Strength of Materials
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Lecture – 2

Good morning. This is Dr. S. P. Harsha faculty of Mechanical and Industrial Engineering Department, IIT Roorkee. I am going to present today the basic course of Engineering Science, that is The Strength of Material in which the first lecture is the introduction lecture in which I am you know present the key features of the strength of material like what are the forces, what kind of forces are being applied in the solid mechanics like if there is a pulling kind of thing or the compression is there or if there is no uniaxial-biaxial forces and then, how these forces have been set up within the solid bodies. Due to these forces, what are the internal resistances in the solid object through which there are you know like the stresses are there, the strains are there, the deformations are there. So, all these issues I represent here in this first lecture. This course is basically developed under the National Program on Technological Enhanced Learning.

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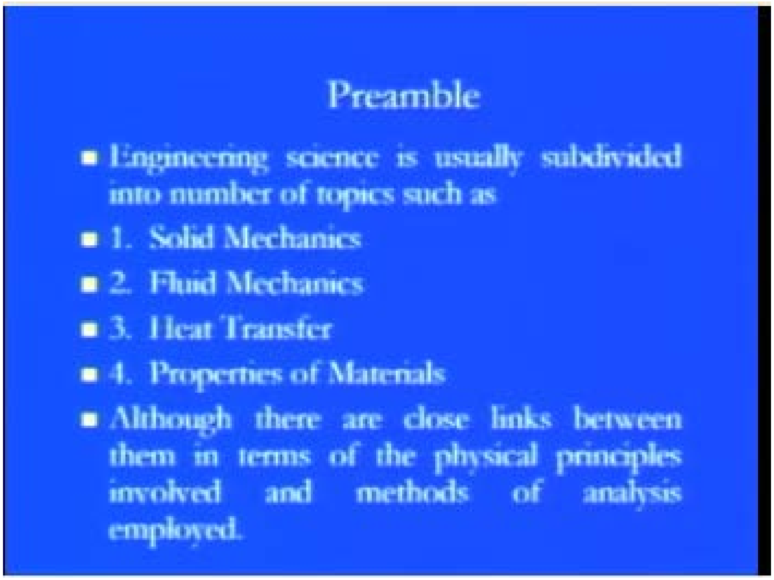

So, as you see you know like this course comes under Engineering science because in that there are lots of applications. So, we can you know like usually subdivide these engineering sciences into various category, and the first category is solid mechanics in which there are solid objects which are interacting to each other. So, we need to analyze those solid objects using the mechanics concept.

So, in that there are you see you know like the two main branches. One is the statics in which the static forces are being set up in the solid bodies, and the forces are there due to interaction. So, the other branch of the solid mechanics is the dynamic which the dynamic forces are there in which the forces are being you know like the time varying component. So, when the objects are in the moving part, we know that the dynamic forces are then dominating in those conditions. So, the solid mechanics is basically dealing with the solid objects which are interacting.

Then, the second subdivision is there under the engineering science part is the fluid mechanics. In fluid mechanics, basically we are you know like dealing with how the fluids are interacting to each other, and what are the molecules in these fluid mechanics. They are interacting, that is what you see there are various forces which we can say that cohesive forces are there, or the combined forces are there due to which the fluids are being confined to in the main object. That is what you see you know like here, there are various categories in the fluid mechanics also like if the fluid is very tiny or thin. Then, we can say that you know the laminar flow is going on when there is no dynamics in the fluid particles, or the second category we can say there is a turbulence in which there are hectic motion, or we can say truly non-linear dynamic motions are their of the fluid particles. So, there is the interaction or we can say there is intermediate portion in between those laminar as well as the turbulence parts.

So, these two you know like the subdivisions of the engineering science is basically dealing with the different domain. One is the solid as well as another one is the fluid, and the third one is the heat transfer. So, heat transfer can take place into you know like either the solid as well as in the fluid. So, that is why you see we are categorizing this heat transfer into three main categories. One is you know like the main mode is there, that is the conduction mode which is highly molecular phenomena like if you see you know like if you have the different temperatures all across the solid, then there is a heat transfer right from one end to another end through conduction. So, this is a purely molecular phenomenon.

Second we have the convection which is different than the first one because in that there is a interaction between the solid as well as the fluid, and the convection takes place, and the third is there is the radiation which you know like is the macroscopic phenomena in which the radiations are there which is emitting from an object, and there are you see you know like the different laws are there to analyze those things. Then, the final which is an important division of an engineering science, that is the properties of material in which you see know like we are generally categorizing the material into various categories, but broadly speaking there are two main categories under this that is the ductile material as well as that is the brittle material.

In the ductile material, again there is you know like that the ductility is the property. So, in that we are assuming that if a material is ductile, then it is pretty easy to extend or it is pretty easy to just pull those materials, but if we have a brittle material, then it does not have that kind of property. So, what we are doing in that we are it is because you know like the brittle materials are good in the compressive stress, the compress strength. So, they are good you know like the harder material. So, based on what properties are there we are always applying you know like the material towards application.

So, this you know like if you are dealing with the individual subdivision of the engineering sciences. Then we will find that it is not like we cannot fully analyze all the structures using the individual you know like concept of these mechanics, either solid mechanics, fluid mechanics or the heat transfer in which the temperature phenomena's are there or the properties of material in which you see there are various properties like the stiffness is there like the damping is there, like hardness is there, toughness is there, the impact is there. So, these are the properties you know like which always gives you the basic information which material is applicable to what kind of application.

Although you see there are you know close link in between them in terms of the physical principles, and that is why you see we are using these basics. These are we can say are the four basic pillars of the engineering sciences, and you see if you want to make any kind of building, we need to know that what these interactions are there in between these four properties, or we can say subdivisions of the engineering sciences. So, that is why we are saying that you know like we need to put the basic link based on the physical principles involved and that is the nature.

Nature is always saying that you see you need to maintain that what the physical setup is there in between these objects. And then you see we can go for the variety of the methods of the analysis which are employed for all these things, and that is the basic study of the engineering sciences, but here you see you know like as far as this course is concerned or main focuses on solid mechanics that actually how these solid objects are being set up, how these forces are being well set up within those objects. Then, if we are going towards introduction as I told you that is as for the subject is concerned.

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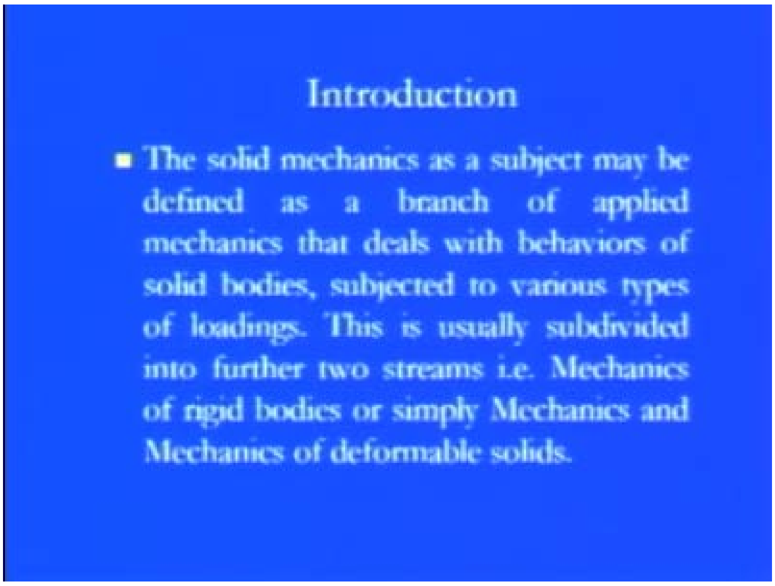

The solid mechanics as a subject may be defined as a branch of applied mechanics, because again you see you know like what we are doing here is in the applied mechanics we can go for solid as well as fluid mechanics. But here it is the basic branch of the applied mechanics, solid mechanics in which we are dealing with the behavior of solid bodies as I told you earlier subjected to variety of loads.

If there is a pulling, then we can say, technically we can say it is a tensile pulling, or the tensile load is there. If there is a compression, then we can see the compressive loading is there, but these two loads you see you know like comes under the main category known as the uniaxial loading because you see if the load application is there, always you see you know like load can be defined by the variety of things like you see if you are saying that it is a force, then force is nothing, but the mass into acceleration, but the key feature in the force is what is the point of application. If the point of application is same like if I am pulling from both the side, this force is known as the load that is the tensile loading. That means the pulling is there. If in uniaxial even loading if I am saying that this is the compression which is also acting on the same axis, we can say it is compressive kind of loading.

So, these two, either the tensile as well as the compressive comes under the uniaxial loading, but if it is a biaxial loading means you see you know like on the plane like this x and y, if the load is there, then we cannot say it is uniaxial loading. So, loading can be of uniaxial. As I discussed, it can be of biaxial or triaxial, but we need to know that actually if these loadings or the forces are being there. They have to be you know like satisfy the static as well as the dynamic conditions of the object and then, all we can say that the object is under equilibrium position. So, there are as I told you the variety of various types of loadings.

So, if it is a uniaxial, then tensile as well as the compressive loading is there. If it is biaxial, then it is shear loading. If object is stationary or if objective is moving, then we can say it is a kind of torsional loading like the shaft is moving, and both the side if the forces are there, the reacting or couples are there or the forces are there, you see we can say this kind of torsional loading is there. This is usually subdivided into further twisting which is the basic thing.

