Strength of Materials
Prof S. K. Bhattacharya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecturer # 10
Analysis of Strain - IV

Welcome to the 4th lesson of module 2 which is on analysis of strain part IV. In the previous lesson we discussed some aspects of analysis of strain. In this particular lesson we are going to discuss some more aspects of strain analysis. Let us look into those aspects.

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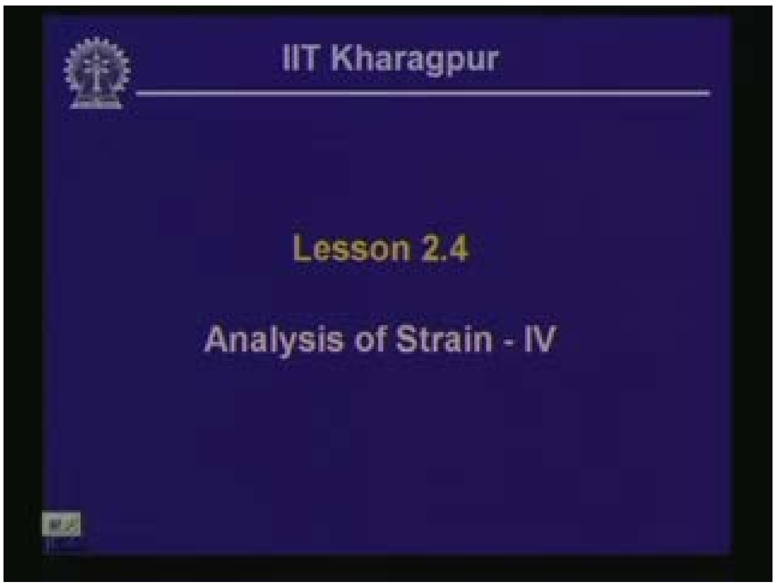

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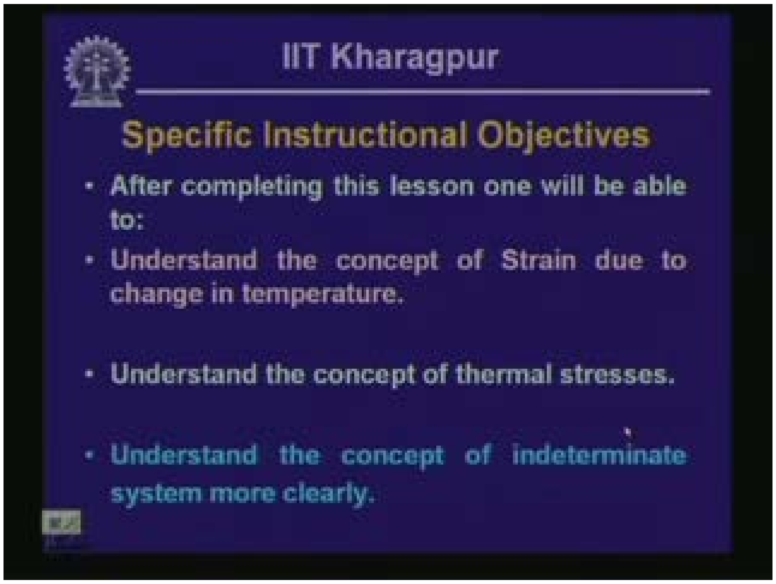

After completing this particular lesson it is expected that one should be able to understand the concept of strain due to change in temperature. We have discussed about the aspects of strain and we have seen how to compute strain at a point in a body and in a member when it is subjected to axial pole. Now let us discuss some aspects of development of strain due to change in temperature. Also, one should be able to understand the concept of thermal stresses. Earlier we discussed about the determinate and indeterminate systems where we find that we need additional criteria to evaluate the internal forces which we termed as compatibility condition.

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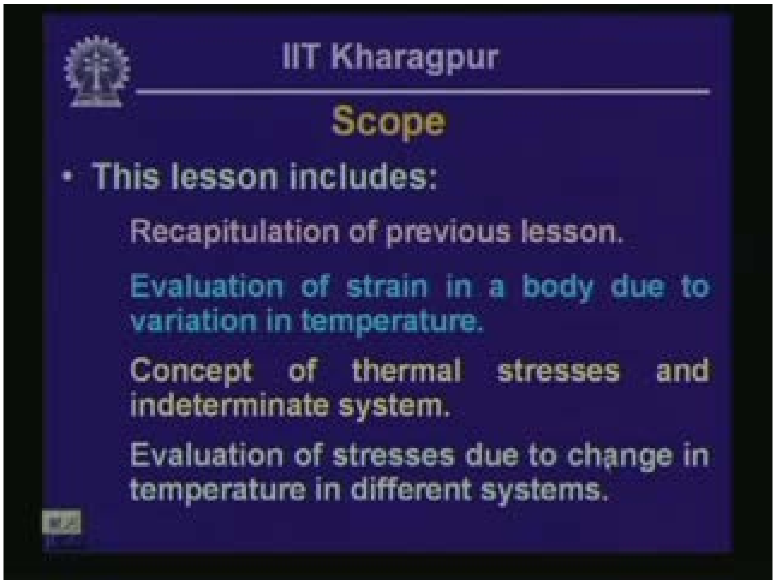

This particular lesson includes recapitulation of the previous lesson. Let us look into some of the aspects. It is evaluation of strain in a body due to variation in temperature. we will be looking into the concept of thermal stresses and indeterminate system such as this change in temperature, the strain which is caused due to change in temperature, whether this is determinate system or indeterminate system and subsequently we will evaluate the stresses due to change in temperature in different systems.

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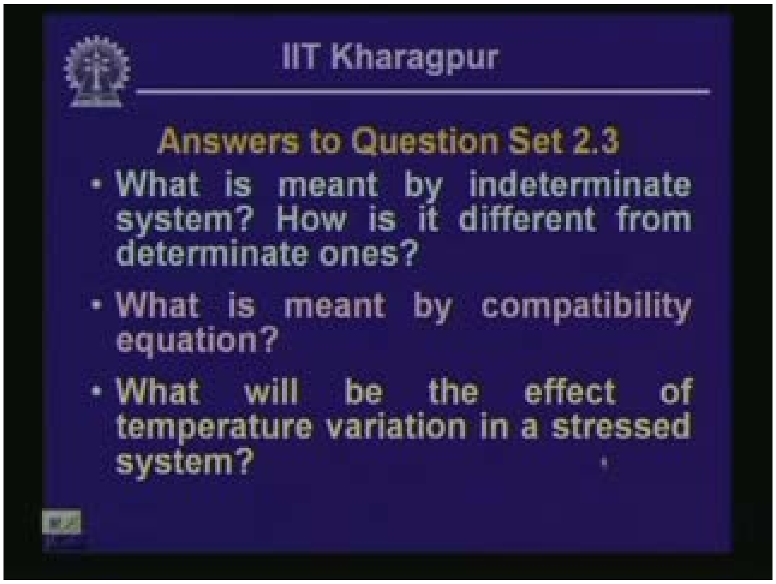

Questions:
What is meant by indeterminate system and how is it different from determinate ones?

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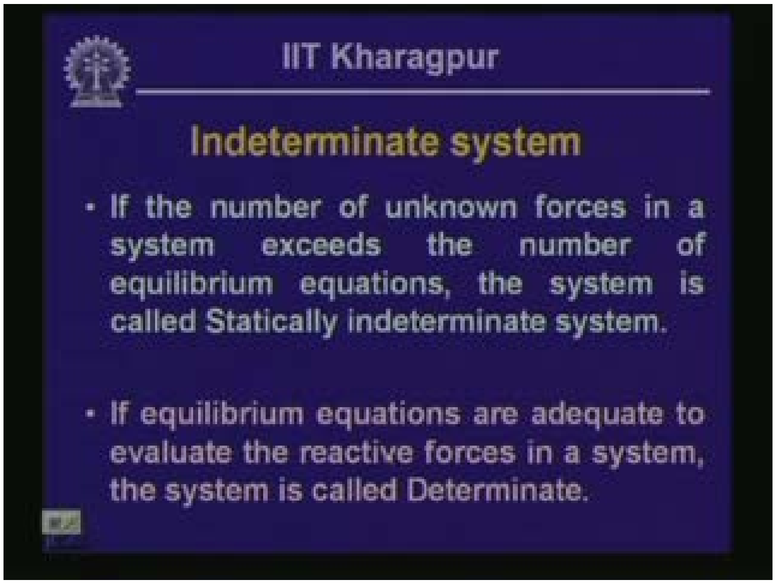

In indeterminate system the number of unknown forces is more than the number of equilibrium equations available and those kinds of systems are called as statically indeterminate system.

We have seen what is meant by equilibrium equations and what the solution of such systems is; we have seen that we need additional criteria to be brought in so that we can evaluate the unknown forces and the way it differs from the determinate system. The equilibrium equations are adequate to evaluate the reactive forces or the internal forces, we call those kind of system as determinate system and these distinguishes between the indeterminate system and the determinate system.

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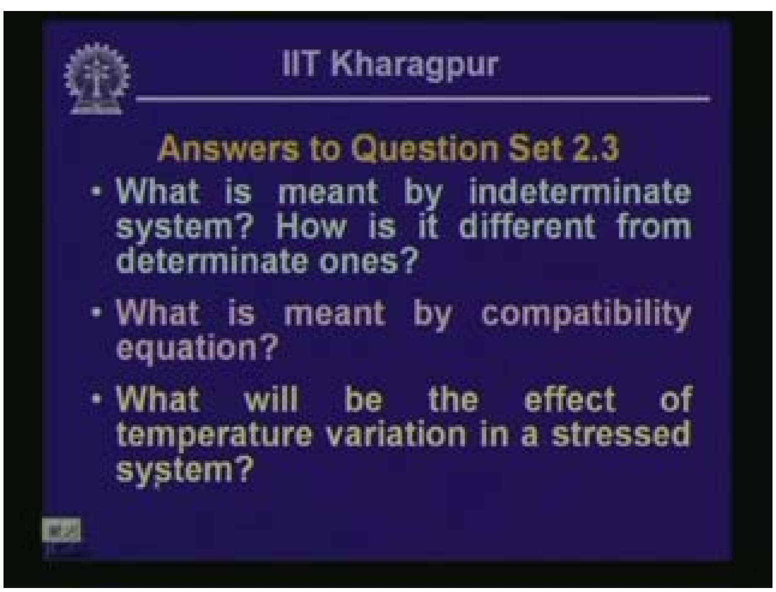

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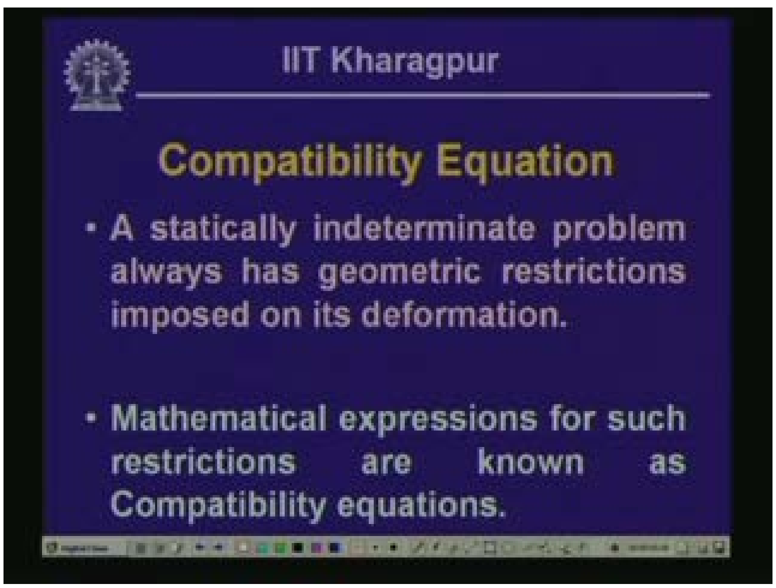

The 2nd question was, what is meant by compatibility equation?
Let us look into the definition of compatibility. As we had seen last time that statically indeterminate problem has geometric restrictions imposed on its deformation and the mathematical expression of such constrains of the restrictions are known as the compatibility equations.

