Design of Machine Elements – I

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Lecture No - 25

Design of Joints with Eccentric Loading

dear student

let us begin the lectures on machine design part one

this is lecture number twenty-five and the topic is design of joints with eccentric loading [Noise]

in the last few lectures we have studied ah many things about different kinds of joints

some joints are non permanent types that is they could be detached for example the screws and flange coupling etcetera

and some are permanent type joints {tho} (00:01:19) those could not be detached without damaging the components the examples are welded joints or ah riveted joints

now in those cases we have studied only the simple type of loading

in this class we are going to study something about a complex type of loading which is known as eccentric loading [Noise]

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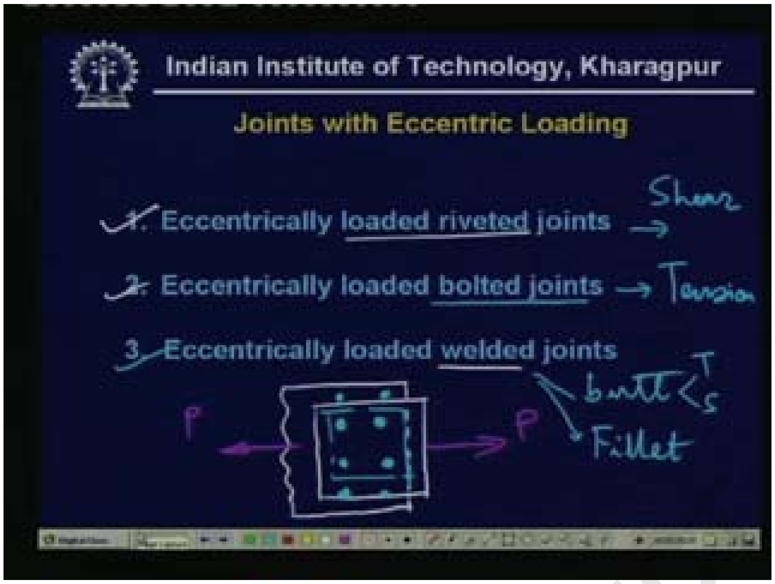

now let us look at [Noise] the joints with eccentric loading

we have eccentrically loaded riveted joints

then eccentrically loaded bolted joints

and eccentrically loaded welded joints

now let us come to the first case eccentrically loaded riveted joints

now rivet joints as we have studied these are joints which look like the following if i draw it

if we are loading here and load applied here P P then the joint load so these are rivets

the rivets are meant to take load primarily in shear

and here you see there is no bending moment acting on this joint because here if we take ah one small section of it that is one pitch then the load is passing normally through the center of gravity of the of the riveted joints

but if it doesn't pass through the center of the gravity of the loaded of the riveted joints that happens sometimes in ah the case of brackets or ah in some other um {ve} (00:03:29) ah the load carrying members as we shall ah um see different cases

then the loading becomes complicated and eccentric and the stresses becomes also complicated we have to take utmost care so that the rivet stress doesn't become too much similarly we have the eccentrically loaded bolted joints

now here rivet joints mainly take load in shear the bolted joints take primarily load in tension

you may remember we talked of the ah the effect of pre stress there we had to initially tense the bolt by initial tensioning we relieve the bolt of the ah final loading if the loading is tension type but primarily always we talk of the tensile load in a bolted joints

when it comes to the welded joints then there will be two possibilities you remember there are two kinds of welded joints one is butt weld which can take tensile load as well as uh the ah shear uh as well as the shear load

so in the butt joint we can take tensile as well as {sh} (00:04:43) shear

but the fillet joints there is another thing called fillet joint which can take load or which is designed to carry load only in the ah in the shear

that is it is not mandatory that all the loads will be shear type but we carry the design procedure assuming that entire load is shear and acting on throat cross sectional area this must be very clear from the last lecture

in this lecture we are going to study something of this kinds of joints that is eccentrically loaded riveted joint eccentrically loaded bolted joints and eccentrically loaded welded joints

[Noise]