You see first is the mechanics of the rigid bodies, or we can say it is simple mechanics in which the statics and the dynamics is there. Second is the mechanics of deformable bodies. That means you see you know like one side we are saying that this is the rigid body in which there is a minimum chance of the deformation. Since, the solid objects are there, they are interacting, but they are so rigid that there is no deformation and if there is no deformation, then there is no excitation, but if on the other side if you are saying that the deformable objects are there like you see you know like most of the objects, they are deformable based on what the stiffness is there within this object.

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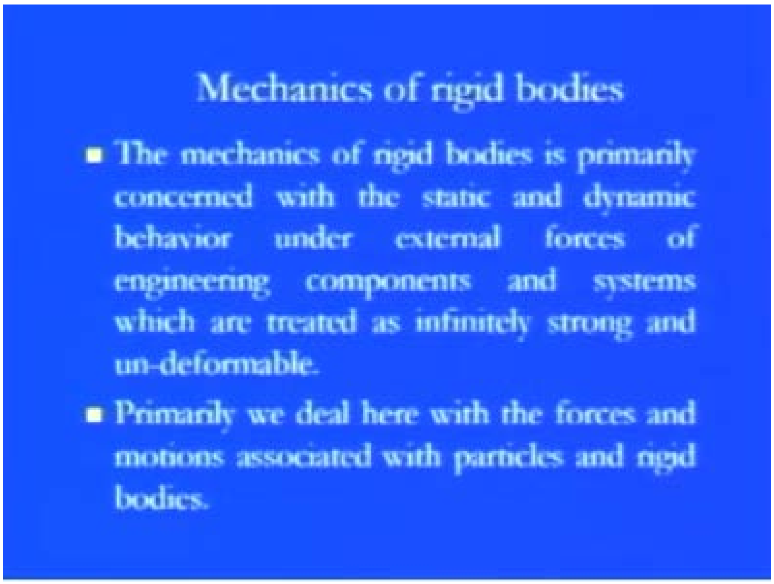

This is a unique property of the deformation and then, you see we need to you know that actually how much deformation is there. It is a temporary deformation or the permanent deformation. So, all these kind of analysis which is being studied under the mechanics of the deformable bodies, first you see that under the introduction of this mechanics of deformable solids, which is also a part of or we can say the category of the applied mechanics is known by several names like strength of materials, mechanics of materials, and in that you see again we are dealing with actually if there is a deformable body, then whether it is a temporary deformation. Then, you see you know like under the temporary deformation, there are varieties of laws like there is this modulus of Young's elasticity where the force is you know like proportional to the deformation, or there are other models of elasticities.

So, we are dealing with many things and many of the limits like yield limit is there, proportional limit is there under the deformable bodies, but if it is a permanent deformation, then there is a kind of cracks are there or the spells are there on the object. Then, we need to know that actually how much the stress or the force concentrations are there within those permanent deformations. So, this a different branch of the applied mechanics in which we are dealing with the deformable part, and that is why you see you know like in all those strength of materials or the mechanics of materials, you are basically dealing with the stress stain and the deformation, but if we are dealing with the other part that is mechanics of the rigid bodies which is primarily concerned with the statics and the dynamic behavior static, and dynamic behavior under external force is of the engineering components and system which are treated as the infinitely strong and un-deformable.

That is what you see you know like if you are saying that the stiffness is too hard, we say if the body is so stiff that even if we apply the load, it cannot be deformable and then, it is pretty hard to analyze because you see the forces are there and they are interacting. We can set up those forces, but we cannot analyze using the stress strain or the deformation concept. So, this is a different part of the applied mechanics and then, you see primarily we are here with the forces motion associated with the particles as well as the rigid bodies in which there is a stress strain as well as the deformation occurs.

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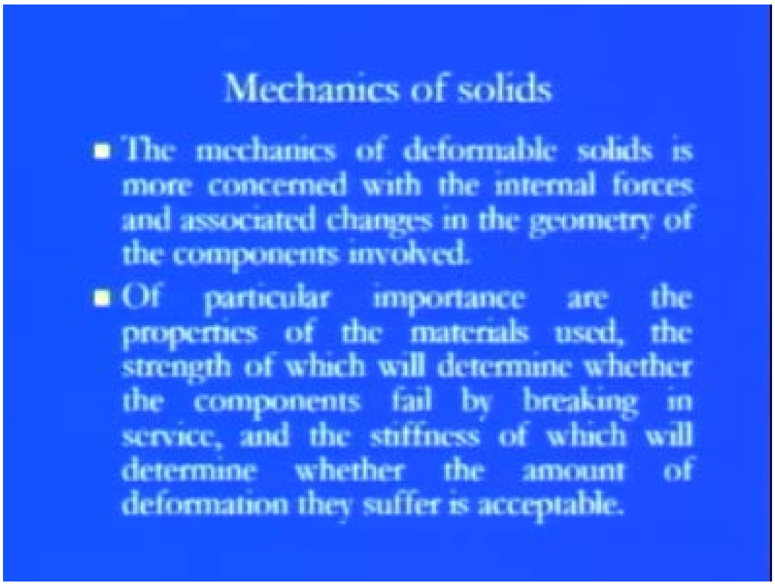

So, here you see as I told you that mechanics of solid, it is a branch in which there is kind of deformable bodies are there. So, mechanics of deformable solid is more concerned with the internal forces and associated changes in the geometry of the components involved because of the interaction of these objects. So, here you see of particular importance as you know like we are discussing with the geometric changes because if there is an impact, you will always find that there is a kind of noise. Why these noises are there? It is because of the deformation.

So, how these deformations are being set up whether these deformations are permanent or temporary, these kinds of analysis which we are going to deal in this kind of subject of a particular importance which we need to give on the properties of material. What are the properties which we are using is either the ductile as well as brittle material, the strength of which will always determine, always gives you the information whether the component will fail by breaking in the service means how long it can bear those forces or we can say whether these forces, what are the forces which are applying to those things, whether it can sustain those forces or not are up to what you see all those designs basically you know like use this kind of basic information and the stiffness. This is the basic property as I told you for the deformable object, a stiffness of which will determine whether the amount is deformable. They will suffer whatever you see the deformation object is there whether it is acceptable or not acceptable.

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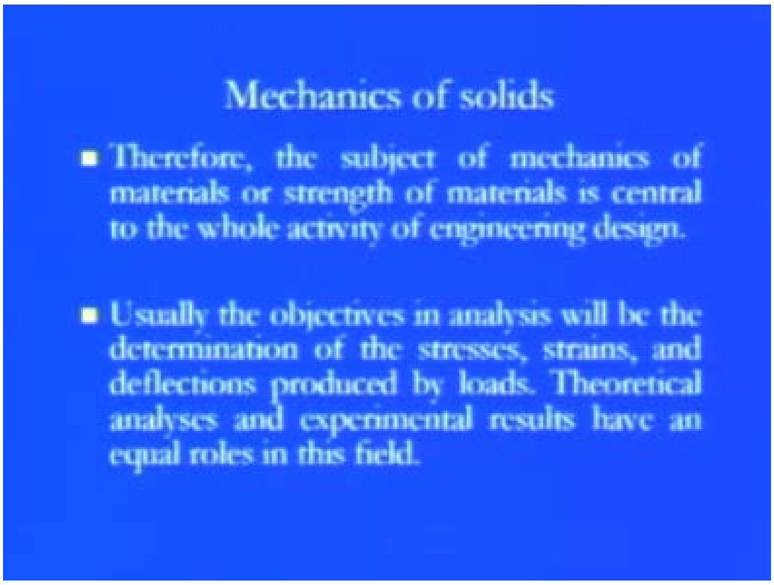

So, in that if you see, therefore the subject of mechanics of material or the strength of material is basically central to the whole activity of the engineering design because in engineering design, basically whatever the drawing is supplied to us, we need to know that you see whether those objects or the dimensions are sustainable to the load application or not. In that what you see in that engineering design, we always apply that what the material properties are there or what kind of loads are being applied, or whether you see this material can observe those kind of energies or the impacts or the load, or it can be safely operated or not.

So, this kind of you see you know like the interaction of the information, we are always using for the mechanics of material and for the basic of the engineering design. Usually the objective you know like objectives in the analysis, any kind of analysis, the dynamic as well as the static analysis will be determination of the stresses, the internal resistances like the strains. That is how we see deformations are there and the deflection produced by these loads.

These are three key terms in the mechanics of solid which we need to see that what kind of stresses are being set up within the object, what strains are there and how deflections have been taken place by these load application. And in that what you see that theoretical as well as the experimental analysis always gives the key information whether whatever the analysis which you have done is real to the nature, or which is applicable to the real nature or not, and that is what you see you know like we are doing both kind of analysis here. Now, the stress is the key feature as I told you that we need to now define what you mean by the stress. Let us introduce the concept of stress.

