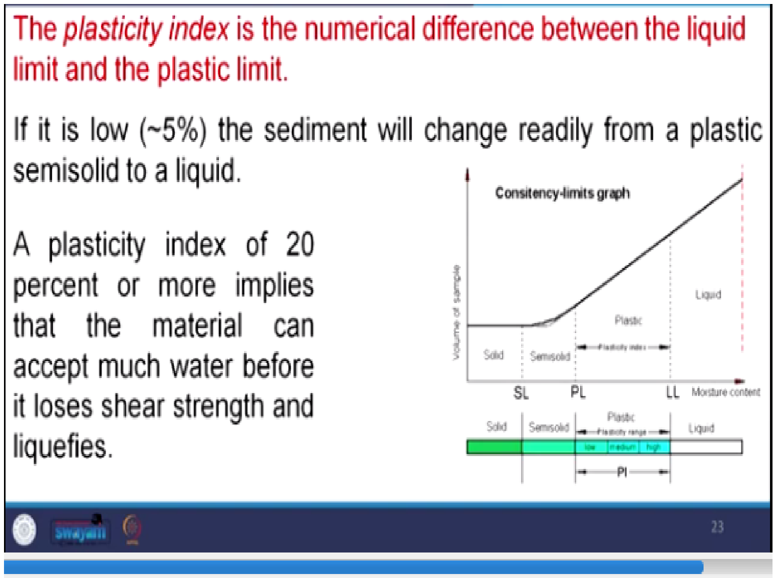
Similarly, plastic limit; plastic limit is also another measure of water content defined by the water content at which the mass from solid to plastic state, so it is defined by the water content at which sample can be rolled into 3 millimetre diameter like soda straw rod without crumbling. So, here if in figure, if you see, this is the clay content or this water content, when the clay or the soil which is rolled like a rod.

If the rod remains intact without breaking, that means it is within the plastic limit, if it is breaking that means, the plastic limit process and generally, the liquid limit and plastic limit it is dependent upon the clay content of the soil, it is a good measure of clay content of the sample because silty or sandy soils with little clay content cannot be rolled into such type of rods, so the number of; the percentage of clay increases, this plastic limit also increases.

So, more the clay is there, it can be; this rock can be created thin rod less than 3 mm also without breaking, so the plasticity index is the numerical difference between the liquid limit and plastic limit. If it is low suppose, it is 5% is; 5%, the sediment will change readily from a plastics semisolid to a liquid. A plasticity index of 20% or more implies that the mineral can accept much water before it loses its shear strength.

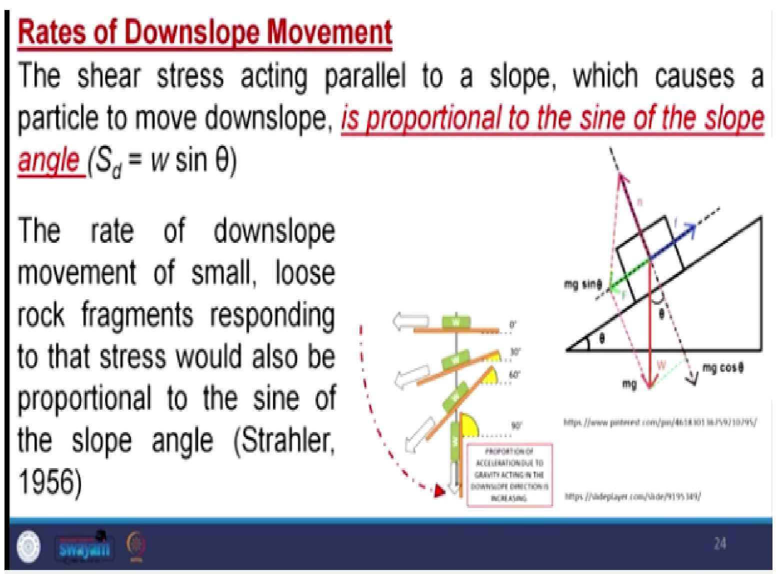
So, that means, here we can define the plastic limit of the slope material, if this plastic limit is more that means, the chances of failure will be less, so that is why the plastic limit, liquid limit.

(Refer Slide Time: 31:04)



And this plasticity index that define, whether this slope is going to fail for a particular amount of water or not.