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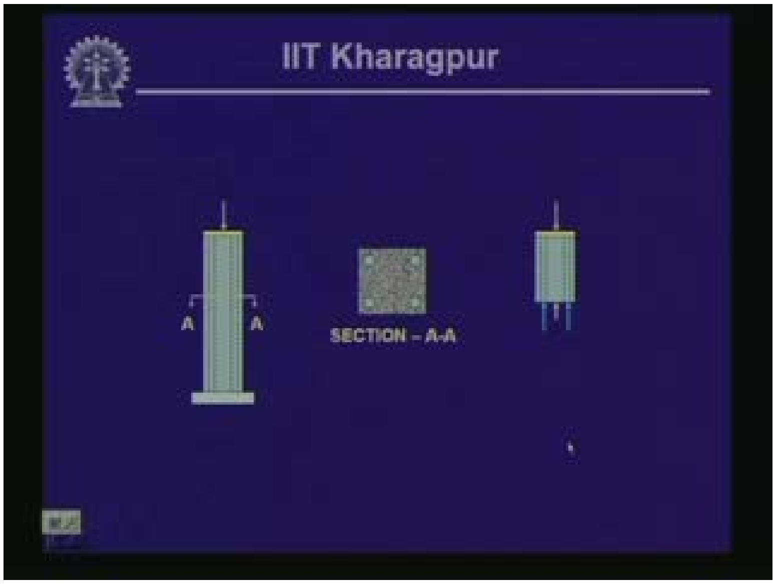

Let us look into this particular example which is quiet common. You must have seen that the vertical members made out of concrete are provided with some steel bars if we cut a cross section here and look from the top then the section looks like this. Let us assume that the cross section of this vertical member is a square one with the sizes of the sites as A.

This particular cross section of the member is provided with four steel rods, if bearing plate is connected to the top of this member and it is subjected to the load p onto top of the plate. If we take a free body diagram, if we cut the member here and take the free body of the top bar, the free body diagram looks like this, where the top force is p and for the equilibrium of the whole system, we will have the forces generated internal forces which will be exerted by the concrete, let us call that as p c and the steel rods in a combined form as P_s so the equilibrium condition demands that P is equal to P_c plus P_s.

As you can see here, that we have two unknown parameters P_c and P_s and we have only one equilibrium equation, hence the two unknowns from one equation cannot be evaluated and hence we need an additional condition which you call as a compatibility criteria. When we put the restrictions on the deformation and convert that in terms of mathematical expression we call that particular condition as the compatibility condition.

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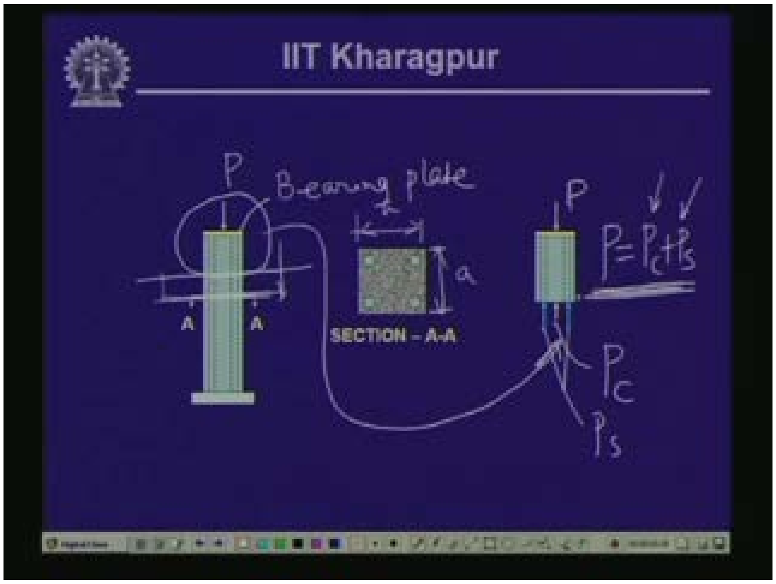

Similarly, here when the load is applied onto this member, the deformation of the concrete and steel, these two different materials which are placed in this particular diagram or in this particular member, the deformation of concrete and the deformation of steel should be same. If we say that the deformation of concrete is deltac this should be deformation in steel.

In other words, we can say the strain in concrete equals to strain in steel. Now, we convert this strain right in terms of stresses using Hooke's law which we call as the constitutive relationship between the stress and the strain and that will give us another condition for forces between the concrete and the steel. Now that we have one equation from here, we get another equation from here and using these two equations, you can solve for P_c and P_s. So this particular condition that P is equal to P_c plus P_s is termed as equilibrium equation and another equation in terms of forces which are generated from the second half equation where strain in concrete equals to strain in steel we call these as compatibility equations. And as you can absorb here that the restrictions on the deformation, we have said that the deformations of concrete and deformation of steel is same and based on that this compatibility criteria has been derived.

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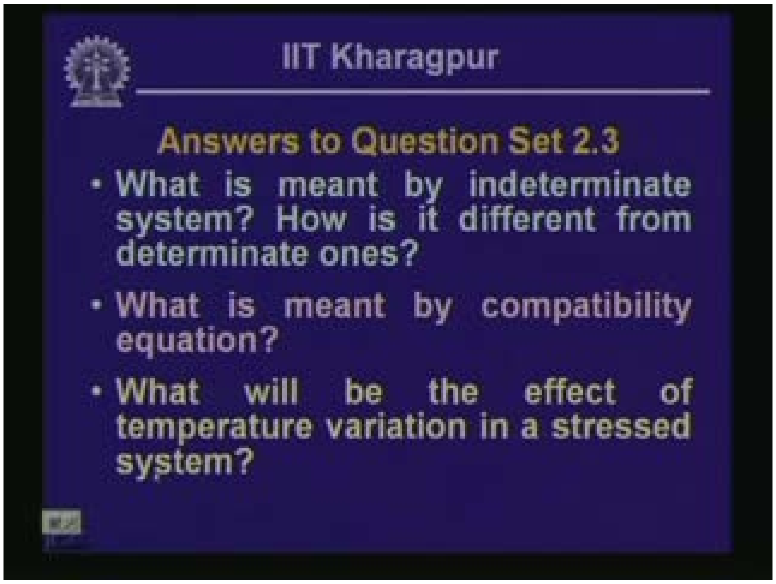

The 3rd question was;
What will be the effect of temperature variation in a stressed system?
This is the aspect which we are going to discuss about.

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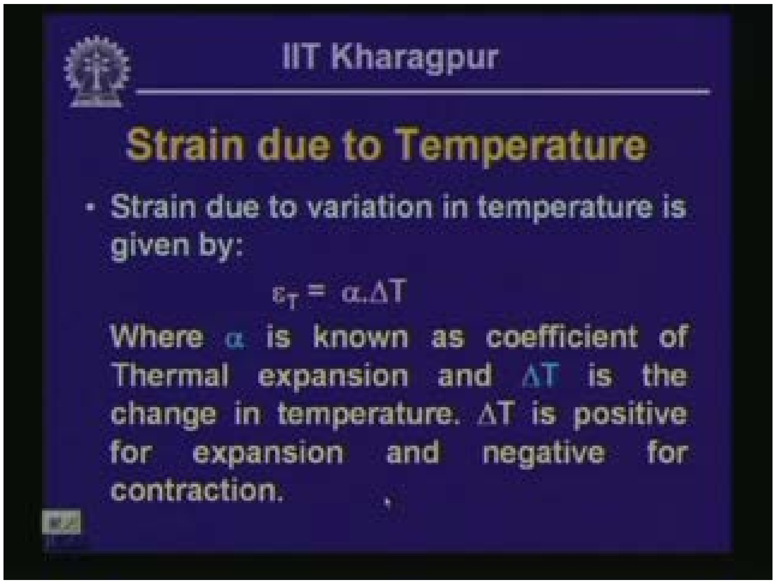

Strain due to temperature:
This is known that, if a body is subjected to temperature variation then it undergoes changes in its dimensions. This volume expands if there is an increase in the temperature or it contracts if there is decrease in the temperature.

In general, this change in temperature, if the temperature is uniformly increased or decreased you get same amount of expansion or contraction in the body and this is tropic in nature. The variation in temperature causes change in the length of the member which you call as deformation and that deformation leads to strain in the body. The strain due to variation in temperature is given by this particular expression, epsilon T is the strain due to change in temperature and deltaT is the change in temperature.

Let us say if the initial temperature is T_0 the final temperature is equal to T then deltaT is equal to T minus T_0 and alpha is a term which is known as the coefficient of thermal expansion. So the strain due to temperature variation is given as alpha(deltaT) for T minus T_0 and deltaT is (positive) when we take this expansion or there is a (positive) change in the temperature, where there is a raise in the temperature we call deltaT as (positive), when there is a decrease in the temperature we call that as (negative) or contraction of the body.