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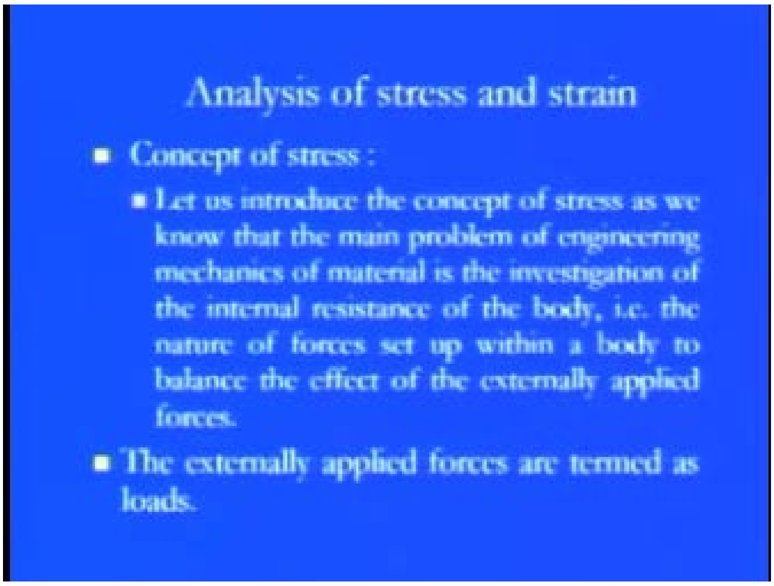

As we know that the main problem of engineering mechanics of material is the investigation of the internal resistance of body because you see you know like if we apply the load, always body will react by the third law of the this Newton that the reaction you know like action reaction is there. So, as you apply any kind of load, whether it is a uniaxial, biaxial or triaxial load, always a kind of resistance will take place. So, whether you see you know like this kind of resistances can be well setup within the object or not.

So, as we can say that the internal resistance of body, or we can say the nature of forces which are being set up within the body can balance or not. If it cannot balance, then body will break, but if it can balance, whatever the applied forces are there and internal forces if they can well set up within those object due to the external application, we can say that the body is well established under the application of load because load is always you see as I told you that force can be you know like defined by two ways. One by magnitude that is mass into acceleration. That is nothing, but the load and by the point of application how these forces are acting on an object and accordingly, the resistance forces are coming and we are saying that the intensity of the internal resistance is the stress. Either internal resistances per unit area, that is the intensity and that is external applied load as I told you forces are always termed as the loads.

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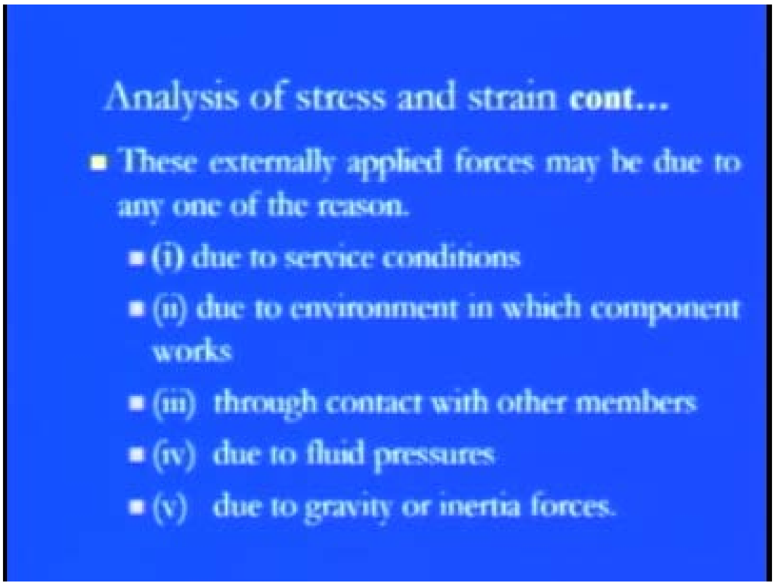

Now, you see these external applied forces, which are the key generation of this stress can be due to many of the reasons. First, the basic reason is due to service conditions, the objects are under the cyclic loading or the tensile loading or like you see you know like as we are going towards any of the machine. If you are analyzing, we will find that the bearings are there, gears are there, the shafts are there. They are always under the different kinds of loads, and accordingly we are considering we want to design the bearing.

We want to design the shaft. If you want to design the gears, or if you want to design any of static part of the machine, we are always you know like clearly observe that how these forces are being set up or due to the environment in which the component works, whether it is on the normal temperature condition or severe temperature conditions. Because of these things you see the thermal expansions are there, or we can say later on that thermal stresses are there, or you see through I know like other reasons for the applied forces are through the contact with other members. And that is why you see the contact mechanics are there, and we are you know like here concerning about that how deformations are being taken place due to this interaction.

Then you see due to the fluid pressure that you see if rho g h if you are saying that rho is the density g is you know like the gravitational acceleration, and height up to how much you know like height, these fluid pressures are being accelerating on an object, and you know like in that even the g is there. That is the gravitational acceleration or the inertia forces. Due to inertia forces also, you see there is one of the basic reason that the stresses are you know inducing in an object.

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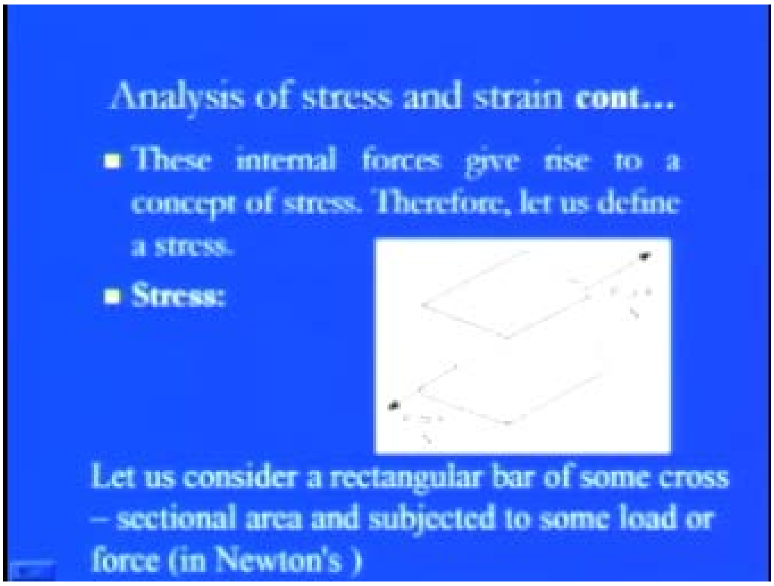

So, now you see you know like if you come to the main point that these internal forces give rise to a concept of the stress. Therefore, we can say that you know like the stress is nothing, but the internal forces, the internal intensity of the forces like internal force per unit area, and if you see this figure, in this figure as we have used the rectangular bar in which there is an axial pulling and since, it is a uniaxial pulling, we can see that this is the P P or F. This is tensile for which the extension is there, and if you want to analyze those things, then first we need to see whether this object is under stable condition or not.

If it is under stable condition, that means, whatever these forces or axial pulling are there, they are well set up within those objects. That means, you see whatever the internal resistances are there within this object, they are well set up and these internal resistances are basically due to this external, this excitation force that is P or F which is there in terms of the Newton, and always we are concerning about these forces because of where the part of application of these forces are, and that is why we are saying that these are the tensile pulling like here you see from both end, this the tensile pulling.

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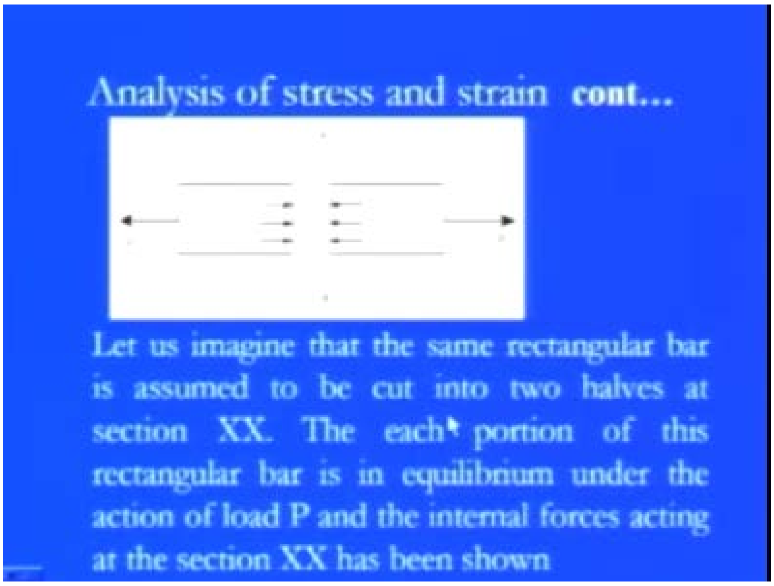

So, if you want to analyze those things, first we need to make the cross section and that is why you see you know like in this, then this diagram we are shown here that there are two main parts and on both of the sides, both of the end sides here, the P external excitation force is there and due to this externally applied load. We have seen that if you cut those thing at both ends through this XX line, these internal resistances are there.

So, each portion of these rectangular bars, either on the left or right side is in equilibrium under the action of these applied loads, the tensile load I should say and the internal forces are always acting at the XX section just opposite to the applied load, and that is why you see we can say that this is well established or equilibrium region.

