Rock Engineering

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Lecture-12
Factors Influencing UCS and Modes of Failure in Compression

Hello everyone. In the previous class we learnt about how to make the sample in the lab from the one that we got from the field. Then we saw that what all are the various requirement for this specimen preparation. And we saw that how can we conduct the uniaxial compression test on these specimens and we saw that what all are the factors which influence the value of UCS based upon the lab condition, testing condition.

So, today we will discuss in detail that what all are those factors which influence the value of UCS. And why do they have that kind of influence? What is the reason behind that? And then we will have some discussion on the failure modes under uniaxial compressive strength tests. So, to start with let us have the discussion on various factors which influence the UCS. So, the first and foremost and the most important one is the friction between end platen and the end surface.

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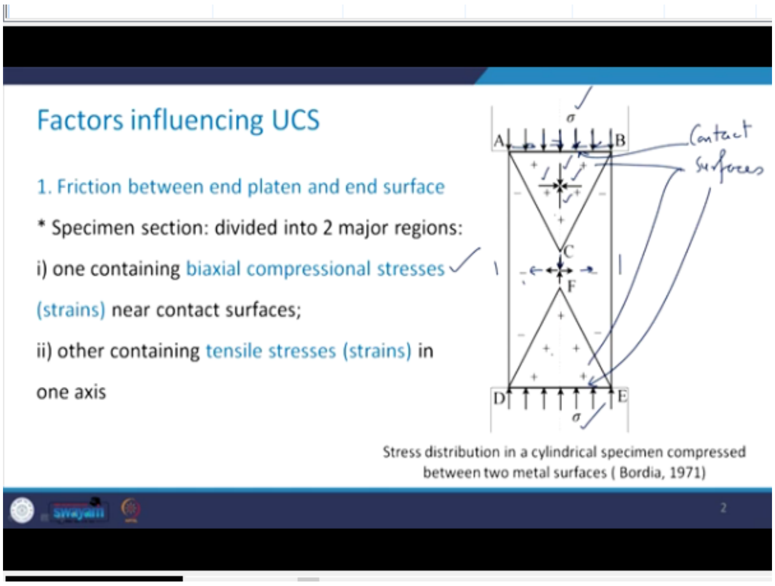

When I say that, it means, see this is the specimen and when the loading platen is there through which the load is being mobilized onto this specimen, there is going to be a friction between this and the loading platen. Now what happens because of the presence of the friction between these that means at this interface. Let us see that. This specimen section it can be divided into 2 major regions, take a look at this figure.

That there are 2 major regions, one is these 2 conical portions. And the other one is this remaining portion. Now see what is happening because here this vertical load is there. This axial load has been applied and there is a presence of the friction. So, what is happening in the zone which are near to the ends? Because of the axial load you have this stress and then because of the friction you have another set.

So, basically in these 2 regions you have biaxial compressional stresses or strains near these surfaces. So, these are the contact surfaces. This is the one and this is the other one. So, at these contact surfaces because of this friction you have biaxial compressional stress or strains. However, what happens in the remaining part? You see that because of the compressive nature of this load which has been applied you will have the stress compressive in this same direction.

However, because there is no confinement here or here, what will happen? The sample will be subjected to the tensile stresses at the centre like this, in one axis. So, again let us see because of the friction you will have biaxial compressive stresses in these 2 triangular or conical zones. However, in this zone in the center part you will have the tensile stresses along one axis. Ideally because it is the compressive stress test, there should not be any tensile stresses. But then that occurs here. So, what does it do?

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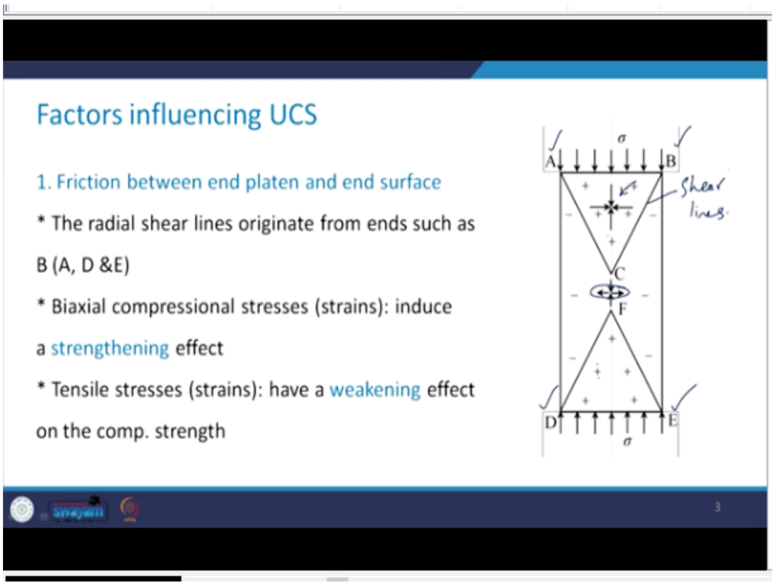

So, see what happens because of this is that you have the radial line which originate from these ends A, B, then D and E. These are called as radial shear lines and so what happens because you have the biaxial compressive stresses or strains, these induce strengthening effect in the specimen, while the tensile stress here along one axis it has the weakening effect on the compressive strength.