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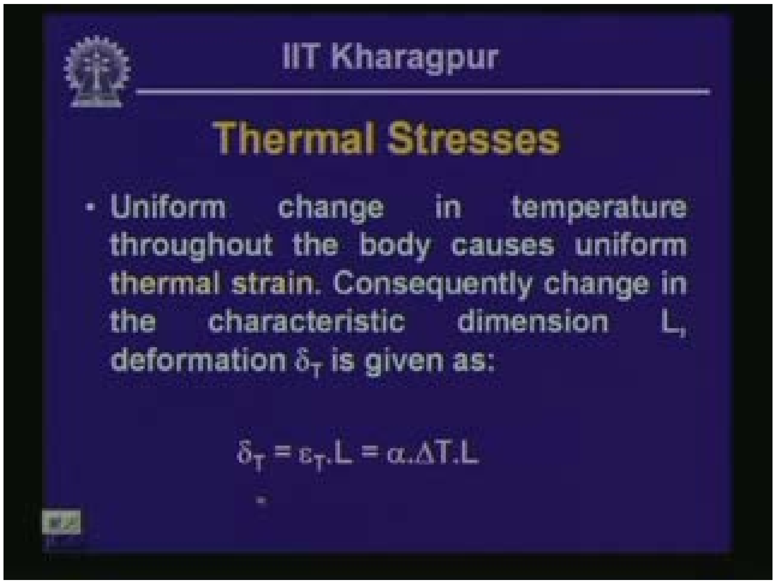

Uniform change in temperature throughout the body causes uniform thermal strain. This is important to know that there is strain which is developed in the body due to change in temperature; we call that as thermal strain.

Supposing this is a body which undergoes change in temperature, if it is free to move, this will undergo expansion or contraction depending on the change in the temperature. If temperature rises it will expand, if temperature decreases then it will contract. If it is not restricted or constricted by any actions from outside it will undergo movement and it will undergo strain. If we take the characteristic length of this particular member as L or for that matter any of this length which undergoes deformation then the deformation deltaT of that length can be given as the strain(length). And strain as we have seen due to temperature is equal to alpha(deltaT) so the deformation deltaT because of temperature is alpha(deltaT) L where L is the dimension of the body which we are concentrating on.

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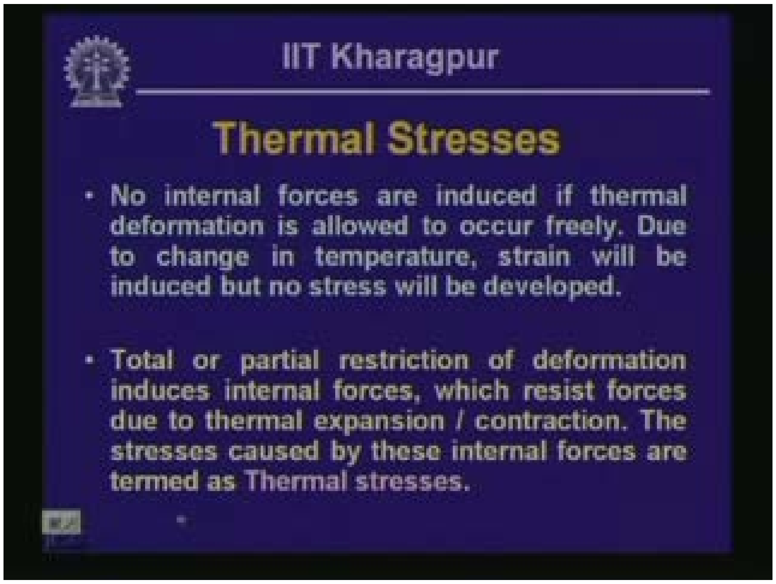

If the thermal deformation occurs that if it is allowed to move freely then there is no possibility of inducing any stress in the member as there are no internal forces induced if thermal deformation is allowed to occur freely. There will be strain induced but there will not be any stress in the member. As there are no internal forces being developed naturally there will not be any stresses. But since it is undergoing deformation, either this is expanding because of the change in the temperature or raise in the temperature or it is contracting because of decrease in the temperature. So there is movement, there is deformation in turn there is strain but since the movement of the body is not restricted there is no internal forces that are getting generated. Hence there will not be any stresses in the member. That is why it says that strain will be induced but no stress will be developed. Total or partial restriction of deformation induces internal forces, if this particular body which is free to move due to change in the temperature.

Supposing if I hold this body from two sides and do not allow this to move since it will try to expand it, will exert pressure on this support and as a result the body will be subjected to some internal forces and thereby there will be stresses induced in the body. If total or partial restrictions are imposed on these deformations, then they are going to resist these forces due to thermal expansion or contraction and thereby there will be stresses caused by these internal forces and these stresses.

Generally designated as thermal stresses, you must have notice that in many times is structures will provide a gap between two structural elements. We allow the structural member to move expand or contract due to the variation in temperature, you must have noticed in the railway tracks are not continuous, some gaps are maintained at certain distance interval. Due to change in the temperature on the railway track, the track undergoes expansion. If those gaps are not kept, then the rail track will be subjected to tremendous amount of stresses.

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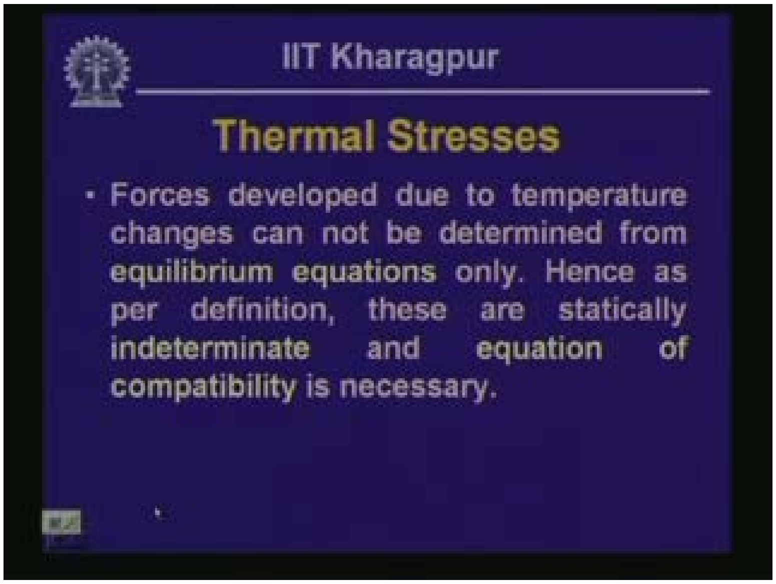

The forces developed due to the changing temperature, causes forces if they are restricted and these forces cannot be determined from equilibrium equations as we have seen earlier. Since we cannot determine the internal forces which are getting developed due to change in temperature, we call this kind of systems as indeterminate system according to the definition.

As we have seen earlier, for the systems which we can evaluate the internal forces based on the equations of equilibrium, we call those systems as determinate system, but if we cannot evaluate the forces which are getting developed due to change in the temperature from the equilibrium equations, then we call this system as indeterminate system, hence statically these kinds of thermal stresses are induced in the member. Basically, statically indeterminate and we need to use the equation of compatibility for the solution of these forces for evaluating the internal forces.

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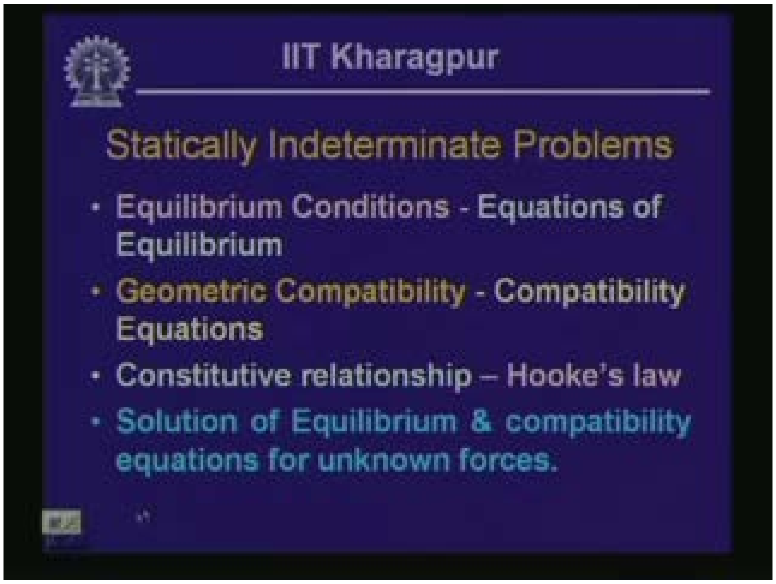

If we summarize the statically indeterminate problems; we need the equilibrium conditions the equilibrium conditions has to be satisfied and that is either in a local concept or in a global sense or the whole structure.

Secondly, the geometric compatibility has to be satisfied if we get more number of unknowns than the number of equilibrium equations available. They are known as compatibility conditions or correspondingly compatibility equations which give us additional information based on which we can solve the unknown forces.

Thirdly, we have written down the compatibility in terms of the geometric deformation and we have related the strain parameter to the corresponding stress parameter using Hooke's law. And this relationship between the stress and the strain is generally referred as the constitutive relationship which in this case is based on Hooks law we are arriving at the constitutive relationship. These three are the essential parts for the solution of statically indeterminate problems.

First one is equilibrium equation, second one is the compatibility equation and Third one is the constitutive relationship which gives us the relationship between the strain and the stress and thereby we can write down the equations in terms of forces. We have one equation which you have written in terms of equilibrium criteria. We have another equation which we have written in terms of compatibility criteria from which we can solve for unknown internal forces. So, solution of equilibrium and compatibility equations for unknown forces using equilibrium and compatibility criteria.

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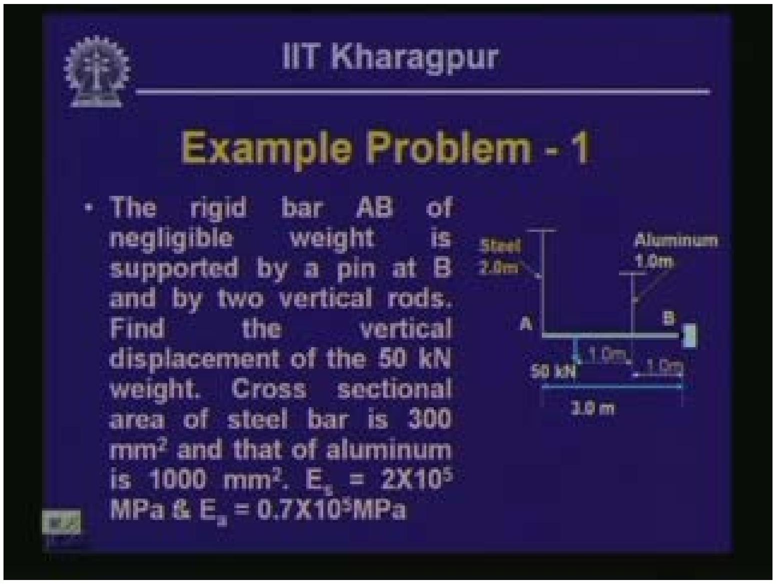

Having known about this different kinds of strains that is getting induced into a body either when they are subjected to external loads or they are subjected to change in temperature, let us look into some of the examples of that how do we evaluate these forces?