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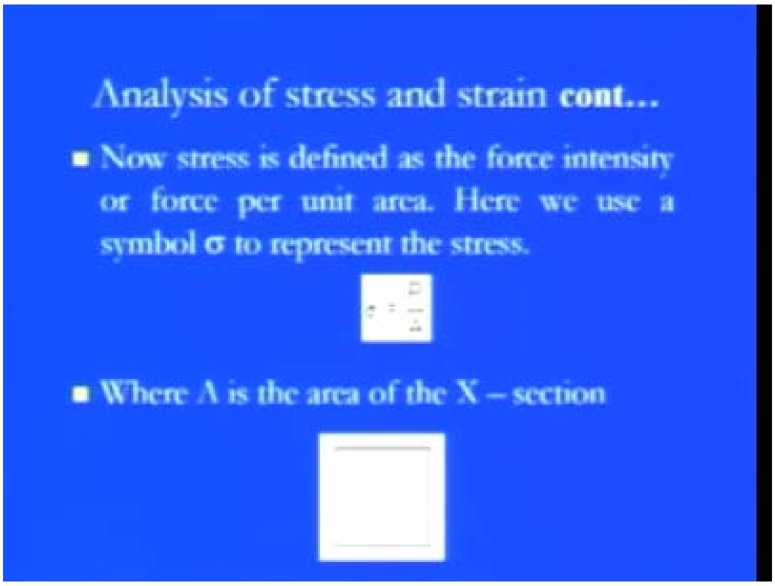

If you are talking about the analysis of the stress or strain within those things, we can say that the stress is defined by the force intensity or the internal resistance force is per unit area. And hence, we use the symbol sigma just to represent the stress, that is P by A, where A is the cross-sectional area here which is the rectangular area is there because the rectangular bar we have used in the previous case.

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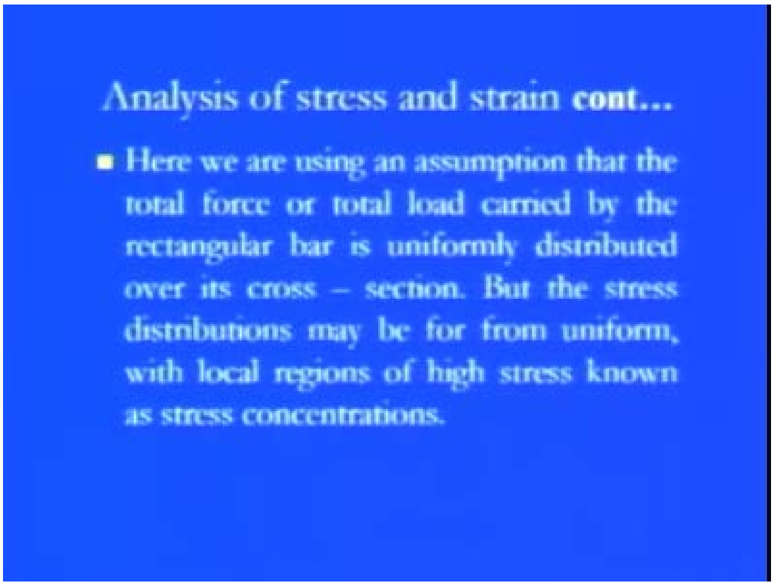

So, here we are using an assumption that the total force of the total load carried out by these rectangular bar is uniformly distributed all across the area, because if the load is non-inform, that definitely you see you know like the deformation or whatever the internal resistances are non-uniform. And then, we cannot say that this object is in equilibrium position, but the stress distribution which we can say that you see you know if the area is different at different regions. The stress distribution is obviously different from uniform, or may be local regions of high stress regions are there known as the stress concentration.

So, if there is any abrupt change in an object, we can say that the stress concentration is more and we need to design carefully for those kinds of regions. So, if we are talking about the normal stress, then there is no problem because this is uniformly distributed because of the uniform force distribution in an object.

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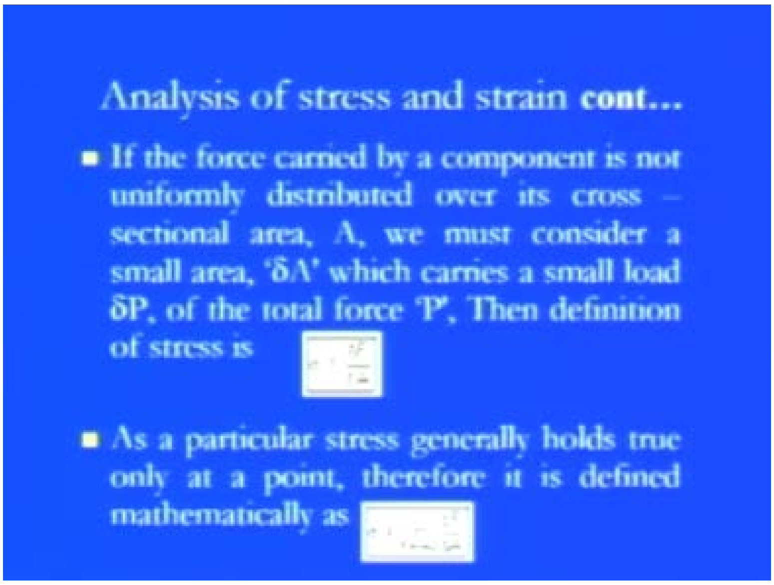

If the force carried out by a component is not uniformly distributed as I discussed during that stress concentration over the cross sectional area. We must consider the small segment or a small area delta A which carries a small load delta P, or we can say the total load P, and that is why we can define the small segment of deformation that you see the small stress is there. That del F by del A or we can set particular stress. Generally you know like it holds true only when a point, or we can say you know like for small region, or we can say the infinite decimal region that the sigma is nothing, but the limit of delta A tends to be 0 del F by del A.

So, generally what we are doing here is, if we found that abrupt changes are there within the object, or we can say object is not uniformly rectangular or any shape defined shape, what we are doing here is, we are simply categorizing this object into various categories and then, some of those things because you see we define stresses for a small segment as we have seen in this del F by del A. So, you know like we can again sum up those thing by summing of this limit of delta A 1, delta A 2 and delta 3 and so on, and then accordingly we can get the total stress after the whole object.

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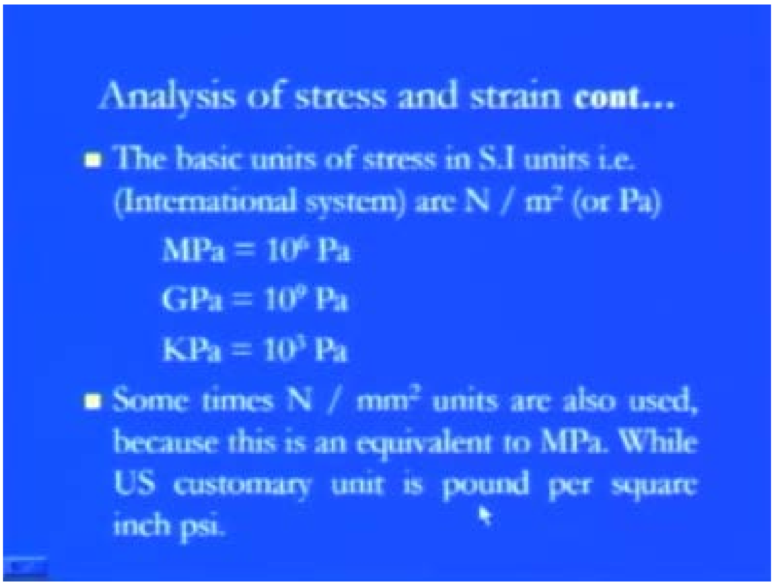

Now, you see if you are going for the unit of the stress because stress is nothing, but the intensity of the internal resistances. The basic units in the S I system is Newton per meter square, or we can say the Pascal well known scientist which gave the concept of the pressure and pressure was also you see the force per unit area. So, it has the same meaning you know like it is the internal resistances, or we can say internal resistance of the force or we can say it is internal intensity of forces. That is why we can define those things by Newton per meter square, or Pascal or if you go for higher side of these things, then it is kilo Pascal that is 1000 Pascal or giga Pascal, that is 100-1000 mega Pascal, 100-1000 Pascal or giga Pascal, that is 10 to the power 9 Pascal or sometimes it is pretty common to use the Newton per millimeter square that is also you know equals to mega

Pascal. So, while you know like this is pretty common, this unit is there in India or in particular i should say Asia or European countries, but U. S. you see United States of America, they are using this pound per square inch that is Psi, that is the FPS unit.

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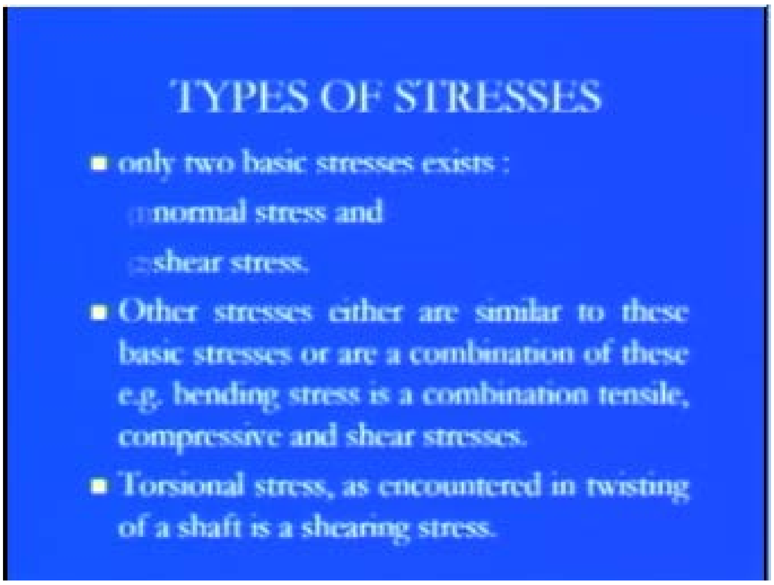

Now, you see you know like this was the basic concept of the stresses. I am sure talking about the types of stresses. There are two basic types of stresses. One is the normal stress and one is the shear stress. Normal stress means as I told you when the uniaxial loading is there, because of the uniaxial loading, what are the internal resistance per unit area that always comes out from the normal stress component. That is why you see we are categorizing normal stress component by either pulling or the compression because they are with the uniaxial part.

