Engineering Geology
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Lecture - 15
Introduction to Subsurface Exploration

Hello everyone and welcome back. This is a new series of lessons; in this one and the next few lessons, we are going to learn the essential aspects of subsurface investigation. Now, today's lesson we are going to talk about some introductory aspects of this subject and we are going to learn a few things about how record keepings are to be done.

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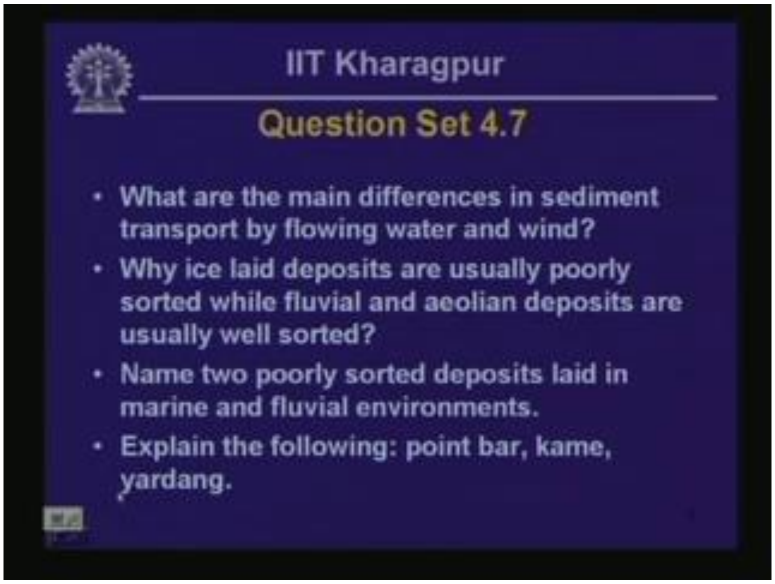

Before we carry on with the presentation of today's subject topic, we are going to discuss the questions that were asked as part of the last presentation. The first question was what are the main differences in sediment transport by flowing water and wind? So essential difference, the basic processes involved in sediment transport by both water and wind are quite similar.

But the basic difference arises because of the fact that the ((…Refer Slide Time: 1:59)) of the sediment particles that are been transported by this agents, they vary quite a bit because the unit weight under ambient conditions of air is about 1000 of that of water. So, what happens because of that is in case of wind, secondary suspension, secondary transport, a transportation process is triggered because of some secondary effects.

For example, saltating clasts if they go and hit another particle when the land at the ground surface, then those particles because of collision may actually get transported because of there being, they are taken into suspension and transported. So, this kind of this sediment transport processes, this type of secondary triggering of sediment transport process is not generally observed in case of water transport.

The second question that was asked was why ice laid deposits is usually poorly sorted while fluvial and aeolian deposits are usually well sorted? Now, ice laid or ice can actually transport huge sized clasts, say upto bolder sized clasts and as a result, the spectrum of grain sizes that are present in an ice lane, ice laid sediment actually covers a very wide range of grain sizes; whereas, that kind of capability is not there when you are considering agents like water and wind.

As a result, the grain size distribution is actually, it varies over a very narrow band. So, because of because of this fundamental reason, the ice laid deposits are going to be a little bit more rich in representing grain sizes as compared to sediments laid by water transport and wind.

Then the third question that was asked was name two poorly sorted deposits laid in marine and fluvial environments. In marine environments the sediments that are laid they are generally relatively very fine grain because very low velocity environment because of the very low velocity environments that generally prevails near the bottom of the oceans.

In some cases though, the velocity can actually go up quite substantially and that may trigger processes which you are aware or the counter parts of which are known to you, known to many of you. If it takes place on the ground such as land slide, the sub aerial land slide, those kind of processes also take place under water and they actually provide a very high velocity or high energy transportation environment and in those environments, if a large grain size distribution is available within the sediment that is undergoing submarine land slide, then the deposits that are going to form when the land slide debris flow to a different location also have got representation from a very large spectrum of grain sizes.

So, in some situations turbidites could have a little bit more wide grain size distributions than the mud deposits, so called mud deposits that are found at the bottom of an ocean known as a mud.

Now the fluvial, as far as the fluvial environment is concerned, one type of deposit that comes to mind is the deposits laid in alluvial fans. So, in that situation, a high energy mountain stream actually enters a very flat line area and suddenly the velocity of the water flow decreases quite substantially.

As a result, all the sediments that are being carried, all the grain sized that are being carried by the mountain stream, they get deposited within the alluvial fan. As a result, alluvial fans have got a very heterogeneous structure which often includes lenses of very fine grain material within coarser matrices or vice versa.

The forth question actually involves explanation of the few terms; the first one was point bar. So, in this case, the deposits, actually it is basically a fluvial deposit and let us consider a meandering stream and the meandering stream is going like this and say, this is the flow direction.

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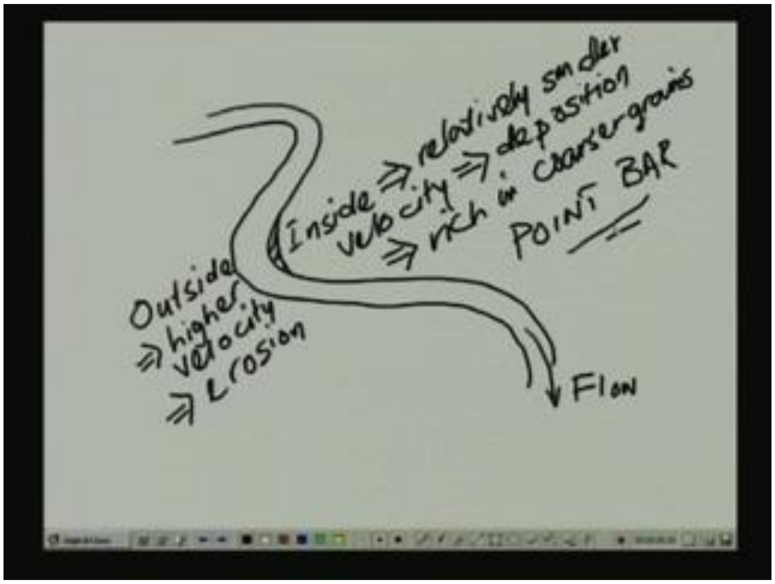

So, what happens actually is on the insides of the curve, the velocities are usually smaller in comparison with the velocity near the outside, near the outside. So, this is the inside of a curve and this particular, for this particular band, this is the outside of the curve. So here, we have got higher velocity, higher velocity and that often triggers actually erosion and what you have got in the inside is relatively smaller velocity and this triggers deposition and since this particular deposit is, deposition is taking place right near the margin of the or the perimeter of this particular stream, so the velocity is relatively much higher compare to a velocity which is laterally further away from the stream bank.