The example which was given earlier was a rigid bar A, B of negligible weight is supported by a pin at B and two vertical rods. They are hung from the top and connected to this bar, find the vertical displacement of the 50 kN weight which is placed at this particular point which is at a distance of 1 meter from end A. So we will have to find out the displacement of this particular point where this 50 kN weight is hung, the cross-sectional area of steel bar is 300 mm square, this is the steel bar of length 2 meter and this is the aluminum bar of length 1 meter.

The cross-sectional area of steel bar is 300 mm square and that of aluminum is 1,000 mm square. The modulus of elasticity of steel E_s is equal to 2 into 10 to the power 5 MPa, and modulus of elasticity of aluminum is 0.7 into 10 to the power 5 MPa. We will have to find out the vertical displacement of this particular point from where the 50 kN were designed. The first thing is that we will have to write down the equations of equilibrium. If we take the free body of the whole system this is the rigid bar A, B and this is connected by a pin at end B.

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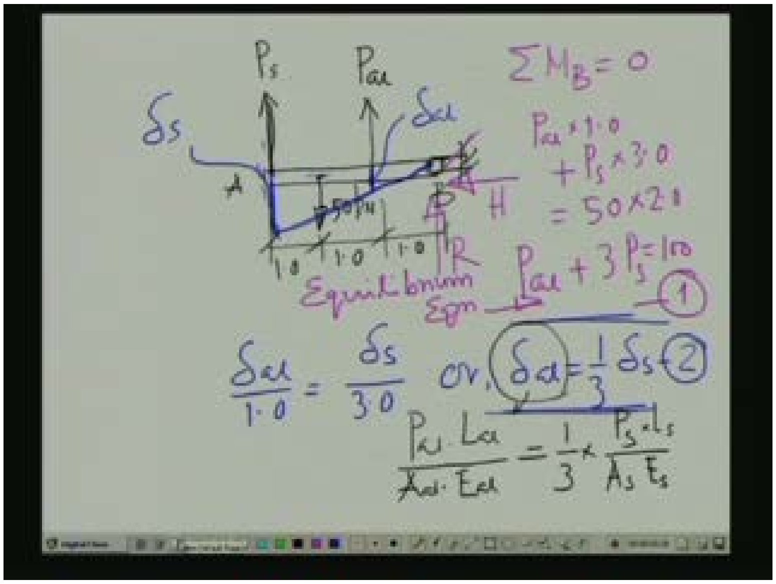

We have one vertical rod connected, this end we have another vertical rod connected at this end, this is made up of steel, this is made of aluminum. Let us call the force in the aluminum rod as p aluminum and the force of the steel as P_s and the 50 kN load is hung at this point which is at a distance of 1m, this is 1m, this is 50 kN. Now if we take of even this B end part of it, we will have the reactive component, the vertical force and the horizontal force, let us call this as R and H. Since we do not like to evaluate R and H, we are interested in p_s and p_{al} because we would like to find out how much force these rigid rods will be subjected to.

Let us take the moment of all these forces about point B, so summation of all the forces with B is equal to 0, this is one of the equilibrium equations. And this gives as the p aluminum into 1 plus p steel into 3 is equal to 50 into 2 or p aluminum plus 3p steel is equal to 100, this is equation 1 which we call as the equilibrium equation. We are not looking into other equations which are summation of vertical forces as 0 and summation of horizontal forces as 0 from which we will get R and H since we are interested to evaluate under this. Because we have four unknown parameters p_s, $p_{al,}$ R and H, these are the four unknown forces and we have three equations which are summation of horizontal force as 0, summation of vertical force as 0 and summation of moment at this point equals to 0.

In this particular equation we see that we have two unknowns and one equation from which we cannot really solve these unknown forces. Therefore we need an additional criteria or additional condition from which we can evaluate these forces. If we look into the deformation of this member, this particular bar A B is a rigid one. Since this is subjected to a load 50 kN this will undergo a movement in a circular path considering point B as a center and since the deformation is small this circular approximate as a straight one and we join this line, this gives us an excorticated form of a deformation. This point undergoes deformation here; this point undergoes deformation here, also this point has deformed to the step.

From this triangular configuration, if we call this deformation as deltaal and this deformation as deltas then from this triangular configuration we can write deltaal by 1 is equal to delta s by 3 because this claim is 3 or deltaal is equal to 1 by 3(deltas). Now we have one equation of equilibrium. We had obtained another equation which is corresponding to the compatibility of the deformation which we call as compatibility equation. So, equation two is the compatibility equation.

Next thing which we will have to do is impose the constitutive relationship. That means first you write this deformation in terms of strain and that we relate to the stress. This if you write in terms of load or rather the stresses we can say that p al length al by a al into e al, this is the deformation of the al bar, this equal to 1 by 3 (p s) is the load which is acting on the steel rod times length of the steel rod divided by area of steel rod times modulus of elasticity of the steel rod.

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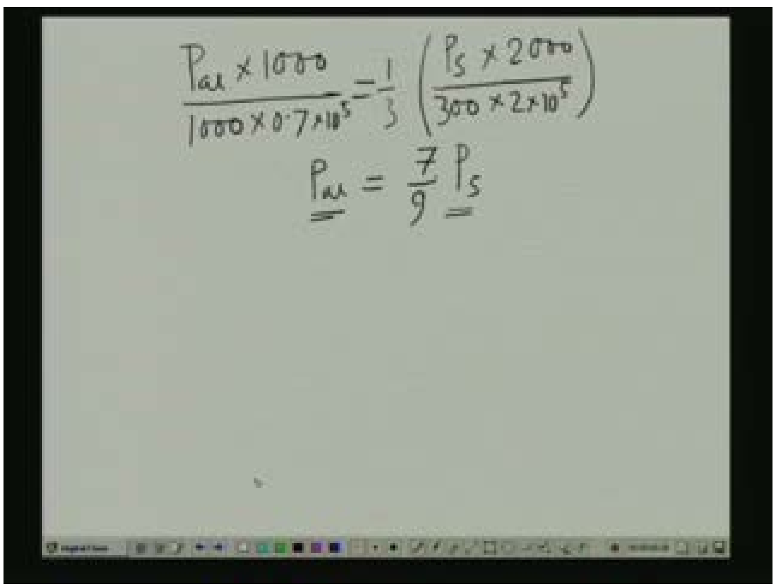

If we substitute the values we get P_{al} into by length of al is 1,000 mm or 1m by cross-sectional area of a al rod is 1,000 mm square into e which is 0.7 into 10 to the power 5 MPa is equal to 1 by 3(P_s) length is equal to 2m by cross-sectional area of steel is 300 into 2 into 10 to the power 5. This gives us the relationship that P_{al} is equal to 7 by 9 P_s. This is another relationship we got from between p in the aluminum and p in the steel.

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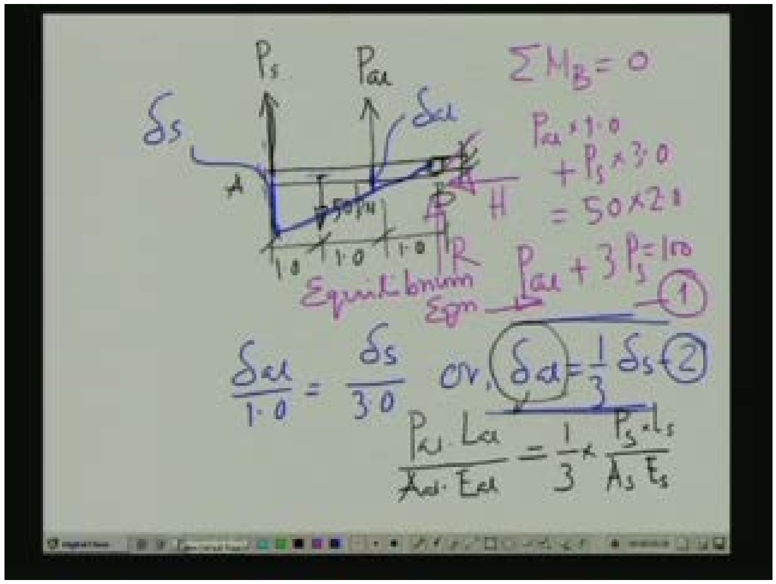

Earlier we had one equation which is equation of equilibrium, this P_{al} plus 3 into P_s is equal to 100.

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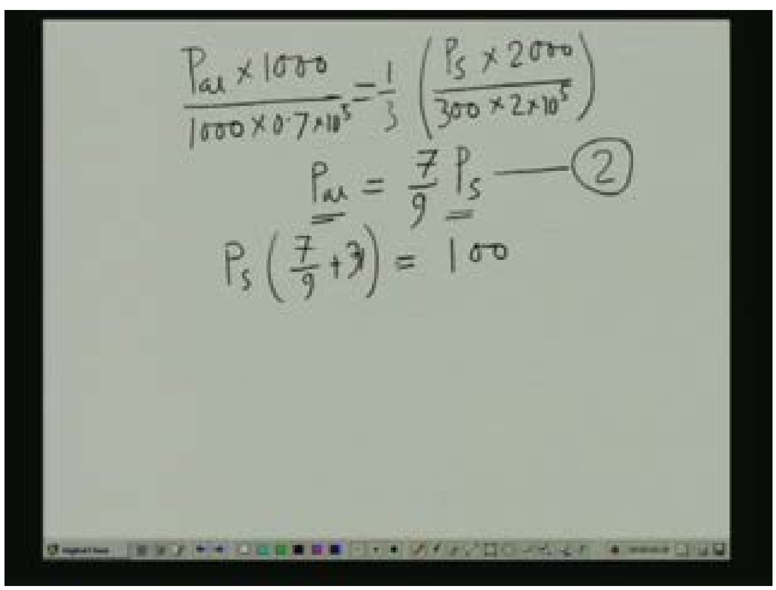

This is, let us call the equation 2 so from equations 1 and 2, we have then P_s(7 by 9 plus 1) or plus we have 3 of this is 3 is equal to 100. We have P_{al} plus 3(P_s).