So, because these biaxial compressive stresses, they have such a significant influence because of the nature of the stress in these 2 conical zones, that if the friction at these contact surfaces is not minimized whatever is the strength that you will get from the test, that will be much higher as compared to the actual value.

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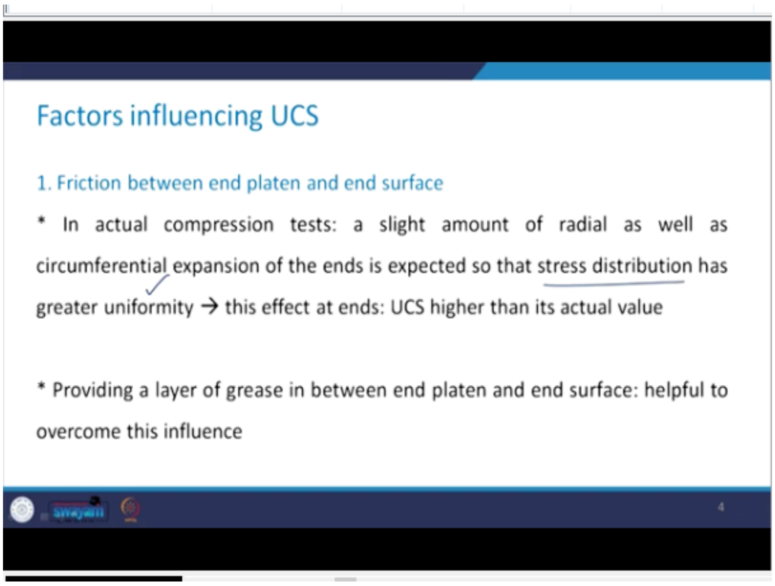

So, we need to be careful about that. So, what happens in actual compression test is that the slight amount of radial as well as circumferential expansion of the ends is expected. So, that the stress distribution is more uniform. So, this effect at ends gives rise to higher value of UCS than its actual value. It is all because of the presence of biaxial compressive stresses or strains in the zone which are near to those contact surfaces.

There are and these things came out in picture that why the strength value is higher than the actual one. So, earlier those researchers they devised lot many ways to reduce the friction between this end platen and the end surface. So, somebody said that I will put a dummy specimen, so whatever is the biaxial state of stress or strain that will be there in the dummy specimen.

But then what will happen if dummy specimen fails first? Our specimen remains intact. So, basically, we will not get the UCS of the specimen which we want to get. So, but these days what is done is we provide a layer of grease between the end platen and the end surface and this helps to overcome the influence because of the friction which is quite significant between end platen and end surface. Next is specimen geometry.

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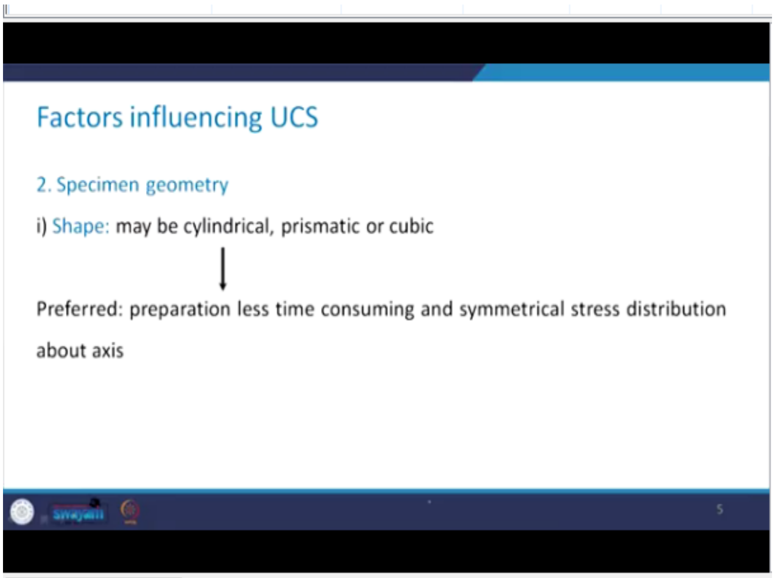

So, in the specimen geometry the first thing is shape. Shape of the specimen it can be cylindrical, it can be prismatic or it can be cubic, regular specimen we are talking about. Now the cylindrical specimen these are preferred because their preparation is less time consuming and the stress distribution about the axis is also symmetric. So, that gives the throughout uniform stress distribution. And therefore, the cylindrical specimen they are preferred. The next one is L/d ratio.