Second basic stress is shear stress. If they are not the uniaxial, if they have some sort of eccentricity or these stresses are there for a plane, where X and Y planes are there. That means, here or here you see you know like these stresses are being coming through the forces. We are always saying that it is shear stress. So, normal stress is an axial stress, shear stress is a plane stress. Other stresses are the derived stresses from these two like you see you know if you are talking about the normal stress, then as I told you there are two components of that. By pulling the tensile, stresses are there and by compression, the compressive stresses are there.

Shear stresses also has two components like one is if it is stationary object, and you see the twisting is there, then the shear stresses are there because it is along the plane or if you see we have the torsional stresses. That means if the object is moving, we have the torsional stresses. Another combination of these stresses is that we have the bending stresses. We have due to you see whenever the object is there in the bending stresses, we have both kind of things, the tensile as well as the compression because both the stresses are coming simultaneously at different points of the bending. Then, we have you know like another that is the thermal stresses. Thermal stresses are always coming which is not the part of that, but it is always coming due to the temperature variation, and it is being set up you know like just to make a component equilibrium under the different temperature environment.

So, these are you know like the derived stresses I should say, and some of the basic stresses are there like the normal as well as the shear stresses just like as I told the torsional stresses which is encountered in the twisting of a shaft which is also a basic form of the shear stresses.

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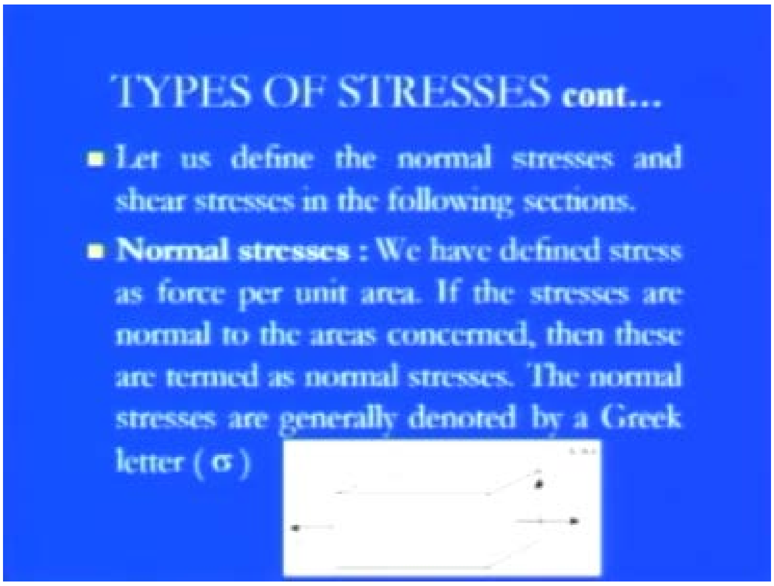

So, now come to the main part that you know like how these stresses are there, and how we can define those things of first, the basic stress is the normal stress. We have defined the stress as force per unit area that is the internal intensity of the resistances. If the stresses are normal to the area concerned like you see here, if you see this is sigma 1 and see this is sigma 1 towards this area, and this is sigma 1 towards that area. So, if the stress is acting normal to the area concerned, so this is my effective area and the stress is acting towards the normal to that. That means, there you see if a stress is acting and this is my plane you see or this is the area of concerned. I should say this is the normal stress, and the normal stress is always defined by a Greek letter sigma as I told you. So, always we need to see that what the point of application of the force or the stress is. Internal stress is there, internal intensity of the resistance is there. If it is normal, then we can say or if it is perpendicular at the area concerned, we can say this is normal stress.

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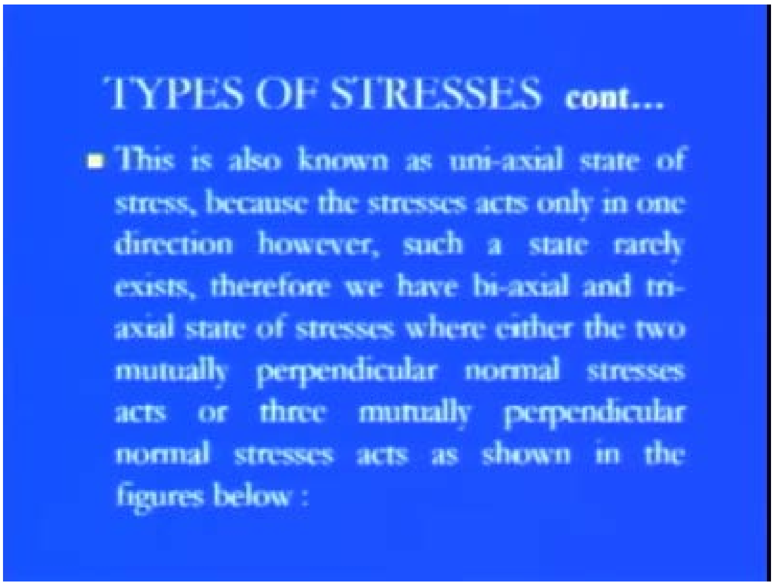

So, this is also as I told you like known as the uniaxial state of stress because they are acting at the uniaxial because of the stress acts only in one direction, either the tensile or the compression. However, a state you know like whatever you see this kind of state which rarely exists in this object. So, what we are doing here is always going for the biaxial or the triaxial state of the stress to define all those stress which are being set up within the component. So, a state of stress is where either two mutual perpendicular stresses are there in the biaxial, or three mutual perpendicular normal stresses are being set up in the object.

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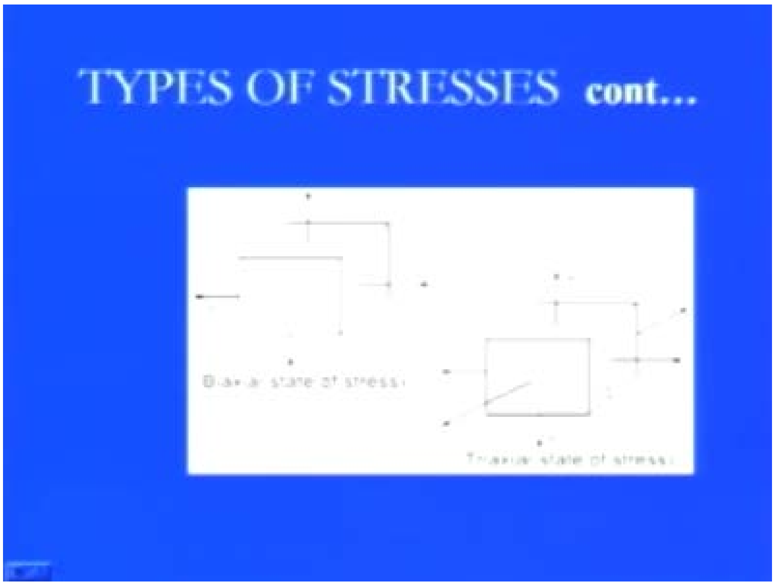

So, we define by this figure like this is the above figure is the biaxial state of stress in which two forms of the stresses are there. In the x axis, you see this normal stress is there. It is always lying along this line and in the y axis also, this is always along this line. This normal stress component is there. So, sigma 1 and sigma 2 are the biaxial state. The biaxial state of stress is there. The two forms are there and the second one is the triaxial state of stress which is you see you know like the sigma 1, sigma 2 or sigma 3 is there. So, if you are considering all three axes, sigma 1 or this sigma 2 or sigma 3, all these stresses are being well set up in this object and we can analyze accordingly. So, uniaxial, biaxial or triaxial, this is always you see. Now, if you want to define the real state of stress, always we need to go to that which will give you the real true value of the stresses in those objects. Now, you see come to the normal stress component.