So, what you get here is the deposits that form in this process, they contain, they are rich in coarser grains and this type of deposit is called point bar, point bar deposits. So, that actually explains the term point bar. Rewarding back, the second question was what is meant by kame moraine, kame glacial deposit. And, this is a sort of long ridge like deposit that forms because of melt water, glacial melt water, streams of which actually flow underneath the ice surface, underneath the surface of the ice and they deposit, they deposit coarser grain coarser grained sediments such as actually varying within gravel size particles. These ridges are called kame deposits.

Now, the third part of the third fourth question involves explanation of the word yardang. This is also a long drawn out ridge but in this case, the erosional process that is responsible for development of this type of land from is basically wind erosion and because of that softer, unidirectional or if the wind direction is relatively uniform in a single direction, then they actually heat up relatively softer areas of the bed rock surface and what is left with, what you are left with is a long ridge of, long ridge jugging out from a relatively flatter surface. So, this type of deposit, this type of this type of land form actually is called yardang. So, that takes care of the questions.

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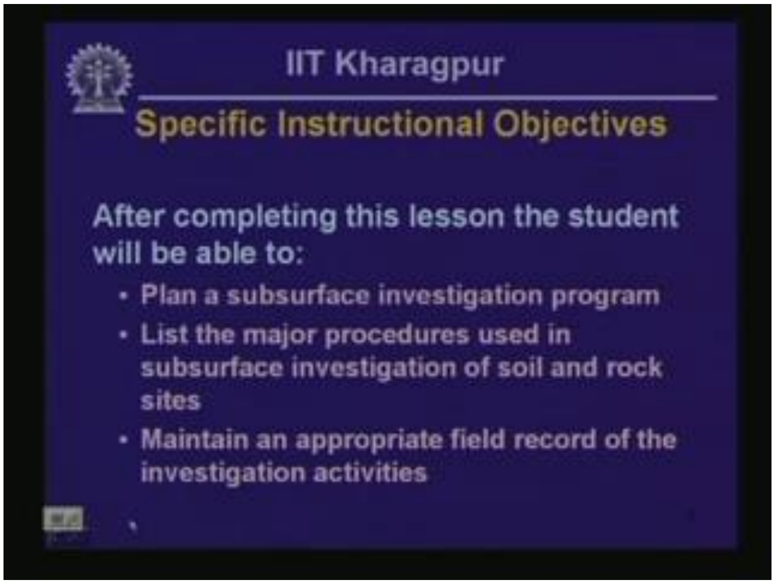

So, what we do now is to move to the subject matter or today's presentation. First of all, the objective - what we want to learn from this particular presentation; we are going to learn the processes, essential processes of subsurface investigation, investigation of the stratigraphy, stratigraphy condition underground and ground water condition.

We are going to list the, we are going to list the plans or considerations that are involved in developing a subsurface investigation program and we also are going to learn how to maintain an appropriate field record of the investigation activities in order to help the designer to make, to pass on the information to the designer or to the engineer about what was the likely condition of subsurface deposits in terms of joints or open form structures or ground water and so on and so forth because these are very important clues that the engineer will require in designing a particular facility at that site. So, these are the three main objectives of this particular lesson.

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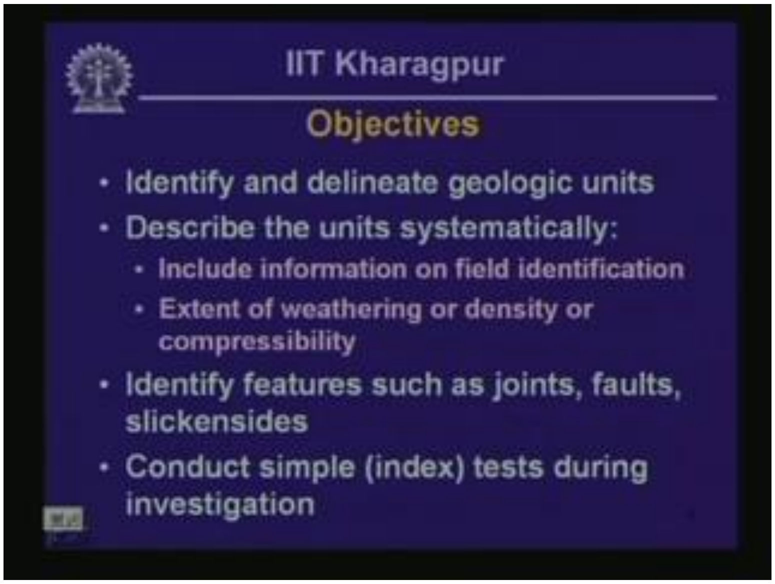

Now, we consider the objectives actually of the subsurface investigation activities themselves and so why we after all undertake subsurface investigation? So, what we want to find after we develop or conduct a subsurface investigation program? So first of all, what we need to find or what we are interested to find is to identify and delineate geologic units.

For example; a particular site may be underlained by a layer of soil. So, this one here is a layer of say sand and then underneath that layer, there could be a layer of silty clay. We do not know actually in engineering terms, what are the meanings or what are the, what are the actual meanings of these terms but we are going to learn those things later on when we talk about the textural classification of soils as we did in case of rock earlier.