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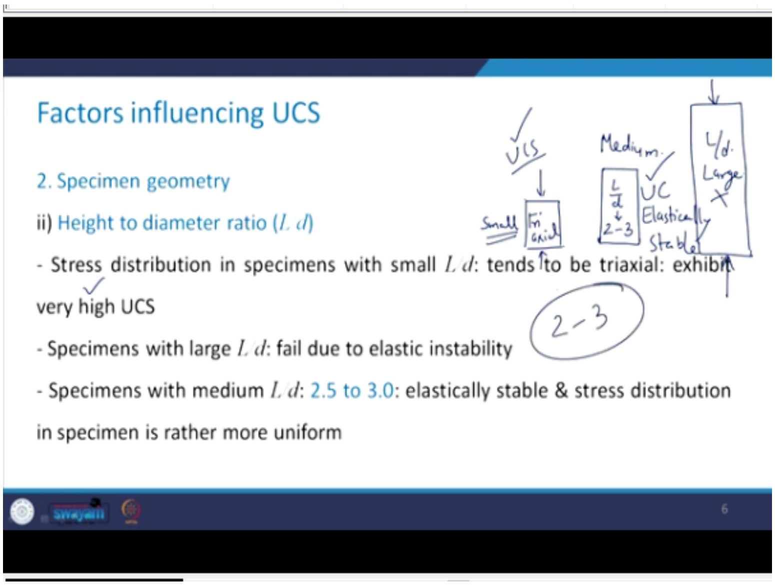

The stress distribution when you have the small L/d ratio. So, let us say I just try to draw it**.** So, let us say you have the specimen, you have this as a one specimen and somewhere here you have another specimen. So, here this L/d is small and this is your large L/d. I will come to the in between case little later. When it is small what will happen? Again, there is going to be say some friction or whatever you cannot eliminate that friction completely we just try to minimize it.

So, what will happen, because the loading is applied here so instead of uniaxial compression, the stress distribution in this specimen is going to be triaxial. Ideally what we need is that it should be uniaxial, because we are conducting UCS. So, when this is very small the state of stress in the specimen tends to be triaxial and in case if you have the triaxial state of stress obviously the UCS is going to be very high as compared to that in case of the uniaxial compression.

What will happen in case of the very large specimen? Let us say L/d is very large. So, what will happen? When you apply the load there is going to be elastic instability in the specimen and the specimen will fail because of that, not because that it is subjected to the uniaxial compression. So, it will fail because of the elastic instability. So, again this is not going to give me the correct picture.

And therefore, we have to go for something like this, where this L/d is 2 to 3. So, this is what is your medium. So, here in this case if you can reduce the friction then more or less you will have the uniaxial compressive state of stress and there will not be any instability because of the elasticity. So, this is elastically stable as well as the state of stress will be more or less uniform stress distribution will be more or less uniform and that will be uniaxial compression. So, that is the reason that L/d ratio is taken to be 2 to 3, please remember this very important.

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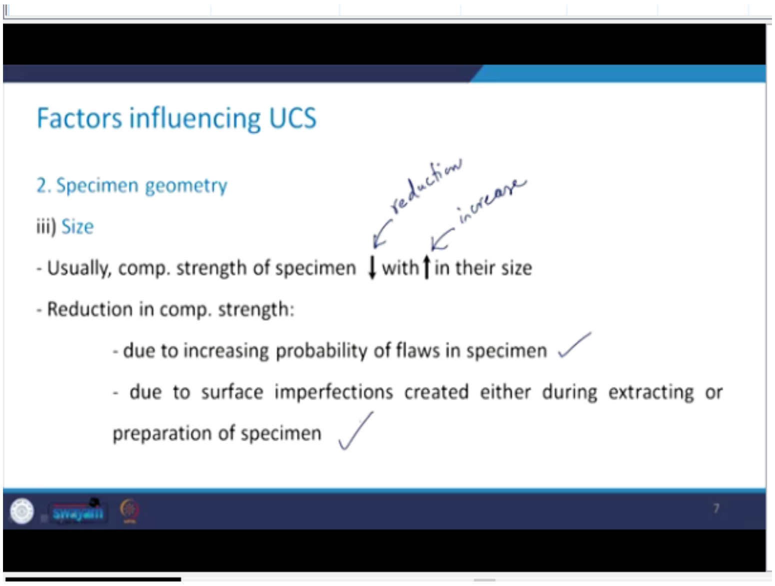

Then the next is the size. So, in general, usually it has been seen that the compressive strength of the specimen it reduces. So, this sign is for the reduction and this is for increase. So, the compressive strength of specimen reduces with increase in their size, now that can be because of the reason that when you have the large size of this specimen there are going to be larger probability of flaws in the specimen.

Then when you are making these specimens, when you are preparing the specimen either in the lab or when you are extracting the sample from the field, then there can be more surface imperfections in case of the larger specimen as that in case of the smaller specimen. So, these are the 2 reasons that there is going to be more flaws in the specimen and therefore there is going to be the reduction in the compressive strength if you take too large size of the specimen.