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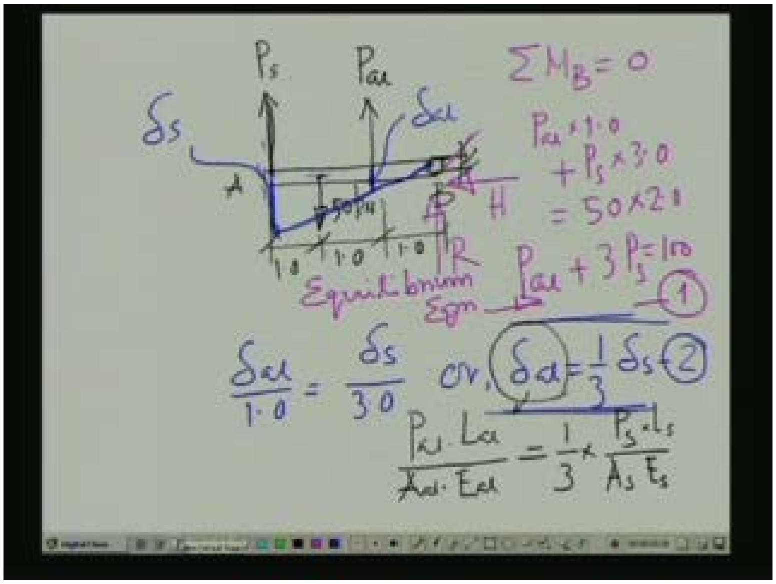

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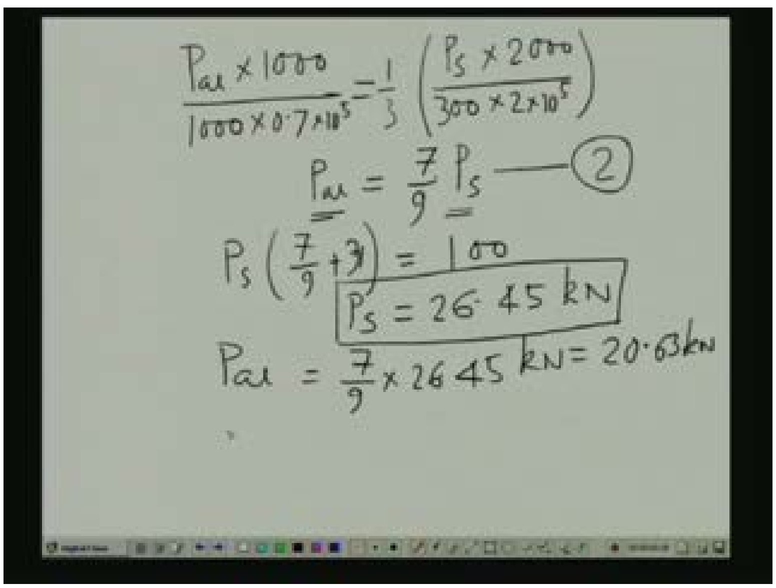

P_{al}(7 by 9 plus 3) is equal to 100 which gives us the value of P_s as 26.45 kN, and from this, the value of al load in al is equal to 7 by 9 into 26.45 and this comes as 20.63 kN and once we get the load we can compute the deformation.

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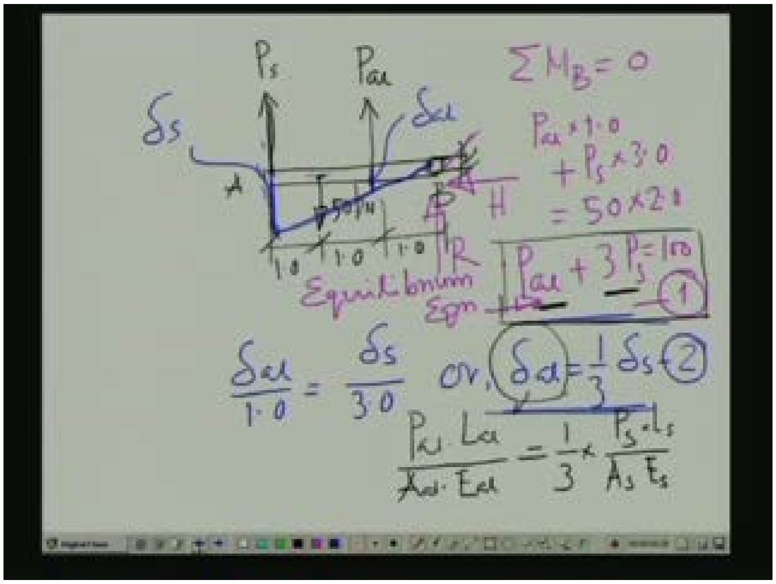

Once we note the steel rod and the aluminum rod they are subjected to the load P_s and P_{al} which we have evaluated. Hence we can compute that how much deformation this particular bar will undergo and how much deformation this bar will undergo. Since we are interested to evaluate the deformation of this particular point, if we know the deformation of this particular bar from this triangular configuration we can compute how much deformation this particular point will undergo.

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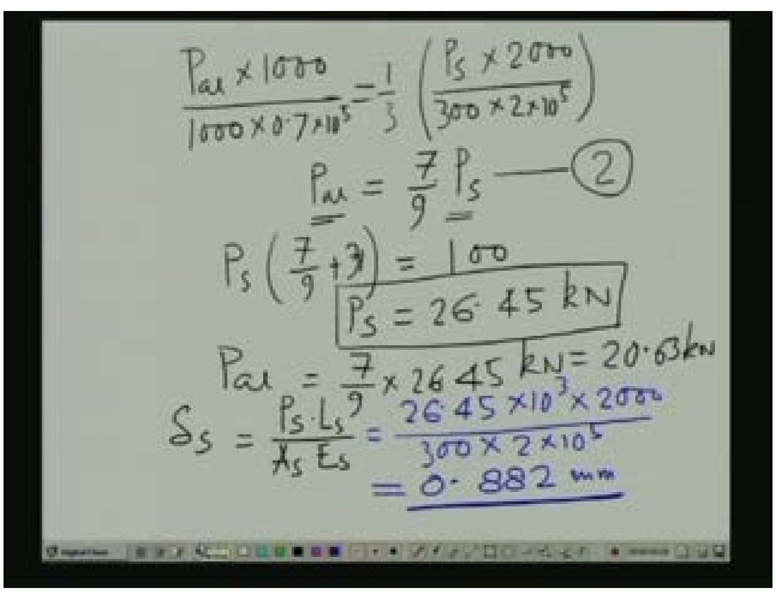

Hence the deformation of the steel bar deltas is equal to P_{sl} by A_SE_S is equal to P_S you got 26.45 into 10 to the power 3 so much of N into A_S which is 2,000 mm and A_s is equal to 300 into E_s which is 2 into 10 to the power 5 hence this gives as a value, is equal to 0.882 mm so this is the deformation of the steel rod which is shown in this particular diagram.

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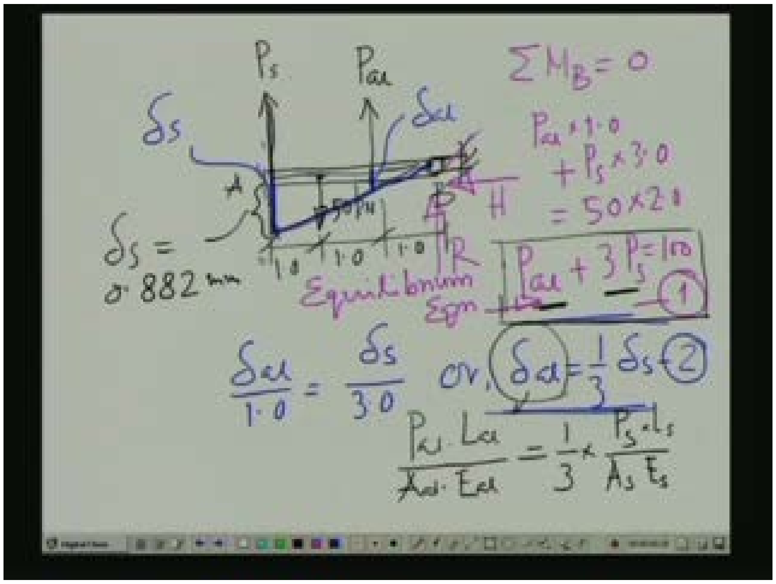

The deformation which we have obtained here deltas is equal to 0.882 mm. From this triangular configuration we can compute the deformation of this particular point which is at a distance of 1m from here, the deformation of this is equal to 2 by 3 of this particular deformation.

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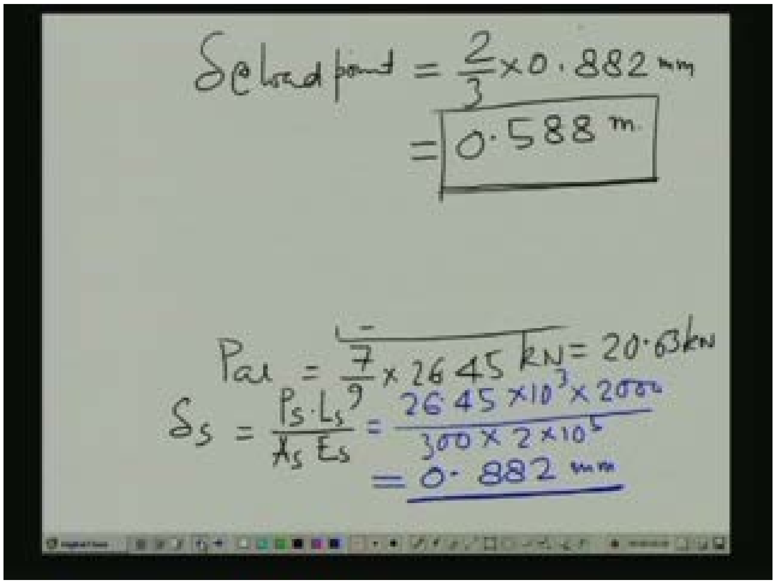

The deformation of the point where the load is acting say delta at load point, where 50 kN load is acting this is equal to 2 by 3 into 0.882 mm is equal to 0.888 mm so this gives us the value of the deformation of the load point and this is what we were interested to know that this much deformation this load point and according to this calculation, we find this is equal to 0.588 mm.