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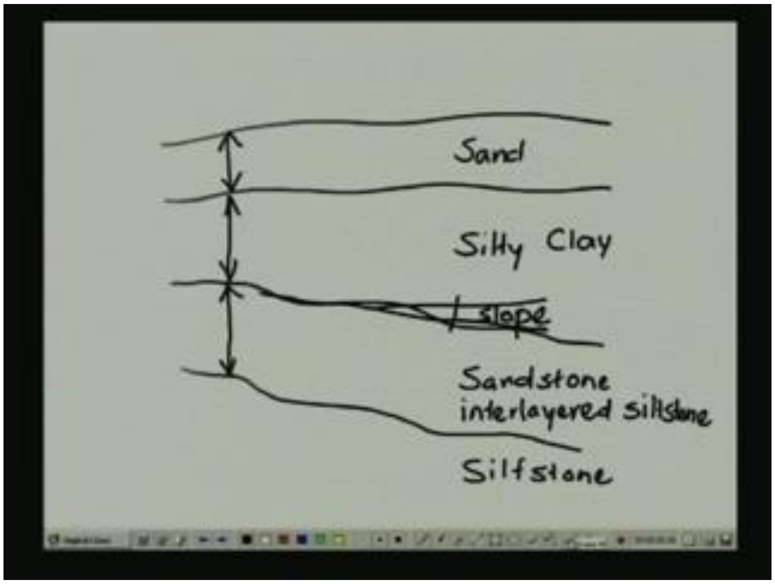

Now, underneath the silty clay, there could be a sand stone bed rock which could be interlayered with, interlayered, say siltstone and underneath the sand stone layer, there could be a silt stone layer. So, in a subsurface, from subsurface investigation, what we want to find is we want to actually find the sequence of these subsurface units that are going to be underlained, that are going to be below underneath a particular site.

We also want to find how the layer, these individual layers thicken or thins out in a particular direction. So, we not only want to find these thicknesses, these thicknesses of individual units; we also want to find the slope of these units. If you recall, this slope is called the depth of these interbeds or this interfaces. So, this is what we want to actually find in a sense from a subsurface investigation, one of the things that we want to find from a sub-surface investigation.

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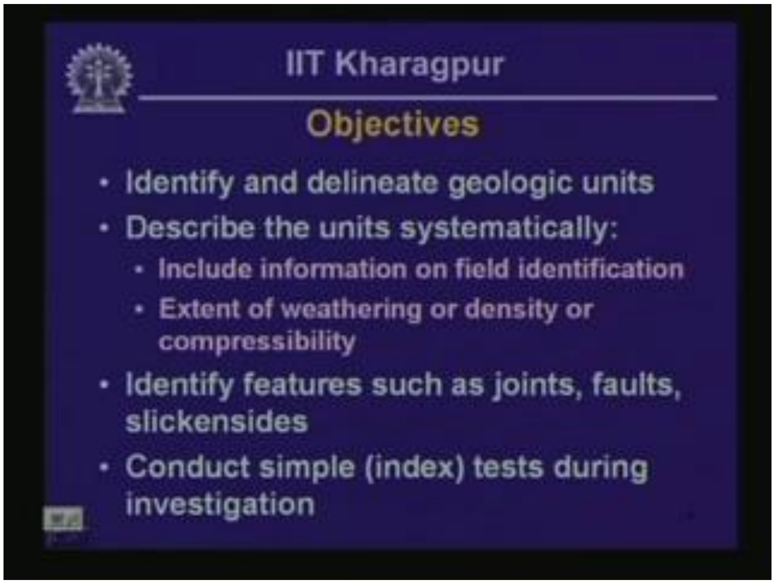

Then the second thing is we want to describe each of those units systematically and this description should include information on field identification of these units. For instance, the inspector needs to say whether the layer that is being encountered during the subsurface investigation is that consisting of sand size particles or it is mainly composed of clay size particles or whether it is sand stone or lime stone or whatever. So, this is required to be identified in the field itself and we will see how these things are recorded and later on in this particular presentation.

And the second thing also, second thing also is important is the extent of weathering or density or compressibility of these units. We need to identify the features such as joints, faults and slickenside's; some of this terms are known to you, some of this terms are not, we are going to explain these terms later on, the unknown terms later on. This is important because these joints, faults and slickenside's ,they actually present plains of weaknesses which might be acting in future after the construction of a facility on top of the this particular formation as plains of weaknesses through which failure, ground failure might be triggered because of the change in this stress region caused by the construction.

Then the fourth particular thing that we are interested to find from subsurface investigation is we conduct simple index tests during the investigating itself to get a picture about how strong is the subsurface unit against a certain type of load.

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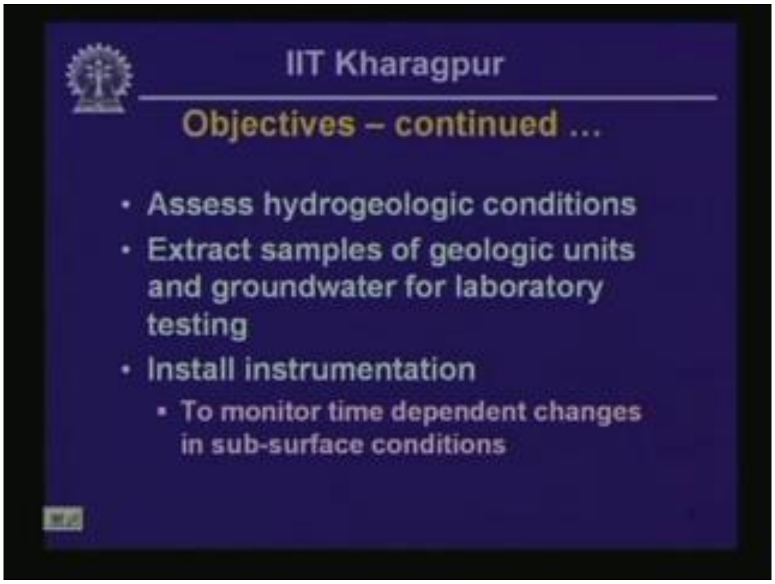

We continue with the list of objectives. Subsurface investigation also quite often involves assessment of hydrologic condition. What we want to find in this case; how the ground water underneath a particular area is or what is the condition of ground water that is there within the subsurface deposit underneath site.

Then we want to extract also samples of geologic units such as different types of soils or different types of rocks for subsequent laboratory testing, we also sometimes sample ground water samples, take extra ground water samples for laboratory chemical tests and finally another important objective of subsurface investigation is to install instrumentation which is going to be left underground for monitoring of the time dependent changes of subsurface condition such as say for example, if the ground water flow, it has got a seasonal variation, then how the ground water regions varies over time, we want to know that; whether it rises to the surface or what depth it actually falls to. This has implication in the design of a particular facility at that site. So, these are the main objectives of a subsurface investigation program.