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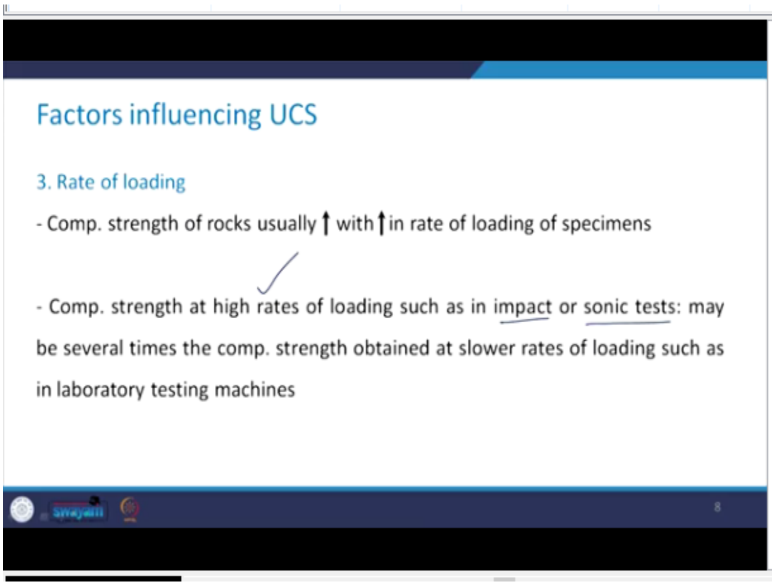

Then, rate of the loading. So, it has been seen that compressive strength of rock, it usually increases with increase in the rate of the loading of specimen. For example, when we say that high rates of loading, so what can be those? Like impact or sonic tests. And this is very interesting. When you conduct the test at such high rate of loadings, the strength characteristic can be several times higher than the compressive strength test which you conduct at slower rate of loading in the laboratory testing machines.

So, one needs to be careful about deciding the rate of the loading. So, if somebody says that this is what is a UCS and you have seen now that what should be the typical range of any particular rock corresponding to each value of the UCS, what can be the range? So, let us say if somebody says that okay for basalt type of rock the value of UCS is this much, which is much larger than the range that you know.

So, immediately the question should come that what were the condition in the lab that they were subjected to? You should immediately try to check with those things.

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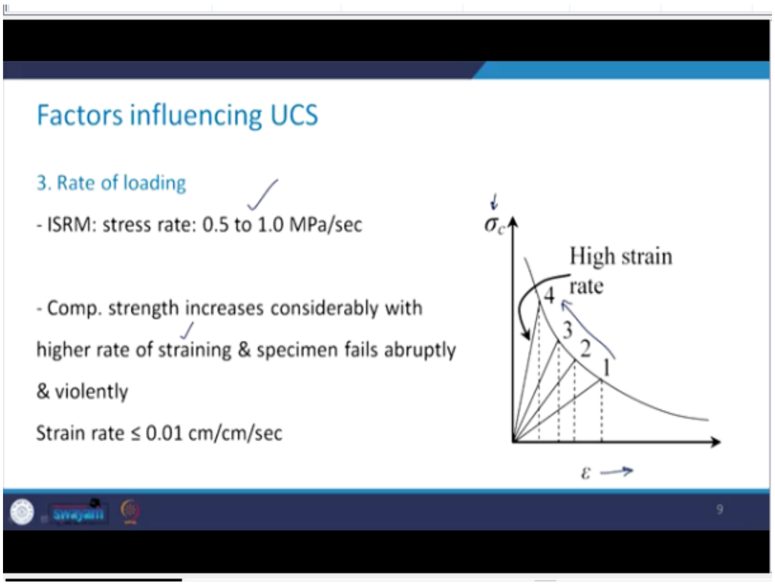

Now ISRM suggests that the stress rate of 0.5 to 1 mega Pascal per second should be adopted to conduct the test in the lab. Then the compressive strength increases considerably with higher rate of straining and the specimen fails abruptly and violently. So, you see a figure has been given here, this is a compressive strength and, on this axis, we have ε. So, as it goes from 1 to 4 the strain rate is higher 4 as compared to 3, as compared to 2 and as compared to 1.

So, you can see that when the specimen is subjected to larger strain rate, how the slope of this curve is steep and when this is steep, then the failure takes place it is going to fail abruptly and violently. So, therefore it has been recommended that the strain rate must be less than or equal to 0.01 centimeter per centimeter per second in the lab.

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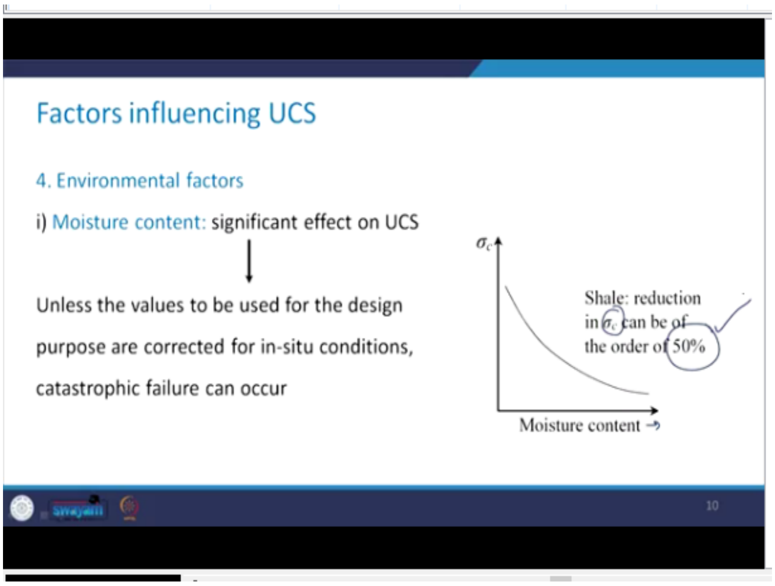