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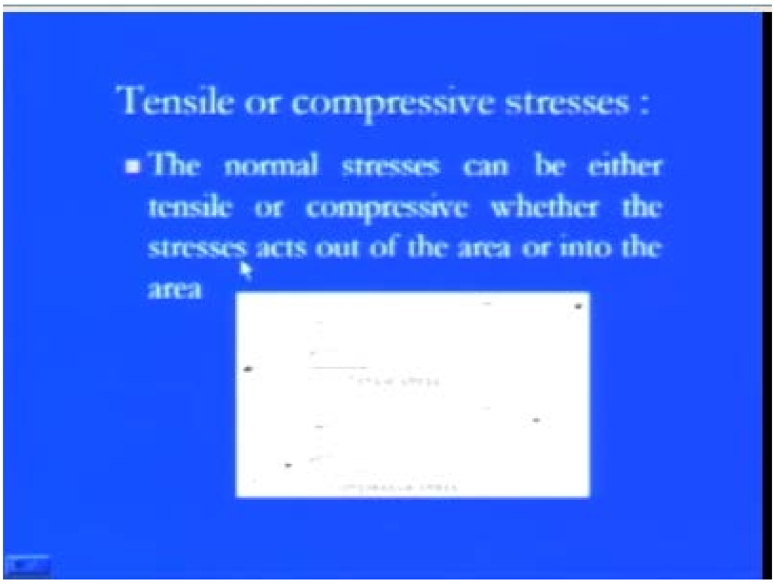

In the normal stress components, it can be either as I told you pulling or it can be compression. So, if it is pulling like you see in this figure, if this is a rectangular bar and if it is pulling from both the ends and since, you see you know like this is the normal stress component is there, uniaxial part is there. So, if it is pulling, we can say that the tensile stresses are being set up within this object. That means, if it is pulling the internal resistances are set up that they will resist this kind of pulling. So, that is why we can say whatever the stresses are being induced in this object due to the application of this force, tensile force, these stresses are known as the tensile stresses.

Simultaneously, we can say that if the compression is there, this is also you see the uniaxial state of stress is there. So, if you are saying that actually these forces are being well set up within those things, we can say the internal resistances are. So, you know like opposite to this kind of compression and they will always towards the opposite to these actions of these forces. We can say these are the compressive stresses. In these two, you know like the forms of the normal stresses like the tensile stress and the compressive stress.

As we have discussed that these stresses are normal parallel to these planes. So, now, our effective planes are we can say the matter of concern is this plane, where these forces or the stresses are just perpendicular or normal to the stress, these things. So, always we need to be very careful that while we are observing or analyzing those forces, we need to be very careful that how these applications are there, where they are applying whether this here, this one or towards that direction or what is our you know like the plane of concern.

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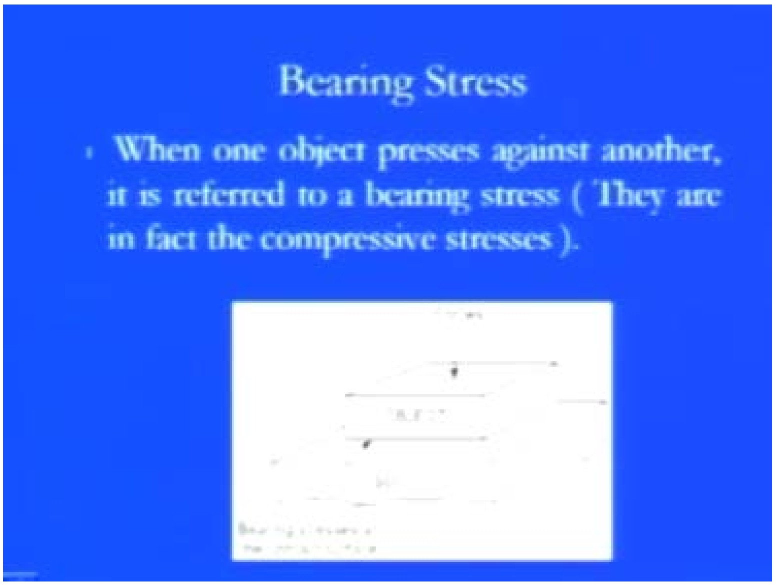

So, either in the tensile or in the compressive, always we need to be careful that actually what the plane of action is, or what is the matter of the area of concern. So, you know like these are two basic forms of the normal stresses, but if we derive those things, then again we will find that one of the derived stresses is there, that is known as the bearing stress.

Bearing stress is nothing you see you know like when one object, when two composite parts is there means two different objects are pressing against each other. It is referred to bearing stresses like you see two surfaces are meeting to each other, and there is a well set up you know like forces are there in between the portion. So, these two objects, they are in fact you know like we can say these are the compressive stresses, but if we see the plane of area, then we will find this in this figure. This is the plane of area or the matter of concern is there, where the stresses are just normal that these are the compressive forces which are acting.

So, if we take the object or the soil, any of you see this is the basic phenomena is there in these soil mechanics. So, always what we are doing here is this object is always trying to press within the soil, and these bearing stresses are well set up within this contact region.

So, this is our contact region and these forces are there from the normal stresses. So, that is why we can say the bearing stresses are nothing, but one of the form of this normal stresses, and since the compression is there, so we can say that the compressive stresses are there.

So, if you want to analyze this kind of object, always we need to be careful that actually how these forces are being set up, and how these stresses are distributing among this contact area. So, that is what you see you know like if any eccentricity is there, or any irregularity is there in this object, then we need to see that actually how this stress concentrations are being taken place at different parts, and how this internal resistances are there within this, either object or the soil because this is the contact region of the soil and here, you see this bearing stresses are forming all around this object. So, this is one form of the bearing stresses, and this is the derived stress of the compressed stress one from, and then you see another part of one part was there the normal stress component, and the second part is there that is the normal shear stress.

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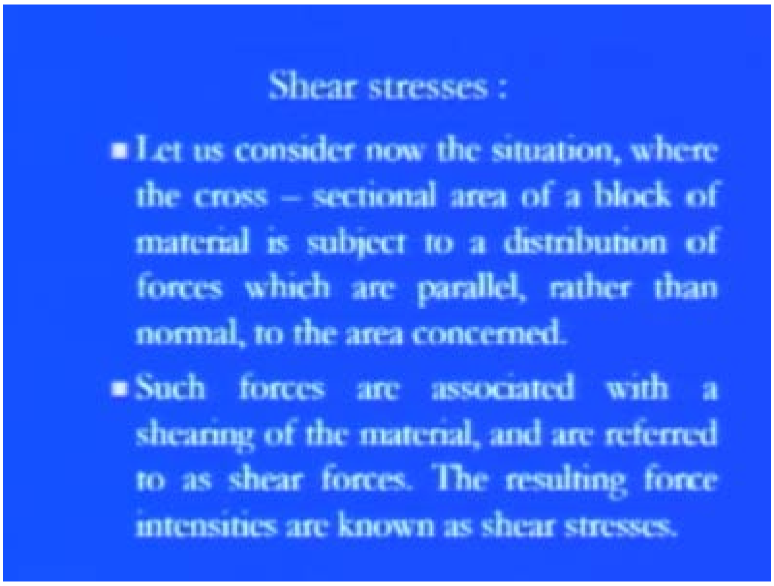

So, let us consider now a situation where the cross-sectional area of a block, of a particular block of material is subject to a distribution of forces, which are parallel. Now, you see this is not normal, whatever the forces, which is not normal to this area concerned. Now, if they are parallel means you see this is object, and the forces are applied parallel to this area of concern. Then, you see you know like this is we cannot say the normal stress component is there and then, we can say that these kind of you know like forces which are parallel to the normal axis always gives you a different kind of resistances or the area of concern.

Whatever the internal resistances are coming due to these parallel forces are always different than the perpendicular forces, and such forces are always associated with the shearing of the material because they are not uniaxial. They are at the different axis due to the eccentricity and since, you see they are running parallely to the object. That means you see these forces are different at different layers of an object. So, always you see we need to be careful that actually how these you know like the forces are being set up, and that is why we are saying that always it create the shearing to these different layers of these particular objects.

So, these forces are associated with that shearing of material and always refer to the shear forces. So, shear forces you see you know like always create some sort of shearing to the different layers of an object, and the resulting force intensity. That means, the resulting shear force per unit effective area is known as the shear stress. So, you see this is the another form of the shear stress in which the forces are parallel.

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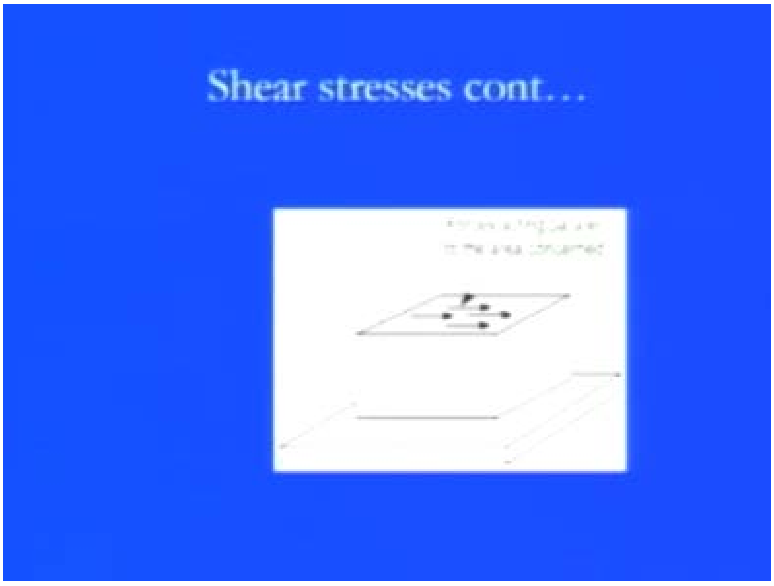

So, here we can see this. We have this object since you see these are here the forces are not coming perpendicularly. They are just parallel to these surfaces. So, we have this effective surface here, and these forces acted parallely towards that, and now this is our area of concern where these forces are going. So, always within this object, we have shear stresses which are being set up within this object, and that is why you see here we are saying that these shear stresses are always plane stresses, because they are always towards this particular you know like those planes means here you see you know like we need to concern this particular plane because they are all along this one.