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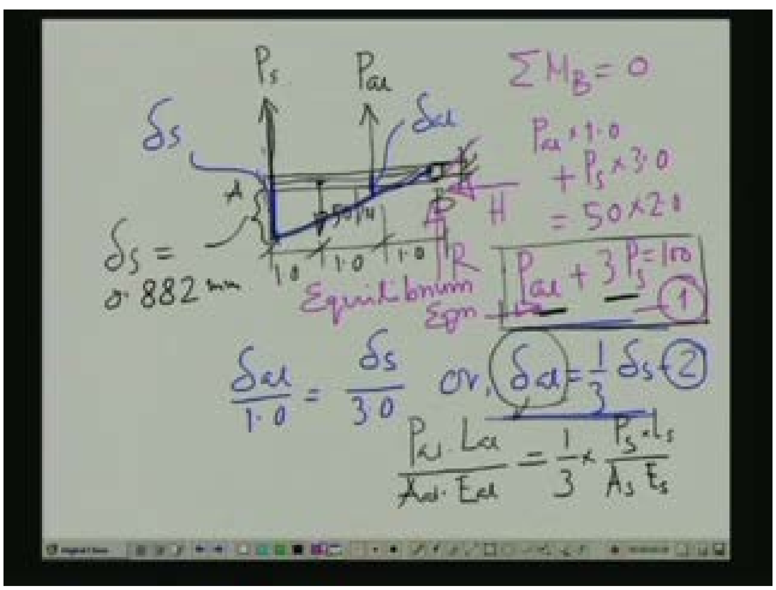

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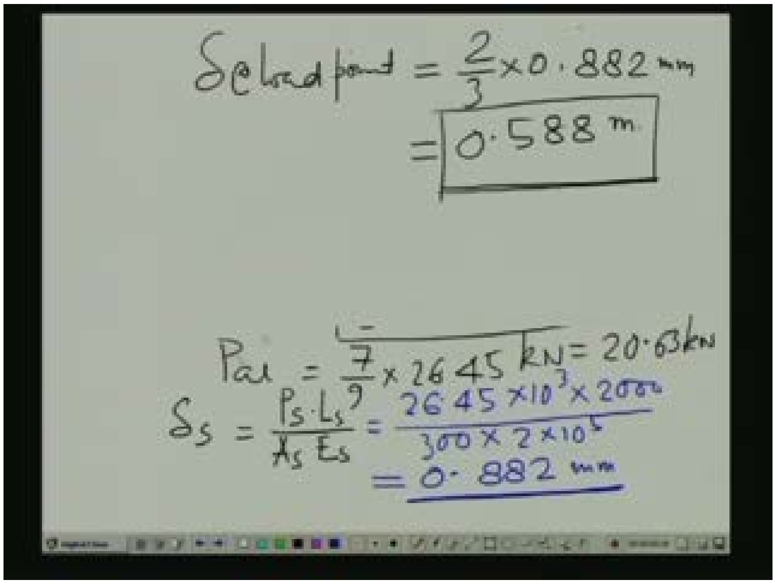

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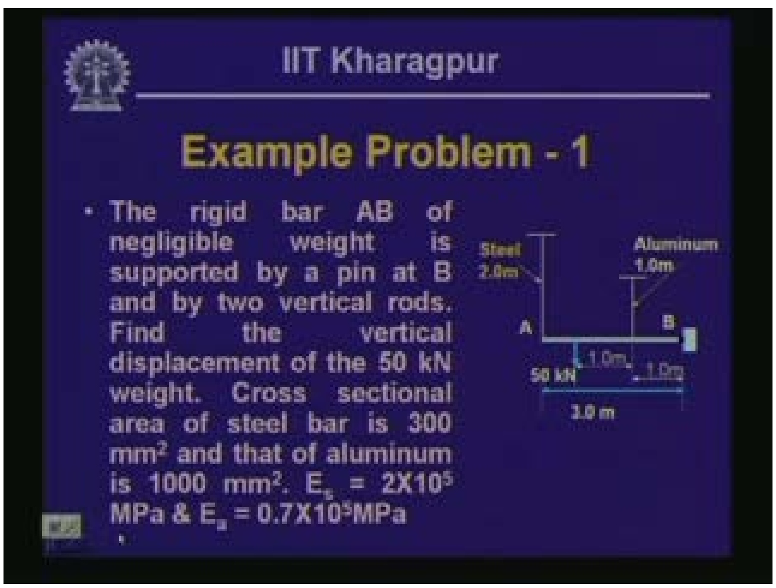

I am sure that you could calculate the values, you can check the values whether the matching with this solution or not, let us look into another example based on the aspects which you have discussed today that due to the change in the temperature there will be deformation in the member and that causes stresses in the member which we call as a thermal stress.

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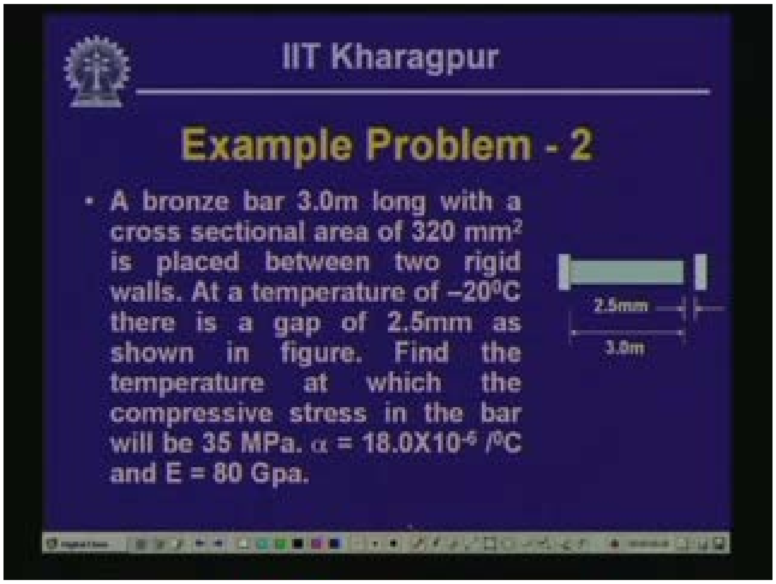

In this particular example we stated that a bronze bar which is a 3m long bar, let us call this as A B this bronze bar 3m with the cross-sectional area of 320 mm square is placed between two rigid walls. This is one wall, this is another wall placed in between these two at a temperature of minus 20 degree C. There is a gap between the age of the bar and the wall the age of this bar and the wall, there is a gap of 2.5 mm.

Now what we will have to do is, we will have to find out the temperature at which the compressive stress in the bar will be 35 MPa given the value of alpha which is coefficient of thermal expansion as is equal to 18 into 10 to the power 8 by degree C and the value of modulus of elasticity given is 80 GPa when the temperature goes off from minus 20 degrees. As there is an increase in the temperature the bar will expand since there is a gap between the wall and the bar first due to expansion, the bar will touch the wall till that particular time.

Since it is free to move, it will not experience any stress but further extension beyond the touching of the wall, the wall will not allow the bar to move so naturally, there will be the stress induced in the bar. What we will have to find out is that, we can allow maximum value of this stress to go up to 35 MPa and we will have to find out that temperature which will allow this expansion of this bar to cause the stress within this body as 35 MPa.

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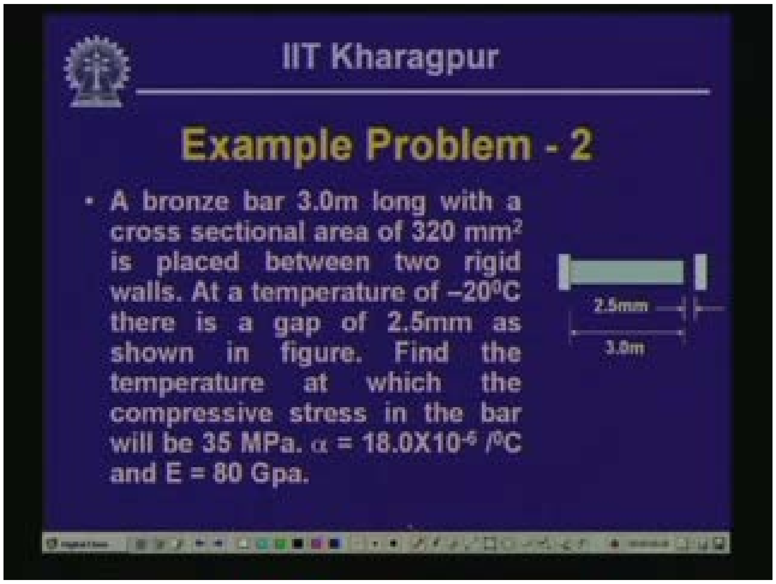

So if we draw a free body diagram then it will be easier to visualize that how the whole process is undertaken. In such problems where we try to evaluate the stresses due to change in the temperature and where such restrictions are imposed like the bar is fixed between the walls or the bar at this point is not allowed to go beyond a certain value. We try to first remove either personally at the whole the restrictions allow the bar to move freely due to change in the temperature.

We calculate how much deformation it undergoes because of the change in the temperature and then if there would have been restrictions then to bring back to its particular position, how much force we need to impose on that we try to evaluate that and that is what is the compatibility criteria. We allow it to move freely thereby there will be deformation because of the change in the temperature and now we impose some external force to bring back to deformation to its original position, thereby, how much force we need to put to bring back the member to its initial form?
We evaluate that and if we compare these two from these we can drive at an expression which we generally call as compatibility equation. That is what we need to do in this particular case.

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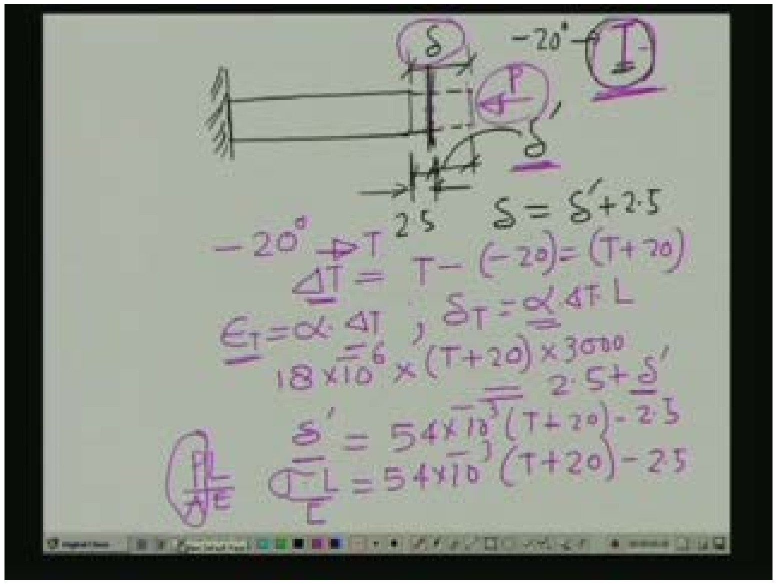

We have the bar and on this side it is fixed to the wall, here we have one restriction which is another wall but there is gap between the wall and the bar. When the temperature goes up from minus 20 degrees to some value T which we do not know which we need to evaluate, initially when it starts expanding it goes up to the wall without any problem and till that time since it is not experiencing any abstraction the bar we will expanding freely and thereby there will be strain but there will not be any stress in the bar.