Some environmental factors which are very, very important. So, first one is the moisture content. It has a significant effect on UCS and if you just take a look on this figure, this has been drawn with respect to shale and with the increase in the moisture content, the reduction in the UCS can be of the order of 50%. So, you see it has that significant effect again it will depend upon what type of rock it is?

For few rocks it can be as significant as 50%. So, unless the values which are to be used for the design purpose they are corrected for the in-situ conditions catastrophic failure can occur. So, let us say that at the site you have some moisture content or ground water condition because of which the rock is subjected to, let us say or it is exposed to water and when you are testing in the lab you are testing it as if you have brought that sample.

And you have dried that and you are testing it in dry conditions. So, whatever that you will get it is not going to be the representative condition as it is there in the field. So, we need to be very careful about the in-situ conditions. Otherwise, we are designing for the higher load but or we are designing for the higher capacity but the capacity in the field is much lower. So, what will happen catastrophic failure can occur. So, we need to be careful, then the second factor is the type of the liquid.

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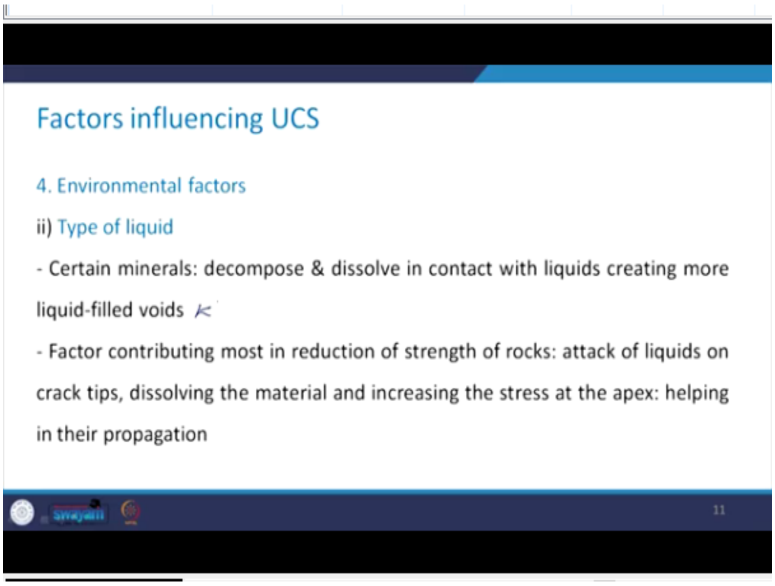

So, some of the minerals which are there, when they come in contact with some of these liquids which may be there in the environment, mostly it is water but let us say, that you have some kind of a treatment plant, some kind of discharge is taking place which has some of its typical characteristic and the rock strata which is lying at the site has some minerals which decompose and dissolve in contact with the liquid.

Then what will happen? That will create more liquid filled voids. So, what happens why this thing happens? So, in this case when you have more liquid filled voids obviously the strength is going to be low. Now what happens because of the liquid? When this liquid comes in contact with those rocks there are always some cracks which are present in the rock. So, the liquid attack on the crack tip.

And depending upon the mineralogical composition of that rock whatever is the mineral which is present at the tip of the crack it gets dissolved in the presence of that liquid and that increases the stress at the apex. The moment that there is an increase in the stress at the apex, that crack starts propagating. The moment crack starts propagating it will have its larger extent in that rock.

And therefore, if you test that rock in the lab you will be getting lesser value of the compressive strength. So, one needs to be extremely careful about these things. So, in case if in the field if the rock is let us say, in contact with some kind of liquid we need to take into account. Further the liquid may influence the surface energy of the rocks. So, basically what do we mean by this surface energy?

This surface energy is the energy that is needed to create a new surface. So, let us say, if the surface energy of the rock is large what does that mean? That large energy would be required. So, if the surface energy is large it will have large strength. So, if there is a presence of the liquid which is reducing the surface energy of the rock and if you are testing it in the lab what you will get is the reduced value of the compressive strength.

Liquids may influence the surface energy of the rock and that rocks strength will depend upon whether the surface energy is reduced or whether it is increased under the influence of the liquid.