So, that is why you see you know like we need to analyze those things that actually how these shear stresses are being setup in these things, whether this is a uniform structure than the shear stresses, or all along uniform along this particular plane. And if any eccentricity or if any non-irregularity is there in the shape or the geometry of the object, then we have to be very careful because these are the weakest area of the object, and we need to be very careful and that is why you see accordingly we are taking the factor of safety for these kind of stresses.

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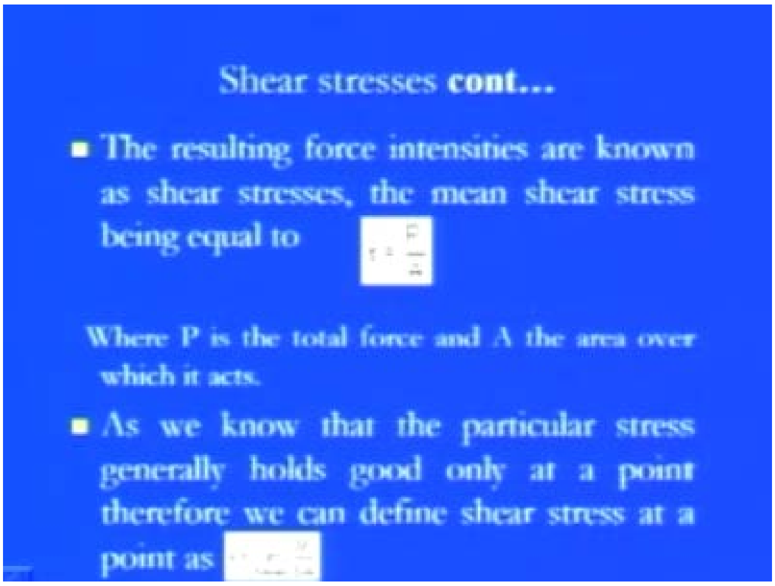

So, shear stresses are more I should say you know like the dangers because you see they are running parallel to the layers of an object. Then, you see you know like if we define these shear stresses, then the resulting force, shear force intensity which is known as the shear stress is the mean shear stress which is equal to this P by A P is the internal force resistance. This resistance force is divided by the effective area, and it is always denoted by tau. So, P is a total force as I told shear force I should say and area is the effective area under which these forces are being acting.

So, as we know that the particular stress generally occurs you know like part only at a point. Therefore, we can say you know like shear stress at a particular point is limit you know the tau which is limits del A tends to 0 del F by del A. So, this is you know like the small segment of force divided by the small area. So, generally you see this equation is valid where you see you know like if we found that irregularities are more, and we are you know like segregating or we are separating those individual components because you see if there strong region is there, weakest region is there.

So, what we are doing here? We know that whatever the force distribution is there within this object is different. Then, we are careful in the strong region how much force distribution is there. For the weakest region how much you know like force distribution is there, and what is the area. This is the matter of area concerned. So, accordingly what we are doing here if you are saying that if you have an object which has you know like if you are categorizing an object in six different steps, what we are doing here is, we are always calculating tau 1, tau 2, tau 3, tau 4, tau 5, tau 6, and in all these tau, always we are assuming that whatever the area of concern is there, they are always to that particular effective area.

So, that is what you see this approach is known as the infinite decimal part because you see any of the engineering sciences we are doing like you see thermodynamics, basically whatever those you know like the process are there like this isochoric process, isobaric process, isentropic process, all these processes are you know like if we are going realistic, then we cannot approach really, because that real nature is always against those things. They are not reversible phenomena if it is a real process, but always we assume that these processes really occur in the nature and they are reversible.

So, what you are doing here? We are always taking the small segment and within this small segment, we assume that these processes are correctly applied whatever you see. So, similar concept we apply here that whatever the small region is there within this small region, we assume that whatever the force application is there and divided by whatever, this effective area is there. If we sum up those things by integrating all those small segments, we assume that this stress distribution is uniform, and because of this stress irrespective of whether it is normal stress or it is shear stress; we assume that this stress is well set up. If you sum up those things, it will give you the average normal as well as the average shear stress component.

Therefore, you know like we are always applying that if it is delta F by delta A. For a small segment, it always limit A tends to delta A tends to 0, and this will give you small shear stress component for a segment, and if you sum up those things, then you will get the full stress component.

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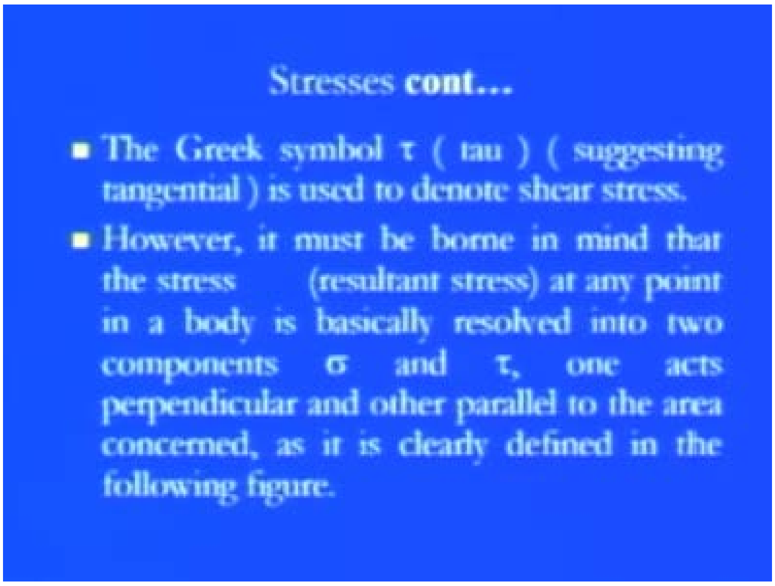

So, that is why as we discussed that actually this shear stress is always denoted by Greek symbol tau just like you see in the normal stress component. It is always either irrespective of that this tensile stress or the compress stress which is always being denoted by the sigma part. So, it is used to denote the shear stress. However, it must be borne in mind that the stress, the resulting stress of these things, any point in a body is basically resolved into two components because you know like as we discussed that there are two main components of the stress, normal as well as the shear and sigma as well as tau.

So, how these stress components are being acted? It acts separately as well as combinedly. How the interaction is there of these? You see it is normal as well as this parallel stresses. I should say parallel because of you know like the parallel forces are there in shear. So, how you know like there the interaction is there of these forces and how the molecules of the matter you know they are affected by the interaction of these stresses. This is really a matter of concern to analyze under the mechanics of material, and that is why you see you know like these two, if we want to analyze any material, then we need to resolve these two stresses.

One is the sigma; one is the tau for normal stress as well as the shear stress. One is perpendicular of the normal stress, and other one is parallel to the area of concern as it is clearly defined in the following figure. So, you see if you see this figure, in the previous figure, then you will find that you see here that always the normal stress as I have shown you that the normal stress component, this is the matter of area concern and this perpendicular is there. If this is my matter of area of concern, then the forces are being parallel to these things and that is why these stresses are being formed.

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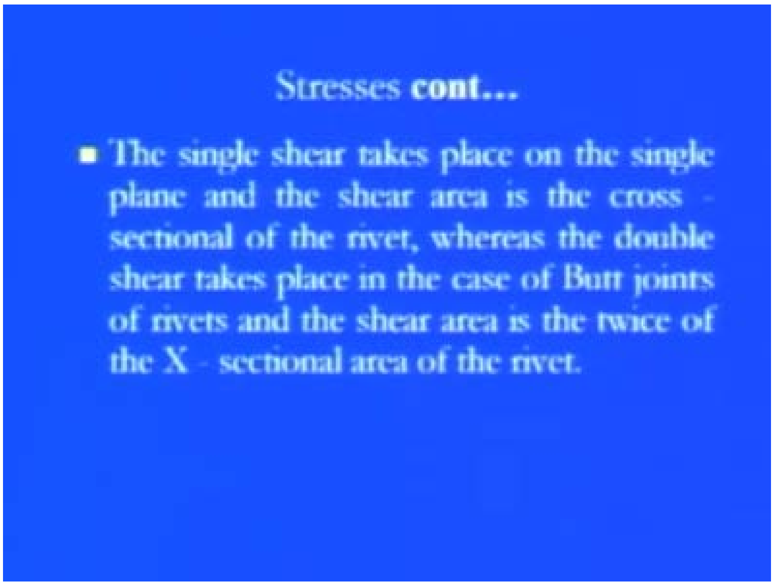

The single shear stress takes place on the single plane and the shear area is always cross-sectional of the rivet. So, if you are talking about any rivet joint, always the rivet joints are being designed on the basis of shear stress and that is how shearing is taking place, and wherever you see the shear because you see if these rivets, they are always you see two sheets are there and they are always combining two sheets. So, if you are pulling you see you know like the force application is there on these two saps, you know like these two parts are different. One is on the top up and one is on the bottom plate.

So, now the point of application of this force is acted at two different axes. So, definitely you see if you want to combine those plates, if we are putting the rivet, then always there is a shearing area towards those connection points. And that is why you see you know like if you want to analyze the strength of the rivet, then always we need to design based on the shear stress whereas, the double shear takes place in the case butt joint. So, if we are having the butt joint, then you see the double shearing is there. That means you see the butt joints are always acted, so that you see the area of the matter of concern is twice than the rivets, and the shear stress is twice than the cross- sectional area of the rivet because you see it is applied at two different points.