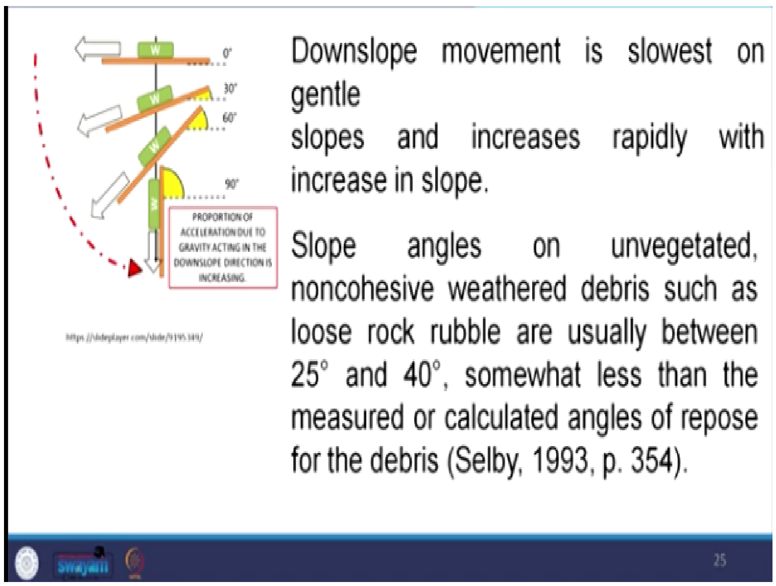
(Refer Slide Time: 31:14)



Now, the rates of downslope movement; the rate of downslope movement it is depending up on the slope, if it is slope is more, the rate of movement will be more, if slope is less, the rate of movement will be less, so here the shear strength acting parallel to the slope which causes a particle to move down slope, is proportional to the sine of the slope angle. So, here the slope is less, suppose if the line is moving like this, so the rate of movement of this block will be less. Here, it is given here; it is 0 degree, then 30 degree, then 60 degree, then 90 degree.

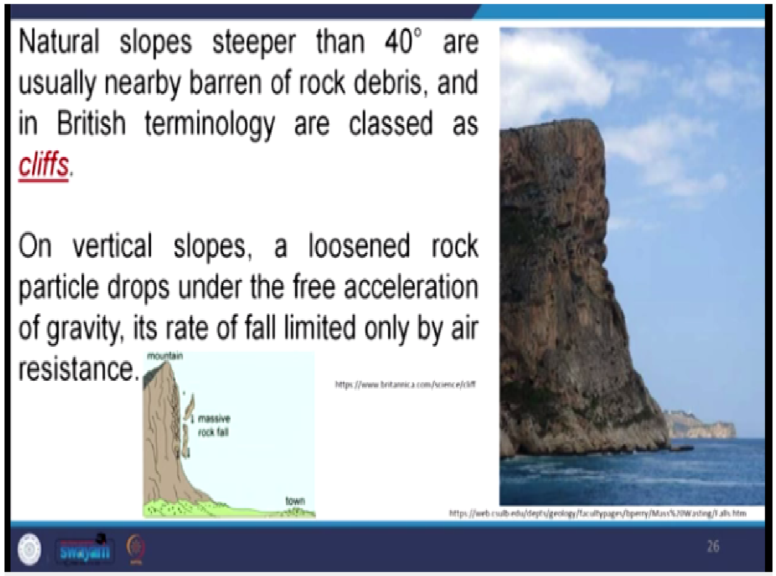
So, once the sine of this angle increases, so that means, the rate of movement of a block also increases, so at what speed, this slide will occur, at what rate the slide will be occur, at what rate or a what speed, the slope failure will occur, at what is the speed of this intact mass will come down; either it is a slow movement or it is a rapid movement that depends upon the slope angle, so the rate of downslope movement of a small loose rock fragments responding to stress would also be proportional to the sine of the slope angle.

(Refer Slide Time: 32:40)



Downslope movement is a slowest on a gentle slope and increasing rapidly with increasing of slope, slope angle on unvegetated non-cohesive weathered debris such as loose rock, rubbles are usually between 25 degree to 40 degree, somewhat less than the measure of calculated angle of repose of the debris, so that means, debris if it is there, it will fail fast rather compared to other materials.

(Refer Slide Time: 33:18)



So, natural slopes of steeper than 40 degree are usually, nearby barren rock debris and in British terminology, it is called cliff, so these are called cliff surface that means, it is a steep slope angle totally devoid of any debris because any debris created here, it will fall down directly because here slope angle is more, so slope angle more, rate of movement is more, so that is why any material which is removed from here can easily fall down here, that is why, this cliff surface are devoid of any rubble material or loose material.

On vertical slopes, a loosened rock particle drop under the free acceleration of gravity, the rate of fall limited only by the air resistance, here if you see in this photograph, this material is falling down freely only the air resistance is there, nothing this is called free fall. So, these are the terminologies has to be understood properly before moving to study these mass wasting and its classification.

And why mass wasting is important to understand before going for a developmental project, before going to slope stability projects, it is in, so I think it is for today and we would meet in the next class, thank you.