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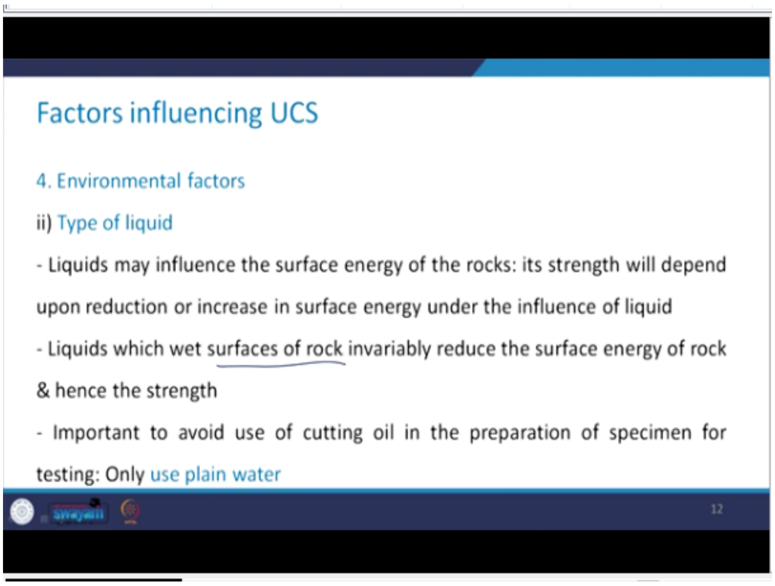

It has been seen that liquids which wet the surfaces of the rock, they invariably reduce the surface energy of the rock. And as I explained the moment the surface energy of the rock is reduced its strength is going to be reduced. So, we need to be careful that liquid may attack at the crack tip, dissolve the material, increase the stress concentration at the apex and therefore crack may start propagating.

Second thing is, liquid may influence the surface energy of the rock. If they are reducing the surface energy, the result is going to be the reduction in its compressive strength. That is the reason that when we prepare these specimens for testing, we avoid the use of any kind of cutting oil. Sometimes when the rocks are very hard then we have to use some kind of the agent.

So, that the less heat is produced in that process. I have shown you that when the drilling and the cutting is goes on in the lab, lot of heat produces. So, we need to reduce that heat because otherwise what will happen is that heat will help more cracks to generate in the rock which we do not want. So, that is the reason that instead of using the cutting oil we use the plain water while we prepare the specimen for the testing in the laboratory.

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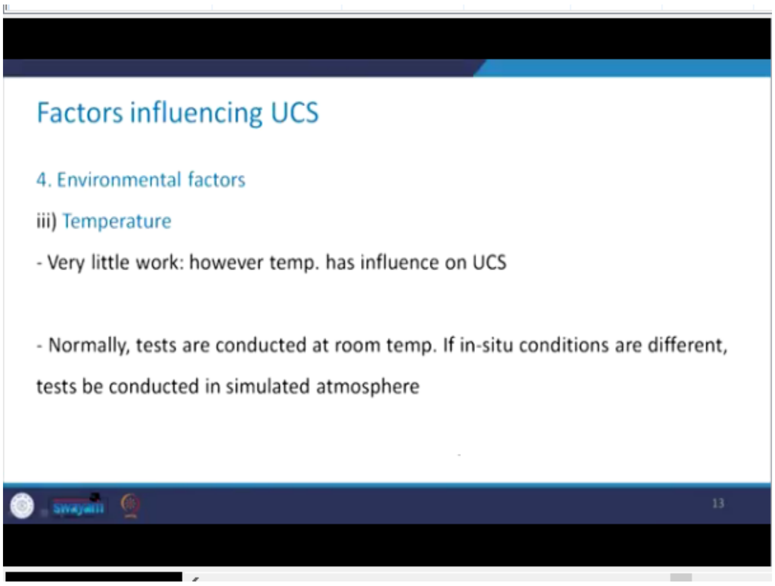

Now the effect of the temperature although very little work has been done, however whatever work that has been done, it shows that the temperature has significant influence on UCS. So, normally the tests are conducted at the room temperature, but if the in-situ conditions are different, then tests should be conducted in the simulated atmosphere. These days we have testing machines where you can conduct the UCS at very large temperature.

Because in case of the let us say, nuclear waste repository, so that would be much deeper below the ground surface and when that nuclear waste is deposited, the temperature is very high. So, if we want to find out the characteristic of the rock at that high temperature, we need to conduct the test at those simulated high temperatures. Similarly, is the case for the low temperatures.

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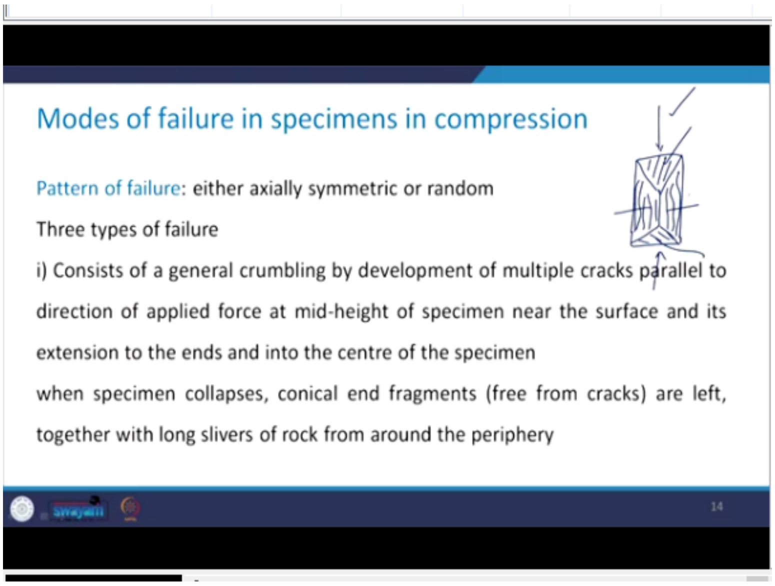