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Now first question that comes to mind is how much of an area is to be covered in a subsurface investigation program? Now, the spatial coverage, the spatial coverage actually depends on the purpose of investigation and subsurface variability. Now, if an investigation is being undertaken for a very very important project, then the spatial coverage may actually have to extend a little bit further out of the foot print of that particular project or the construction, proposed construction so that the effect of the proposed construction on the surrounding areas is also properly accessed during the design process.

Then the second thing is how much of variability is there in the subsurface condition? If the ground condition is highly variable that means the layers are, layers are highly irregular and they do not show any particular continuity over a large lateral extent; in that situation, the investigation locations need to be relatively closed spaced in comparison with a situation where the ground condition is homogeneous, relatively homogeneous and uniform.

Then the second aspect that actually governs the spatial coverage of a subsurface investigation program is how much of an area, how much of an area is being proposed for the construction of a facility? So, the spatial coverage should at least cover the project area and then as I indicated just a few minutes back, the extant of coverage of the subsurface investigation should be an or should also cover an area outside of the perimeter if required because this allows the designer to assess the influence of a particular construction on the surrounding facilities, surrounding facilities which is not within the project area. So, let us try to understand what is meant.

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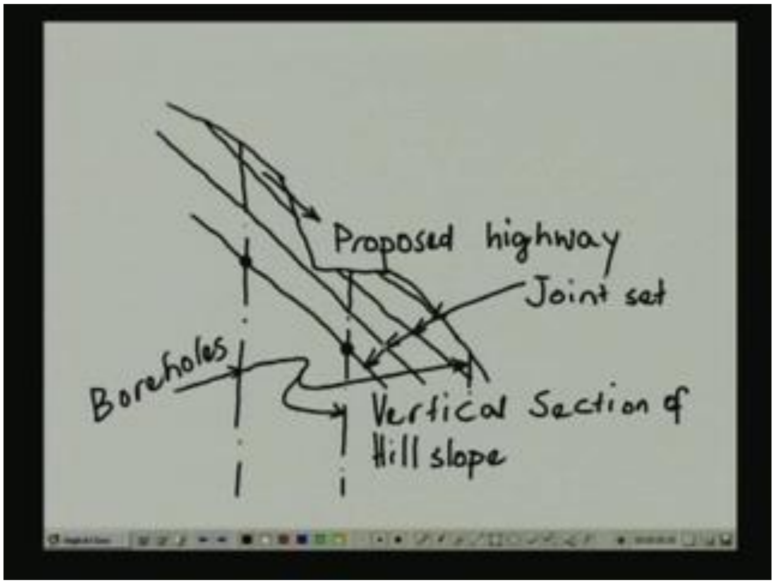

We have dealt with these things some time back, this aspects sometime back. Let us say, let us say there is a hill side and this hill side what is proposed, what is proposed is construction of a hill road on the side of the hill and what we are looking here is a vertical section really, vertical section of a hill slope. So, this is the proposed highway, so this one is the proposed highway.

Now, you could actually argue that since the highway is proceeding in a plane perpendicular to the tablet here, what we are going to do is we are going to drill a series of investigation hole along the center of the right of way and that is going to be or that is going to be yet. Now, whether that is sufficient or not, that is what we want to actually find out here.

Now, let us say, this particular hill slope is underlained by a jointed rock and the joint set, one of the joint sets is oriented in this manner. Now, if you have got this kind of joint set, so this is the joint set; if you have got this type of joint set, then if your proposed investigation of drilling to bed rock is only along the highway center line, then you are not going to be or you would not able to see what is the depth of the joint as you move laterally from the center line of the proposed highway.

So, in order to capture the geometry of the joint sets, we have to have subsidiary investigation, down slope and up slope of the center line of the proposed highway. So, we need to have a set of boreholes laid out in this manner and then we can easily find out the elevations from the drilling information from these boreholes of a particular bedding or a particular joint and then we have got a better idea, better picture of the depth of the joint set in a direction perpendicular to the proposed highway.

Now, that is important that is very important is because if you are proposing a highway through a hill side which is underlained by a jointed rock with a joint set like this, then if you excavate in this manner as shown that is going to be triggering a possibility of rock slides as we have learned from a presentation sometime back. So, this type of orientation, joint orientation is not really very good for the highway facility proposed here.

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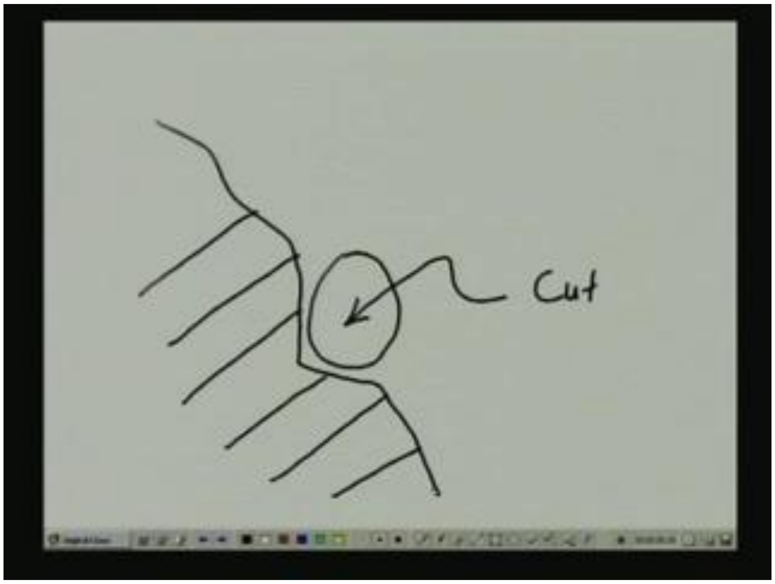

So instead of that, what we also learned earlier is that a preferable orientation of joint set would be like this. So, if the joints were to be orientated like this, then if we have got a steep cut at this location, then the cut is going to be relatively more stable. So, these considerations are verified from having a well laid out investigation, subsurface investigation land.