Let us remove this wall and allow this bar to move freely and because of the change in the temperature it will move. This particular expansion is delta. This delta which is total deformation has two parts: one is this initial 2.5 mm which was unrestricted movement and then subsequently it will be encountered in the wall. Since I have removed the wall so this is also moving freely and let us call this particular distance as delta prime so delta the total deformation is equal to delta plus 2.5 mm.

Our job is to find out the temperature. Since the increase in the temperature is going to cause the deformation of the bar we will have to find out how much temperature we can allow so that when it will be encountering this wall it will be subjected to a compressive force, it will be subjected to a stress and the restrictions imposed on this particular case is that the stress level can go up to 32 MPa. Therefore till the time it reaches 35 MPa the temperature is allowed to increase, as soon as it goes to 35 Mpa we cannot increase the temperature further because then the material may not be able to withstand that amount of increasing temperature. That means when I have removed this particular wall and allowed the bar to move freely naturally the second consideration which is a realistic situation is that I will have to apply some force on this bar and bring back this deformation to this particular stress so that the member is between these two walls. that means these additional deformation delta prime which is getting caused from the wall to this end has to be brought back to this particular position and for that I will have to apply a load p and this load is going to cause a stress in the bar is equal to P by cross-sectional area. And p by cross-sectional area the stress is to be limited to 35 MPa and under that consideration we will have to find out what is the value of T so that the stress level is exactly 35 MPa.

If we calculate the compatibility equation from this particular concept from the concept of deformation if we compute the compatibility criteria, then what we can do is the delta is equal to deformation which you are getting in the bar which you have designated as delta because of the change in the temperature. The initial temperature was minus 20 degrees, the final temperature is T so the deltaT the change in the temperature is equal to T minus (minus 20) is equal to T plus 20, this is the value of deltaT. The strain ET is equal to alpha into deltaT or deformation due to change in temperature which we have called as deltaT is equal to alpha into deltaT into length l.

So in this particular case the coefficient of thermal expansion which is given as 18 into 10 to the power minus 6 by degree C into change in temperature is T plus 20 into l is 3,000 the original length 3 m so this is equal to delta which is delta prime plus 2.5 so this is 2.5 plus delta prime. Now from these we get the value of delta prime is equal to 54 into 10 to the power minus 3 into T plus 20 minus 2.5. Now this delta prime which is being caused from the wall to this end and this particular part has to be brought back to this particular wall level by applying this force P so this delta can be written as Pl by AE by the application of external force p, we are bringing back this delta to the wall position and p by a p by cross-sectional area, we can write this as stress.

In this particular problem since the stress is limited we write this expression in terms of stress. So p by a is the parameter sigma into l by e equals to this particular quantity which is 54 into 10 to the power minus 3 into T plus 20 minus 2.5.

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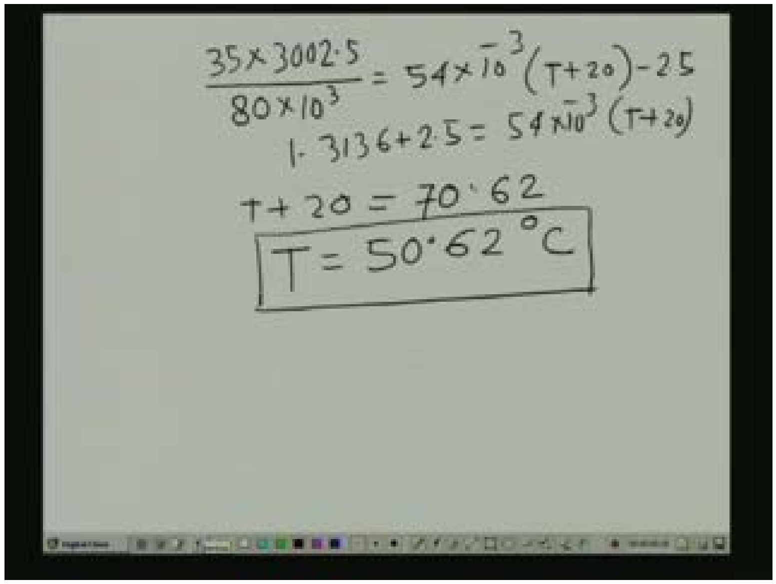

From this we can compute the value of T. Here sigma is given as 35 MPa and the length initially was 3m and then we have allowed it to move because of the increase in the temperature and since there was a gap between the wall and the bar of 2.5 mm this 2.5 mm movement is unrestricted so the stress start getting the generator only when the bar starts the wall. So length which is going to cause the stress or which is going to cause this additional deformation is equal to 3002.5, this 3,000 plus 2.5 is the length and this divided by e which is 80 GPa area so 80 into 10 to the power 3 MPa is equal to 54 into 10 to the power minus 3 into T plus 20 minus 2.5.

Or, if you evaluate this it comes to 1.3136 plus 2.5 is equal to 54 into 10 to the power minus 3 into T plus 20 and then T plus 20 from this expression is equal to 70.62, if we compute this you get this as 70.62 and hence the T is equal to 50.62. So, if the temperature goes up to 50.6 degree C from minus 20 then the bar will be experiencing a stress of 35 MPa and that is the problem. If you allow the bar to undergo a change in the temperature from minus 20 to 50 plus 50 to 62 the bar will be experiencing a stress of 35 MPa.

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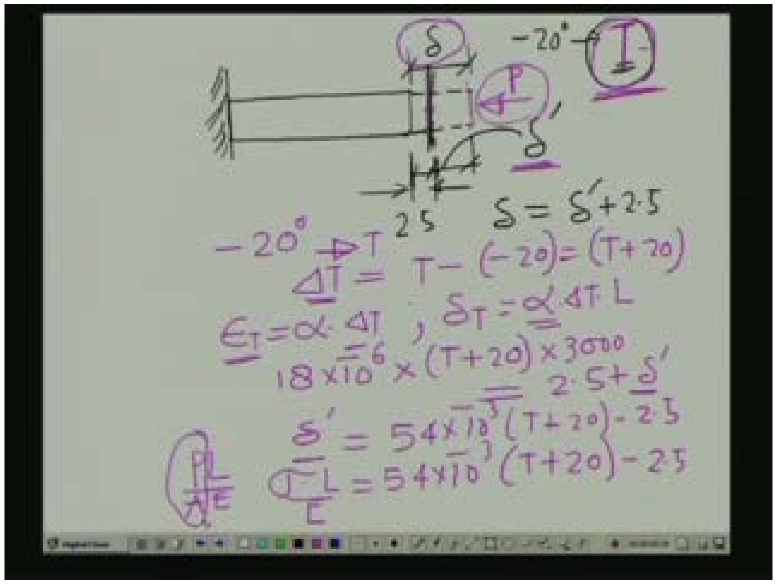

But the interesting part of this to be noted here is that this value of T we have arrived at from the criteria where we have equated the deformation part of the bar. Initially, allowed the bar to deform in such away that undergoes movement freely over the 2.5 mm and then it hits wall and then keeps on increasing because that there is a change in the temperature but when it is giving the thrust on the wall is giving a reactive force which is causing as internal stress in the member. We have derived these equation based on the deformation compatibility which we call as the compatibility equation and so the change in the temperature is basically an indeterminate system and we solve the problem in terms of indeterminate form.

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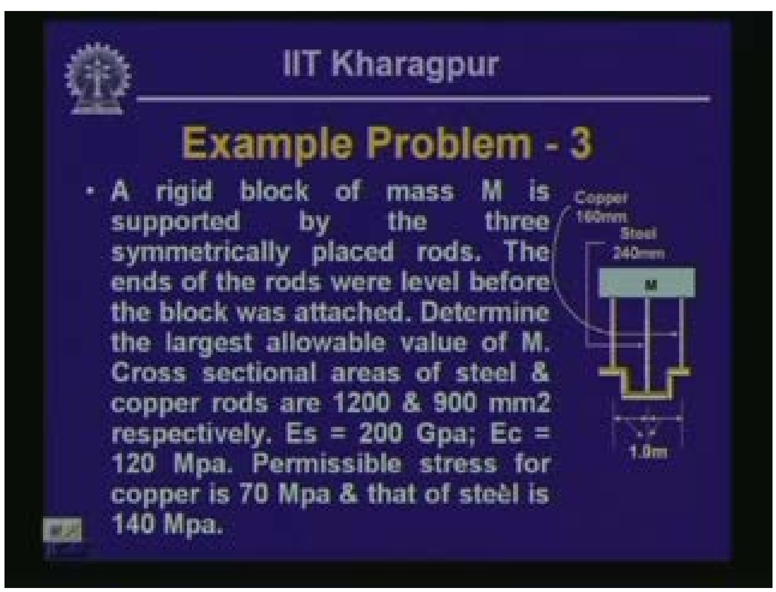

Let us look into another example where a rigid block of mass M is supported by the three symmetrically placed rods and the ends of the rods were leveled before the block was attached. They are in the same level, we will have to determine the largest allowable value of M that can be this bar, can carry cross-sectional areas of steel and copper rods are 1200 and 900 mm square then modulus of elasticity of steel is 200 Gpa modulus of elasticity of copper is 120 MPa and permissible stress for copper is 70 MPa and that of steel is 140 MPa. These are the two copper bars and this is the steel bar of length 240 mm and length of the copper bar is 160 mm and they are placed at 1 meter interval symmetrically placed. Before these blocks were placed they were on the same level.

After the block is placed we will undergo deformation. What we will have to find out is that how much weight we can put so that they are within their stresses, their stresses do not go beyond these values. Let us write down the equilibrium equation.

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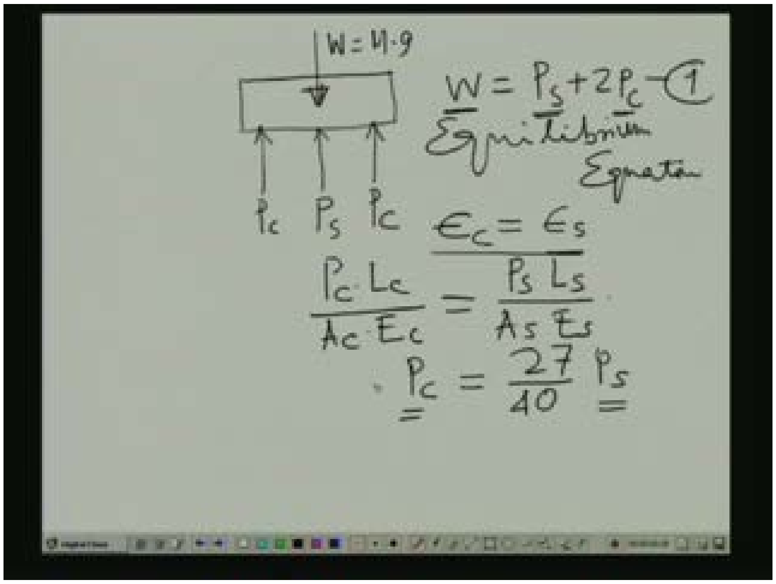

This is the bar or the block whose mass is M so the load that it transmits on those three bars equals the weight of it which is M into g. We have the three bars placed, central is the steel one and two copper rods, let us call the load that will be carried by steel rod as P_s and those of copper by P_c.