Now coming to the pattern of the failure. So, either it is axially symmetric or it is random. There are basically 3 types of failure, the first one consists of a general crumbling by development of multiple cracks which are more or less parallel to the direction of the applied force at the mid height of the specimen near the surface. And then they extend to the ends and into the centre of these specimens.

Take a look here this is the specimen. And this is the direction of the loading and this is the centre of the specimen, let us see. So, multiple cracks are going to be there, because of this applied force, multiple cracks are going to be there and slowly as the load is increased what will happen that these cracks get oriented in the direction parallel to the direction of the loading. And slowly first they originate here in this zone, that is, mid height of the specimen near the surface.

And then slowly they start extending towards these ends and towards this, towards the centre and towards the ends. When this specimen collapses so what happens is? So, you see once again when the specimen is in the about to collapse, so as I already explained it to you that because of the biaxial compressive state of stress you will get this kind of 2 conical portions. So, at the end of the test what you are left with this conical portion, this conical portion and then here you will have long slivers of the rocks.

That is, because all the cracks have been aligned now in the direction of this applied loading. So, when the specimen will collapse, what you will have is these 2 conical end fragments, these will be free from cracks, why? We will discuss these in subsequent classes and then here this portion will be all long slivers of the rock, all around the periphery.

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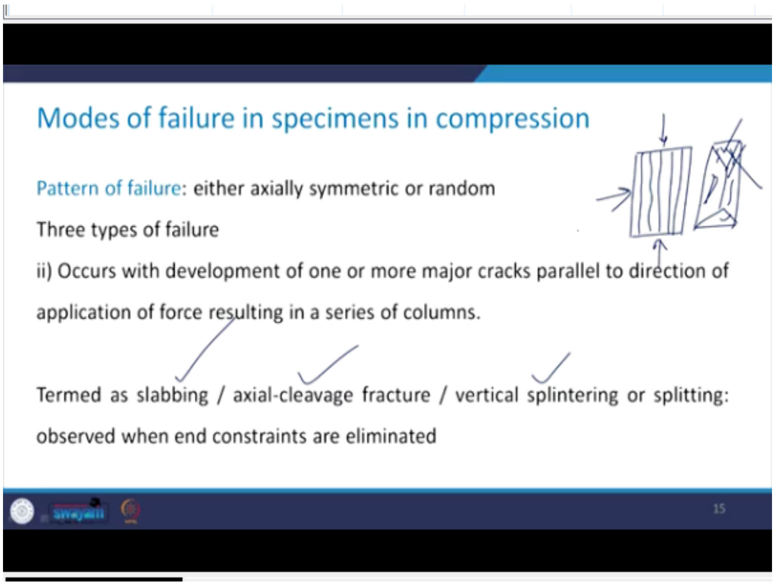

The second type of the failure, it occurs with the development of one or more major crack parallel to the direction of the application of the force, resulting in the series of the columns. So, you see it looks like this. So, it will be this kind of situation can be there, under the application of the load. So, this is termed as slabbing or axial cleavage fracture or vertical splintering or splitting.

And this is observed when you can completely eliminate the end constraint, because if end constraints are there, you are going to get these conical portions and the moment these conical portions are there, the cracks do not get propagate here, like this, no, it is not like this. So, always you will get these 2 conical fragments along with other slivers of the rock, all around the periphery.

But if by some means, you are completely able to eliminate the end constraints, then only in that case you will be able to get this type of failure.

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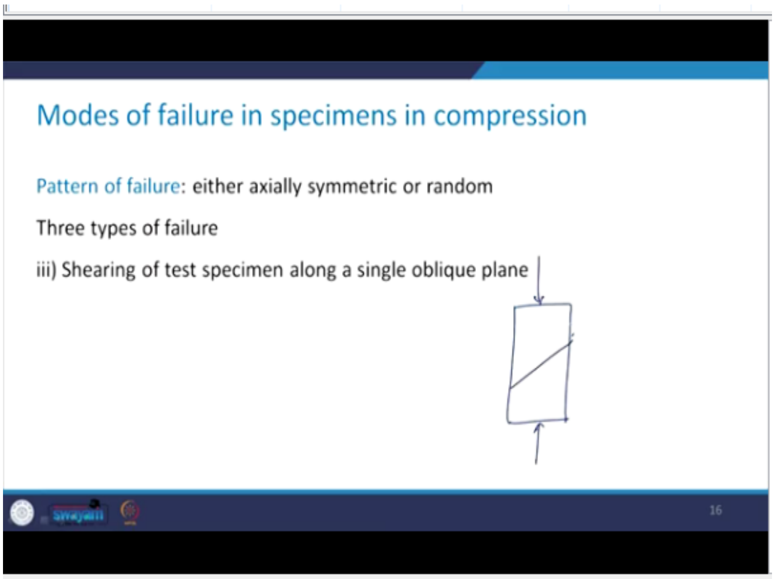

The third type of failure is the shearing of the test specimen along the single oblique plane, that is, let us say it is like this and you have the applied load. So, it is like this. So, along this it has been sheared.