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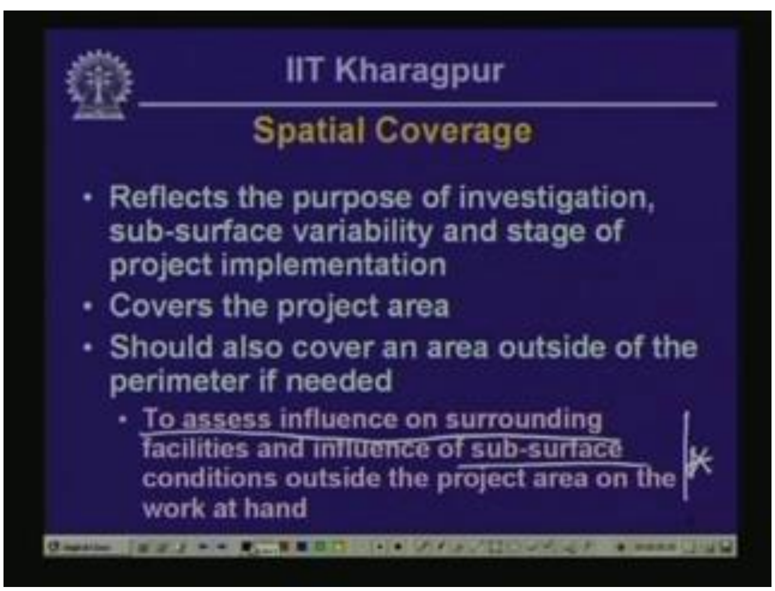

So, you saw there that we not only need to investigate along the proposed alignment of the highway, we also investigated laterally a little bit further out from the center line of the highway. So, that is what is meant in the last in the last particular point here; so you should take a note of this particular aspect as well.

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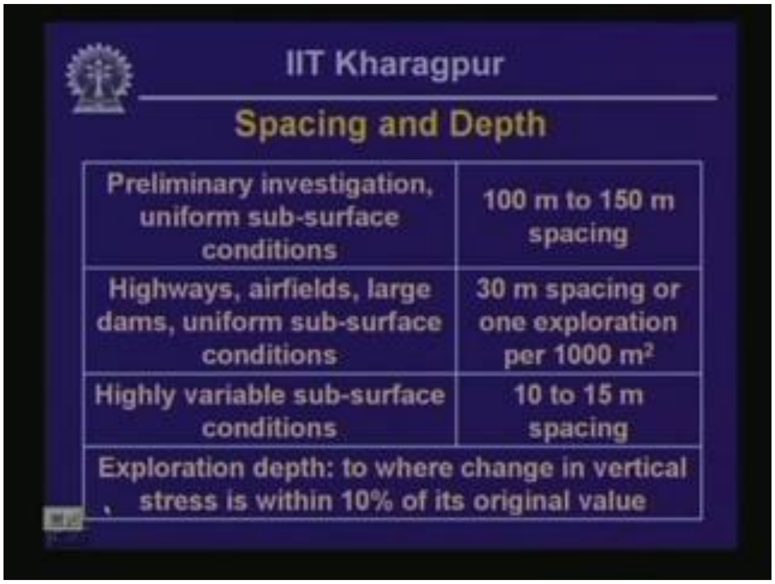

Now, the second question that comes to mind is what should be the spacing and depth of the locations of the investigation program, to what depth actually we should carry out the subsurface investigation and what should be the spacing in between two consecutive locations of investigation?

Now, it is quite obvious if the investigation is for deciding the preliminary alignment of particular linear facilities such as highway or railway; then the investigation can be carried out at a relatively wider spacing in comparison with the corresponding investigation that is being undertaken for a detailed designed project of the same facility.

So, a guide line in this respect is given on this table here; if we have got a preliminary investigation and if we have got uniform subsurface conditions, if the subsurface condition is relatively uniform, then a spacing of 100 to 150 millimeter between two consecutive investigation locations is often considered sufficient.

Now, if we have got a very important structure and I mean, if the project is at a detailed design stage and condition of the subsurface layers is uniform once again; in that case, the spacing is going to be much less and the common practice is to go for boreholes, every one borehole every 30 meters or there should be one exploration, one exploration location covering approximately 1000 square meter area.

Then the third guidance that we have got in this respect is that if the subsurface condition is highly variable that means the layers, the subsurface layers they are steeply deeping and they are also pinching out or thickening in all different directions; in that kind of situation, subsurface spacing should be even less and 10 to 15 meters spacing between two consecutive boreholes is often consider sufficient in this respect.

Then we also have to find upto what depth we have to investigate and a simple guidance in this respect, it concerns the change in vertical stress, so the guidance goes like this; if the change in vertical stress is 10% or less of the initial vertical stress, then that should be the level up to which we want to conduct an investigation. So, let us try to understand this particular point little bit more.

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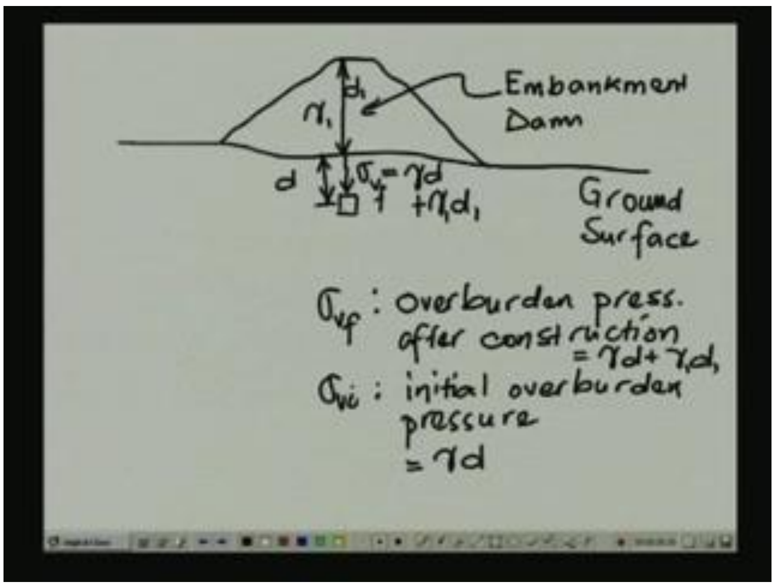

Let us say, we have got a ground surface like this. So, this one is the ground surface and again we are looking at a vertical section and let us say, we want to actually construct an embankment dam at this location, embankment dam at this location. Now, because of this dam construction, the soil elements underneath the dam, it will feel a larger vertical pressure in comparison with its original value. So, let us say, originally you had a vertical pressure at that level of sigma v prime that arose because of a soil column of that much of depth.