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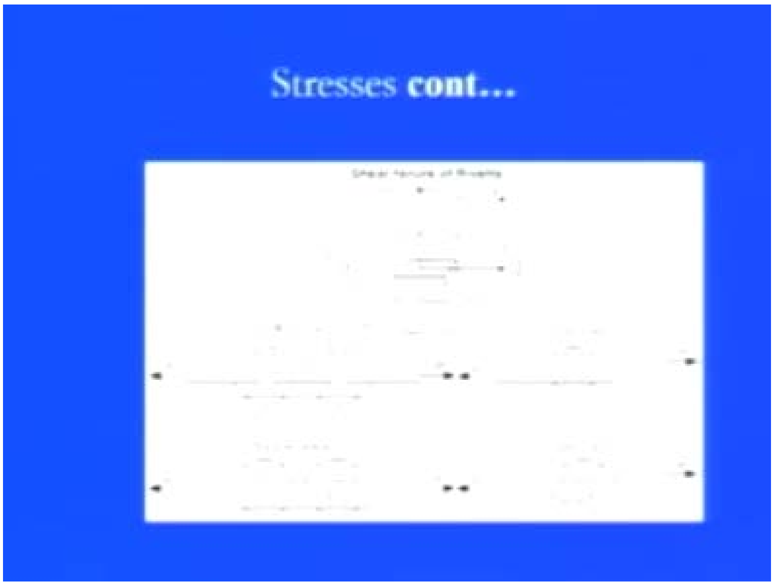

If you see this figure, then we can clearly differentiate those things that you see now the shear failure of the rivet. So, now, you see here in this is our area of matter, this is our plane and this area, the top of that, and this is our area of this matter of concern. So, here you see now these if it is parallel, so this is the parallel part. So, what we have? We have tau that is the shear stress, and this is normal which is the perpendicular part. So, we have the sigma, so normal stress.

So, if we want to find out that how much, what is the strength of these rivets, what we need to resolve these components like one is the parallel, one is the perpendicular, so what is the resultant force is there and you see by resolving those things in this, the resultant force sr cos theta or sin theta. We can get the effective solution that actually how much you know like those individual as well as the combined stresses are being setup, or combined forces are being set up within this region. Once you know these things by resolving in x and y direction, you can get effective solution that actually how these, either shear stress or the normal stress are effectively concerned to the design of these kind of structures.

So, as we discussed in that, that shear stresses are always dominating in these kinds of structures, where the rivet as well as the butt joints are there. So, if we are talking about the butt joint in which we have these two, this is one plate, this is another plate, you see these two plates are there in which the force is acting. So, what we did here is, we simply combined these plates by these butt joints. So, now if we apply this axial pulling here, you know like this is the shearing area because it will just try to pullout, but this will try to make the cohesiveness here.

So, here this is the effective area, where shear stresses are always dominating and you see now we are saying that the two butt joints, if two butt joints mean you see here that we have two different plates. One is this total plate which is being combined you know like by both of the butt joints, these two plates you see bottom and top which is always confined, which is always binded by these butt joints, but we have these you know like the separate plates. So, if you apply those things here, this region is the effective region where shear stresses are being set up.

Now, if you go to another point that is you see the lap joint. In lap joint, it is pretty straight and this is the perfect example of the shear stress because you see here the line of action if you see here, this is my line of action for this force. As I told you the force is nothing, but the point of line of action. So, here you see this is the point where the line of action of force is there. Here the line of action of force is here. So, if I now combine those things, the nature of this force will try to tend this one towards this direction. The nature of force of this P will try to tend towards this direction. So, we have a clockwise region motion is there, but this lap joint will try to you know like put the resistance towards this clockwise motion or I should say actually the line of action.

So, you see here at these portions, where this contact region is there, this whole region will suffer by shear stresses. So, like you see for the single part for either the butt joint as well as the lap joint, always stresses are there, but if you go to the double shear like in the butt joint as we have seen, you see you know like here these are the effective portions, where the stresses are being well set up. These are shear stresses because as I told you these forces are there and because of these forces, they are well parallel to this application. That means, this is my effective area, this is contact area, these all contact areas or the effective areas and the forces are also parallel to the effective area. That means here only shear stresses are being acting on this parallel, these parallel forces.

So, we can say if we want to resolve any of the forces within this butt joint, we need to be very careful that actually how these stresses are being taken place in these object first, and second you see which areas are the concerning areas or I should say the effective areas where the shear stresses are maximum applied. So, here first, this figure or this figure, we can clearly see that these regions, this region or this region or this region or this region, all these four regions where the contact points are there, the meeting surfaces are there.

These surfaces are since parallel to the applied force; these are parallel to the applied force. Shear stresses are being well set up within these things. The internal intensity you know like this shear forces are well setup. So, we need to be very careful that actually if they are uniform, then you do not have to go for delta F by delta A straight way. You see whatever the effective area is there, how much force is there, just divide the force per unit area and you will get the shear stresses, but if you see we have the combine stresses like you see if let us say any other application of the force is. Then we have to be very careful that actually how these forces are being acted on these objects, and then you see whether they are acting perpendicular to the area affected. Then, you have to concern the normal stress if they acted just like parallel as you see in this particular figure.

Then, you need to be very careful that actually we have only the shear stresses and no need to consider the sigma value that is the normal stress, and if you see the final figure that is nothing, but you see again a kind of lap joint in the double part. Then, we can see here there is a straight shifting. So, as you apply the force, there is the load or the force in the previous figure. You can see that there is a straight shifting of these contact regions. So, this nothing, but the pin is there. So, pin is now sheared. So, this one was you see earlier as I told you, this one was the key feature that actually how it can sustain or withstand the forces. So, you see if it cannot, then you see it will go up to this feature. If it can sustain, then it has to be there within this region.

So, this will you know like define the shear loading of any feature, and that is what you see has a good application in boiler design because you see boiler what we are doing here. You know like lots of internal forces are coming because of the basic purpose of the boiler is just to generate the heat. So, as heat is generated high pressure, we are generally categorizing various types if we are talking about the high pressure boiler. That means the highest pressure means actually more than 400 or the mega Pascal of the steam is to be generated within those things, either the cold fire or whatever you see you know like this steam generation is there.

So, in that you see always boiler surfaces are being by lap joint or we can say butt joint. So, in these joints because of the internal forces, it always try to shear those different mating surfaces and that is why these things if boiler failure is there means explosion is there. It is because of the failure of these one of the basic reasons is because of these failures of the joints. So, these joints may fail and you see clear shifting is there. So, in this lecture, since it was a basic lecture, so we discussed that what the forces are. If we are talking about solid part, then there are deformable, there are rigid bodies. In these deformable bodies as we have discussed that actually you know like how the deformation takes place, what is the point of application of load is. Accordingly, we can categorize the two basic forms of the stresses like the normally stresses as well as the shear stresses.

How the normally stress can be acted, what is the point of application of force is there in the normal stress even itself that whether it is towards the pulling side or the compression side, or it is like the bearing stresses. So, accordingly we can categorize those things like you see we have the tensile stress, compressive stress or we have the bearing stress while other thing you see we have if the forces are not parallel or not perpendicular to the plane, then automatically it is parallel to the concerned area. Then, you see we have to be very careful that actually since it is not on the same axis, it is on the plane along the plane.

So, how they are acting? It is whether they are just tried to tend these objects to rotate those things or not because always when they are not uniaxial, definitely they will just try to at a different axis. That means, due to these forces, there is a chance of the object will tend to move in any of the direction clockwise as well as anticlockwise. So, if you want to define the sign convention of these stresses, always we need to see that how this if uniaxial form or biaxial or triaxial in the normal stress component or the shear stresses, how will they act on the object, and correspondingly we will define that since these two forms of the stresses are there, one is the normal stress, one is the shear stress.

In the normal stress, there are this tensile compressive bearing or in the shear stress and even the shear stress torsional stress. So, these are the two broad categories and then, you see you know like there are bending stresses which are nothing, but the combination of the compressive as well as the shear, this normal, this compressive as well as the tensile stresses. So, these are the derived stresses, and the last one was the thermal stresses which you know like due to the temperature variation, they are being setup. So, in that it again depends on what the thermal coefficient of the expansion is. So, it is a property of the material. So, in this lecture, we basically are concerned of those kinds of stresses.

So, in the next lecture, we will just try to analyze that if these two stresses are there, then how many forms of these stresses which we need to define, all those forces which are being set up within the object is necessary, whether these two forms are like you see one part is sigma, one part is tau is well set up, or do we need more part like you see in x direction or in y direction or in z direction. In all the directions if we are pulling uniaxial pulling or the plane forces are there like you see these parallel forces, then these two parts are or do we need more forms of the stresses.

So, like you see you know like all these issues which we are going to discuss, and if they are pulling, then positive direction is there and if we are compressing, then the negative direction is there. So, what is basic direction or if it just due to this shearing part, if it is trying to tend in the clockwise or anticlockwise direction. Then what is the sign conventions, or if we have you know like the direction of the force and the area, if both are acting at the same place, then you see how you can define whether it is stress or shear stress. So, all these sign conventions with the subscripts are there. We just want to define in the next chapter.

Thank you.