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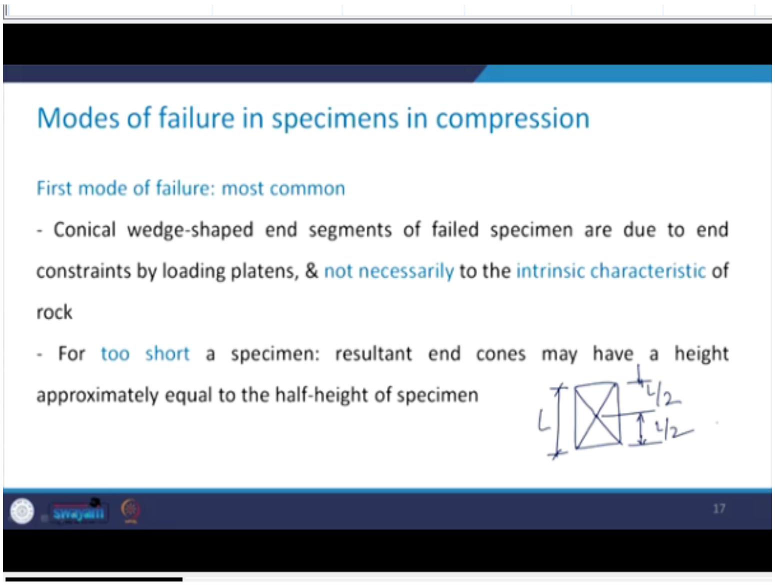

Now the first mode of failure is the most common. As I have already explained it to you that conical wedge-shaped end segments of the failed specimen, they are due to the end constraints by the loading platen and it may not necessarily to the intrinsic characteristic of the rock. So, if we are able to remove the end constraint or the friction between the loading platen and the end surface.

Then we will be able to do away with this conical wedge-shaped end fragments**.** So, do not think that it is the intrinsic characteristic of the rock. What will happen if you have too shorter specimen? See if I have this shorter specimen then I may have this kind of situation. That means, end cone they may have the height that is this much, let us say, the total height or length of the specimen is L. So, the height of this cone is going to be L/2 here and here also**.** So, for 2 shorter specimen this kind of situation can occur.

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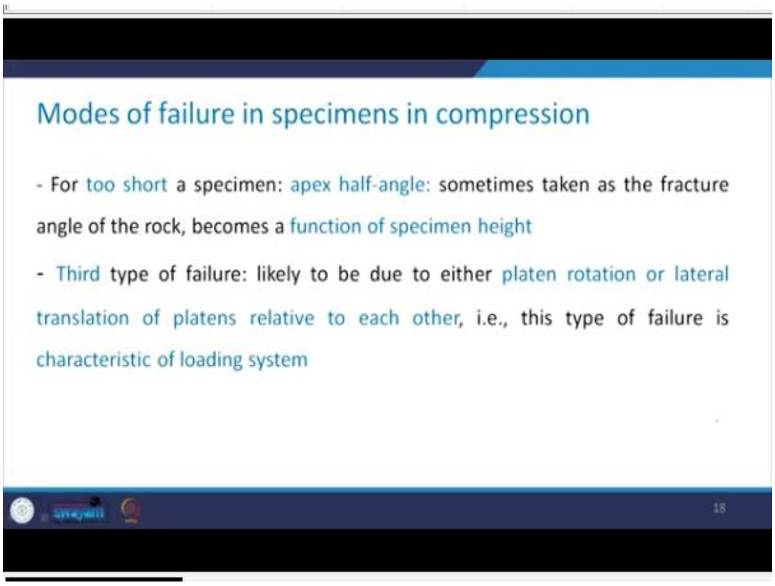

And in that case apex half-angle it can sometimes taken as a fracture angle of the rock and it becomes the function of the specimen height. So, need to be careful. So, that is one of another reason that in case if we have too short a specimen, the state of stress is no more uniaxial it is going to be triaxial. So, the strength is going to be much large. The third type of failure will happen if either the loading platen has rotated in the process of the testing or there is the lateral translation of platen relative to each other.

And this type of failure will occur only because of the characteristic of the loading system not because of any problem with the rock. So, the first mode of failure is the most common one. The second one will happen only if you have removed the end constraints and the third one is the characteristic of the loading system. So, what we have discussed today is that what all are the various factors that influence the value of UCS.

And what is the reason behind that followed by the modes of failure. So, in the next class we will have some detailed discussion on these modes of failure that why such type of things is happening, then we will follow our discussion with the determination of the tensile strength. Thank you very much.