So, this was the original vertical pressure. So, if you consider the unit weight of the soil column to be gamma and the depth from the surface, ground surface before the embankment dam was constructed that was gamma d, then after the dam is constructed roughly, you will also have to include the weight because of the material used in dam construction as well. So, this has got a unit rate of gamma $_1$ and this depth is d_1. So, what we have got here is, finally is a pressure of gamma $_1$ d_1.

So initially, so what you had here, so let us call it sigma $_{vf}$ where sigma $_{vf}$ is the over burden pressure after construction and sigma $_{vi}$ is the initial over burden pressure. So, in this case, sigma $_{vi}$ is equal to as we have said in the sketch there, it is equal to actually, is equal to gamma times d whereas sigma $_{vf}$ is equal to gamma times d plus gamma $_1$ d_1.

Now, what happens actually; as you go down deeper, the effect of the construction, effect of the weight of the embankment actually decays with depth. So, what we have got actually, if you consider the final over burden pressure, then as you go down deeper - let us erase a little bit more in order to get clarity - so what you have got sigma $_{vf}$ decreases or delta sigma $_{vf}$; if we plot sigma $_{vi}$ minus sigma $_{vf}$, so this one here is sorry sigma $_{vf}$ minus sigma $_{vi}$.

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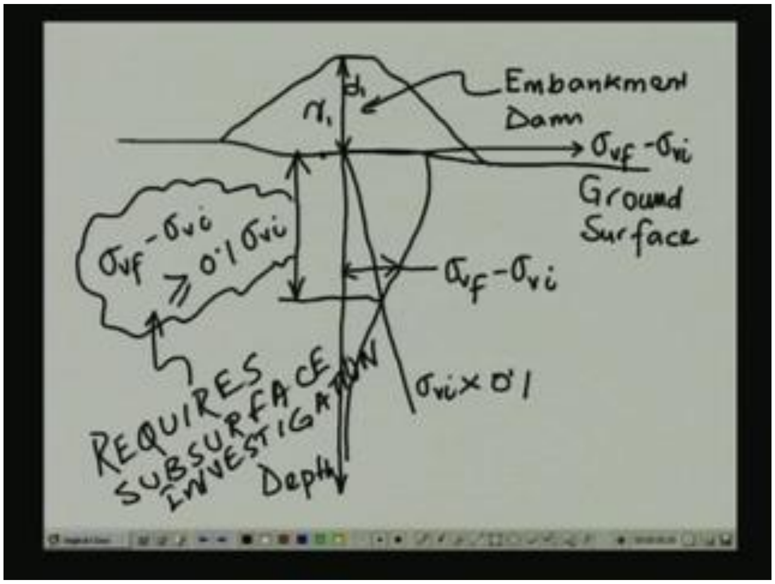

So, this value is actually sigma $_{vf}$ minus sigma $_{vi}$ at a given depth, at a given depth. So, this actually decreases gradually with depth typically. Now typically, the over burden pressure sigma $_{vi}$, so both these things are being plotted against depth; sigma $_{vi}$ actually is going to gradually increase with depth and let us say, we are plotting sigma $_{vi}$ divided by 10. So, 10% of sigma $_{vi}$, we are plotting and you can see that this is the depth upto which sigma $_{vf}$ minus sigma $_{vi}$ is greater than or equal to 0.1 times sigma $_{vi}$. So basically, this much of depth requires investigation, requires subsurface investigation; so upto that depth, you have to conduct the subsurface investigation.

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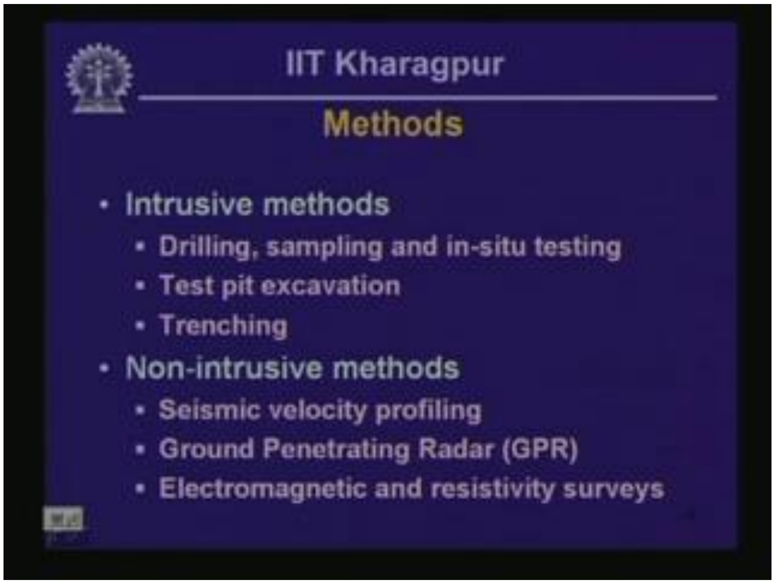

Now, we look at the different types of methods, different methods that we normally use, that are normally used in subsurface investigation. So, one class of methods that involves actually inserting a probe or getting or intruding into the subsurface layers. So, this type of investigation is called the intrusive methods.

So, intrusive method includes all those methods of drilling sampling and in situ testing, this also includes excavation of a test pit; we are also going to look at the procedures later on and it also includes trenching.

And secondly, there could be non-intrusive methods, these methods do not involve insertion of a particular probe in the ground and will see the salient features of these methods later on in one of the future presentations and they include seismic velocity profiling, ground penetrating radar and electromagnetic and resistivity surveys. So here, we do not actually intrude in the subsurface deposits; whereas in intrusive methods, some of which are going to be discussed today, we are going to actually insert something - a probe or a drill stem or something into the subsurface deposit.