So we can write down the summation of vertical forces as 0, we will give us w is equal to P_s plus $2P_c$ so this is the equation of equilibrium. The compatibility equation, next equation which is here, also you see unknown parameters are P_s and P_c and of course we have to find out W in terms of these. We need another equation which is in terms of its deformation compatibility. And since the block is placed when the bars are uniform and is expected that it will be in the same level the strain in the copper bar or copper rods will be equal to the strain in steel or the deformation that the bars will undergo such as the strain in the steel bar will have the same value of the strain in the copper bars. These lead us to the criteria that, if we substitute the values of this strain which is P_c into L_c by A_c.

into E_c the suffix stands for copper is equal to P_sL_s by A_sE_s this gives us a relationship from which we get P_c is equal to 27 by 40 into P_s if we compute the value of W in terms of P_c and P_s.

Here another criteria is to be noted that the maximum value of P_c and P_s can be evaluated from the given stress. Since the allowable stresses on these rods are given, the maximum load that the rods can carry equals the stress in the rod multiplied by the cross-sectional area.

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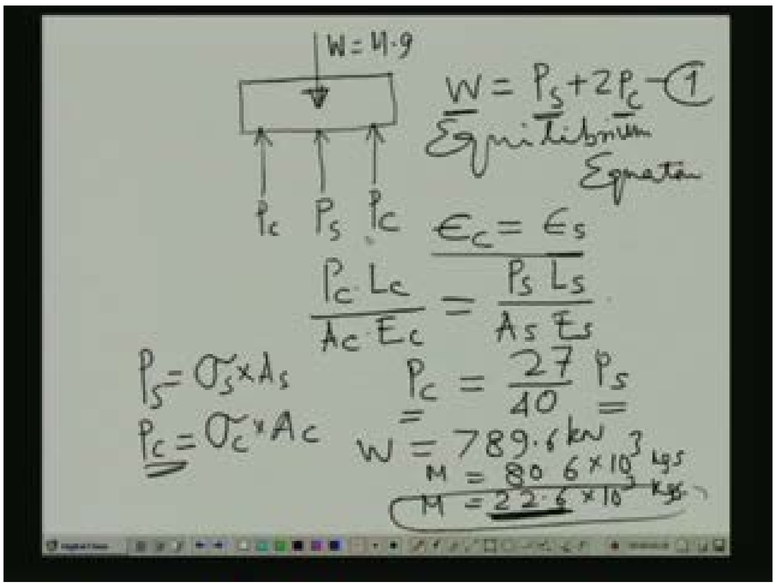

So the value of P_s is equal to the stress in the steel rod multiplied by the cross-sectional area of the steel rod and the load maximum load that the copper rods can carry is equal to sigma_c into A_c. So from these we compute the value of W and from the criteria that from the maximum value of steel rod if we compute we will get W is equal to 789.6 kN or mass we get around 80.6 into 10 cube kilograms whereas from the other criteria from the limiting criteria for P_c we get mass is equal to 22.6 into 10 cube kilograms. Since we are getting two values and out of these this is the lowest one, therefore this is the maximum value we can apply beyond which if we apply that the value of the stresses in the bar will not exceed the permissible limits.

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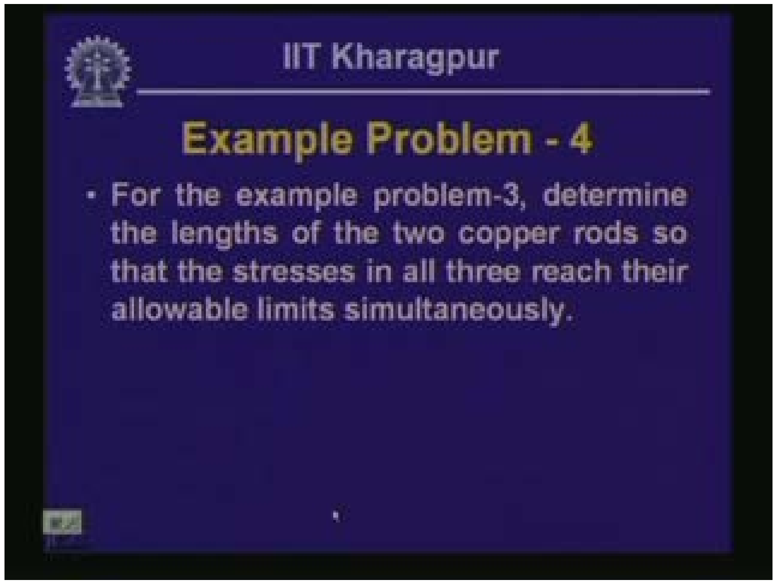

We have another problem similar to the previous problem. We got to determine the lengths of the two copper rods so that stresses in all the three reach their allowable limits simultaneously. In this case, we are allowing the stresses in the bars to reach their limiting values simultaneously then what should be the length of the copper rods?

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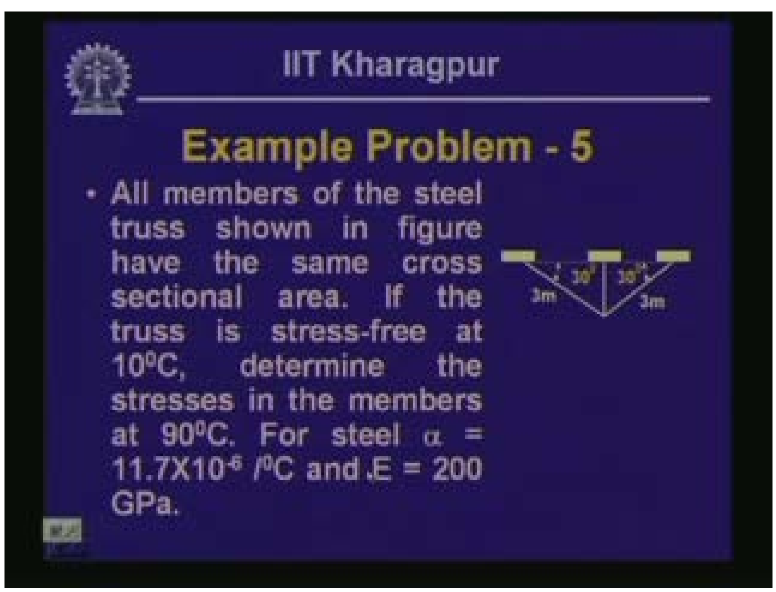

Also, we have another problem which are related to this thermal or temperature changes in the member that all members of the steel truss shown in this figure have the same cross-sectional area. If the truss is stress free at 10 degree C, determine the stresses in the members at 90 degree C, for steel alpha is equal to 11.7 into 10 to the power minus 6 by degree C and E is equal to 200 GPa.

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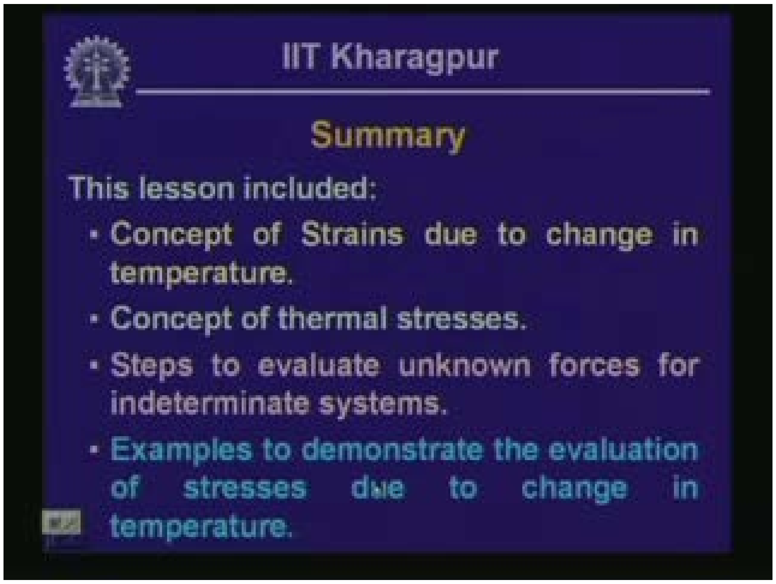

To summarize; in this particular lesson we have included the concept of strains due to change in temperature, we have included the concept of thermal stresses, we have seen the steps to evaluate unknown forces for indeterminate systems and then we have looked into some examples to demonstrate the evaluation of stresses due to change in temperature.

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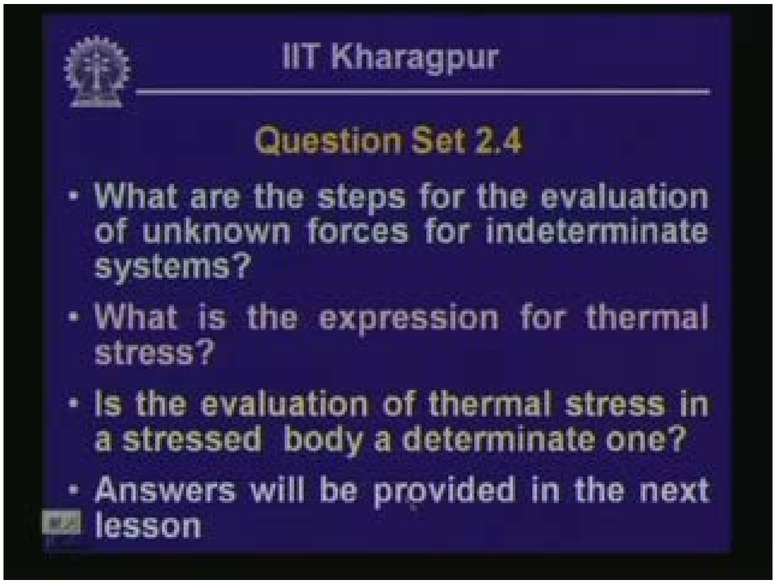

We have some questions:

(1) What are the steps for the evaluation of unknown forces for indeterminate systems?
(2) What is the expression for thermal stress?
(3) Is the evaluation of thermal stress in a stressed body a determinate one?