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Now, before we get into the processes, we want to actually see the details, actually we are going to or let me get the points straight; we are going to talk about intrusive methods in the next presentation and non-intrusive methods, we are going to look at the details of these methods in one of the later presentations after the next.

Now, we want to actually look at the record keepings before we get into the procedural details of the intrusive method and non-intrusive methods because it is extremely important actually, I should underscore this thing, it should not be treated lightly. It is extremely important to have a very complete record about whatever is going on during the subsurface investigation because the investigators report is the only thing that actually gives the details of the different types of happenings during the subsurface investigation to the designer of a particular facility and if the records are incomplete, then the inference that the designer is going to draw from the field record is going to be insufficient and often misleading.

So, what are the different aspects that must be included in a subsurface investigation field report? First of all, you need to very clearly mention, the inspector should very clearly mention what is the exact location and time of investigation. And, for this particular purpose, it is often essential, particularly when an investigation is undertaken for a detailed project design stage, it is very essential to have the locations of investigation properly surveyed in terms of their top elevation or the elevation of the ground surface at the location of the investigation as well as the exact location of the investigation reference to some bench marks or the surveying monuments or in terms of GPS coordinates.

The second thing that must be included on the field log is the name of the person who is logging as well as the name of the driller because if the designer needs some information regarding activities, regarding activities which are not appropriately mentioned on the field log which are missed out from the field log; in that case, the personnel who signs of the field log, they can be contacted.

Then third thing is description of the equipment and procedure used in a particular investigation. That actually tells a lot about how much of reliability can be placed on the information presented in the field log; that depends very strongly on the procedure used in the investigation. Then the forth aspect that must be included in the field log itself is the log of material characteristics or what kind of layers are being encountered during the investigation process.

Then there should be a log of ongoing activity and that should include whether any significant or all significant occurrences such as for example let us consider a drilling activity that is being undertaken at a site underlained by jointed bed rock and there could be actually a cavity inside a bed rock because of removal of rock material by water or some other because of some other reasons and if a drill stem is allowed to be lowered within that cavity, then what is going to happen is if there is an effort to drill through this particular cavity, then the drill rods and the drill bit is going to drop through the cavity and the inspector must record that the drill string drop through a certain depth when the borehole proceeded to a particular elevation because that will tell the designer that there are cavities within bed rock which must have to be considered while designing a particular facility on top of that surface.

Now, if that information is missing, then the designer will assume that the bed rock has got no opening and the strength that he is going to infer is going to be relatively more and stability issue will not be considered in the design because of the presence of those cavities. So, these types of these regarding the ongoing activity must be included in the field log itself.

Then there should be ground water observation, ground water observation; whether the water flow or water used in the progress of the drill hole, that actually is vast within a cavity, that also should be mentioned here, water loss.

Then installation details of any instrumentation like standpipe piezometer, we are going to look at the details of these particular or we are going to look at the details of these things later on. So, instrumentation details should also be mentioned on the field log and as I mentioned earlier, an incomplete record is really a misleading set of information.

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Now, soil description; you have to describe the subsurface units that are encounter during the investigation process. Now, soil description should include all those things; density or consistency, structure, field moisture condition, color or odor, particle shape such as angularity and soil constituents - whether it is composed of sand or whether it is composed of clay or whatever.

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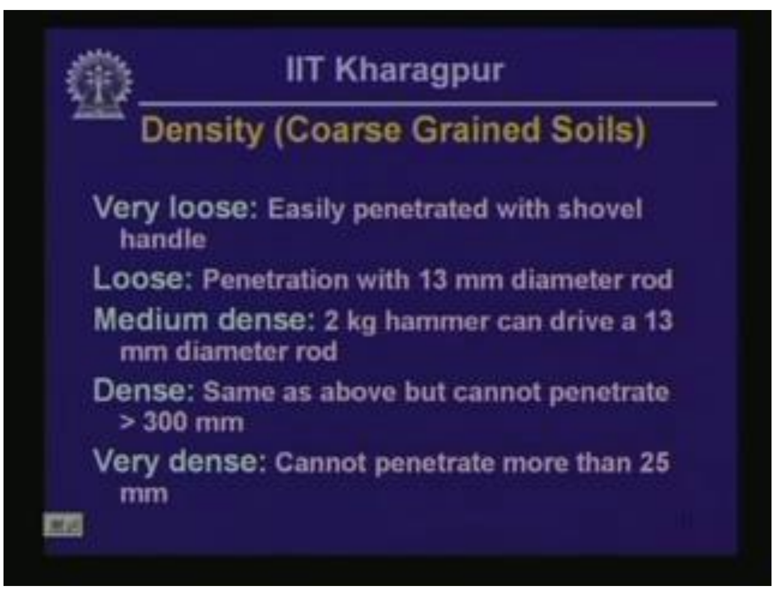

Now, the first aspect that needs to be included in the description of the subsurface units is density and density is applicable, this is for coarse grain soils actually; if you recall coarse grain soils, they derive there material strength basically from interlocking between individual grains. As a result, density becomes a very important parameter affecting the strength of that particular subsurface unit. So here, we could have a spectrum of different densities; it could go from very loose to very dense. So very loose is a type of or you can infer actually, these different densities by conducting very simple tests such as trying to penetrate the formation by a steep by a shovel by the handle of a shovel or trying to insert a rod into the deposit.

For instance, if you have got a very loose deposit, then that particular deposit is easily penetrated with a handle of a typical shovel; whereas if it is loose, then it can be penetrated with a 13 millimeter diameter approximately, 13 millimeter diameter steel rod. Now, if you need to use a 2 kg hammer to drive that 13 millimeter diameter steel rod, then you can say that the deposit is medium dense and if it is dense, then even after hammering the rod, you would not be able to penetrate a depth of more than say 300 millimeter or if the deposit is very dense, then the penetration is less than about 25 millimeter of the 13 millimeter diameter steel rod.

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Second thing is consistency. So, consistency actually is applicable for fine grained soils such as cohesive soils or clays. These type of soils, they actually derive their strength form inter granular electrical bonds; we will see this aspects later on. The consistency of a fine grain soil can vary from very soft to hard and here also I mention a series of simple test that can be performed on a sample extracted while the investigation process is going on and this test will tell the inspector whether a soil is approximately very soft or it is hard.

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Then you have to mention structure; you have to talk about structure of the particular deposit. Now, structure could be massive - massive structure is relatively homogeneous and featureless, no joints or bedding plains apparent within the unit of soil or rock; it could be homogenous - homogenous is relatively uniform in composition and color; it could be heterogeneous which means non uniform in composition and color and it could be layered - there could be parallel layering or the layers could be pinching or thickening in a particular direction or there could be laminations - these indicate very closely spaced alternating layers of different soils.

Now, if you have got only two different types of soils in terms of grain sizes; then laminated soils are called varved soils.

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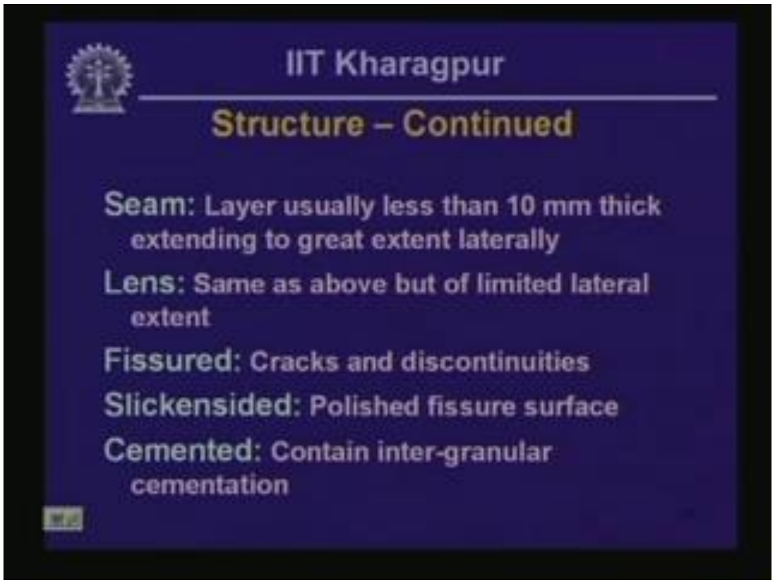

More structural aspects; structures could be seams - seams are basically layers which are less than 10 millimeter thick and they extent to great depth, great lateral extents; there could be lenses - lenses are basically similar but they are all limited lateral extent, similar to seam but they are all later limited lateral extent; then there could be fissures or cracks of discontinuities within the within in the mass of soil; there could be slickenside's - slickenside's are essentially joints again, fissure again but this fissures, the surface of this fissures are very highly polished, they are very slippery; the soil can be cemented which means there are inter granular cementing agents between individual particles.

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Then you have to describe moisture color and odor of a particular soil deposit. Moisture condition could be dry to wet. Dry means there is no visible moisture, moist means the deposit is moist to touch but there is no free water and wet means there is free water, free water film present on the surfaces of the individual particles.

Then you have to also describe the color of a particular soil unit and color have to be described as the sample is dug out of a particular borehole because color changes with exposure to, exposure to the ambient condition and color actually include a primary color or there could be a secondary, you also have to include the description of the secondary coloration such as patches of a secondary color, this type of patches are often called mottling and this particular feature is associated with ground water, with seasonal or with time dependent ground water fluctuation within layers.

So for example, the layers within which the ground water level fluctuates, they have often colors which is basically, it has got a one, it has got one primary color say orange and it has got dark patches and this particular type of coloration is called mottled orange black.

Then you have to describe the odor and that is important because for example if there is a lot of organic content within a particular soil, then the odor is going to be indicative of such organic content.

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Then finally, you have to name the soil constituent; here you have to name the primary constituent of the soil and this includes say for example sand or clayey silt. And, you also have to name the secondary or tertiary soil constituent, secondary or tertiary soil constituent; so here you use qualifiers such as trace, little, some, with or and.

And, the percentages of the secondary or tertiary constituent meant by these qualifiers are indicated over there. For example; if you have got little, if you have got clayey silt with sand, that means it has got or it is primarily a clayey silt soil but it has got 20 to 30% of sand and it could also include trace gravel as is given in the example at the bottom of this particular slide.

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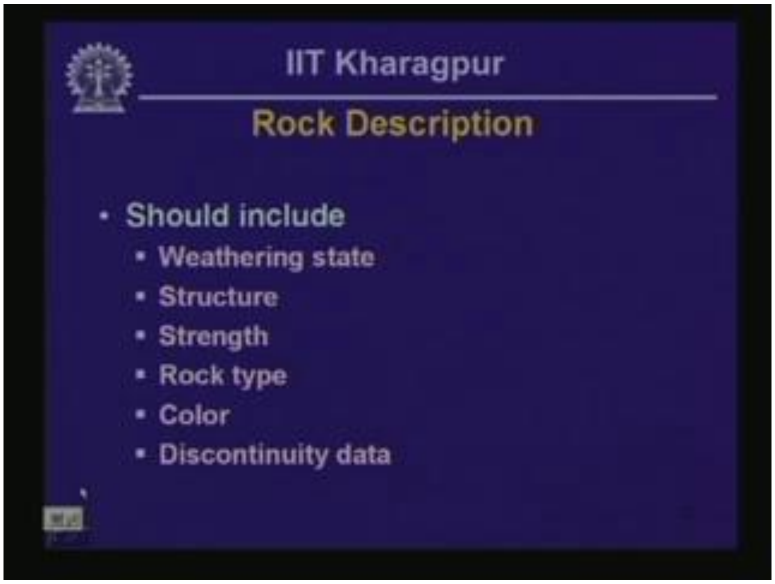

Now, we are going to continue with this particular presentation, we are going to continue with the description of rock units when we meet in the next presentation and we are going to look at the details of how the information gathered during the subsurface investigation, the systematic information gathered during a subsurface investigation, they are recorded and after that in the next presentation itself, we are going to move on to the inclusive testing methods.

With that actually, I am going to wrap this particular presentation here and we are going to consider the question set of this presentation together with the question that is going to come once we complete the lesson in the following presentation. So, until we meet for the next time, bye for now.

Thank you very much.