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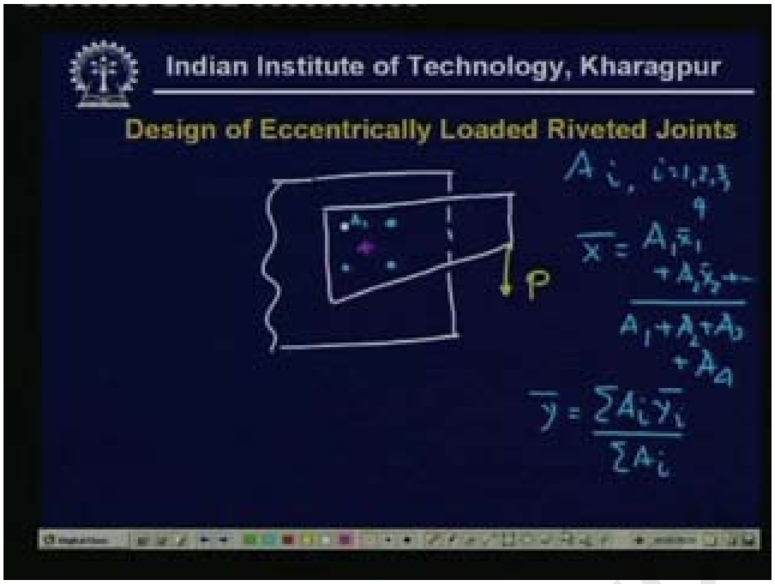

let us now start the discussion of eccentrically loaded riveted joints

see if we have a rivet joint of this shape let us say this is the plate which is acted on by a force P over here and there are few rivets let us say there are some rivets here and it is connected to another plate

now clearly you see the cross section that is the the load does not pass through the center of gravity of the riveted joints and what is meant by the center of gravity of the riveted joints

now if the cross sectional area is A one A two A three Ai where i equal to one two three and four then there are the cross sectional area of these joints is given as x bar which is equal to A one x one the x coordinate of the first rivet plus A two x two etcetera plus A three x three plus A four x four all these things will come divided by the total area A one plus A two plus A three plus A four

so this is the area of ah area of cross sections of the at the uh center of gravity center of the geometric uh center of the rivets

similarly we have y bar which is equal to summation Ai Yi bar a ah this x one bar x two bar etcetera these are nothing but the {se} (00:07:42) ah the x coordinates of the ith rivet

similarly we have y coordinate and if we do this then we get x bar and y bar the center of gravity of the entire riveted joint

let us see let us denote the joint that is the center at this point okay so this is the center now the load clearly doesn't pass through the center so therefore the tendency will be first to shear off because every bolt will take some shear load as well as there is a tendency to rotate about the center of gravity

so definitely there will be two kinds of loading which we are going to study let us come one by one

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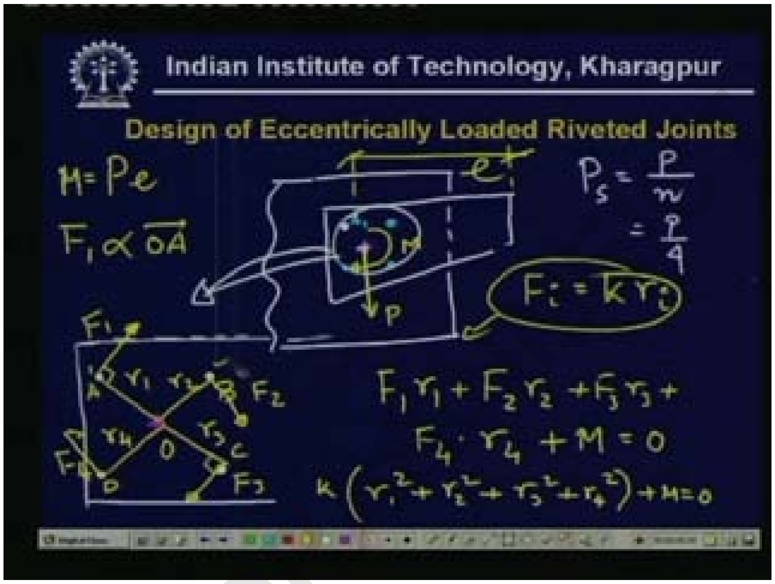

first there will be there be there will be the shear force acting there are now four such rivets so therefore each rivet will carry a shear force P divided by total number of rivets which is equal to four therefore this is P by four and then we have to calculate the bending the force that is acting because of the tendency of this entire plate to rotate about the center of gravity

what will be that force that is difficult to find out analytically

so there is no exact solution possible

ah but we make some assumptions we assume that we assume that the {bo} (00:09:21) the riveted joints rotate about this point and the load acting is proportional to distanced from this cg

now let us look at it

if we replace this load now it it is clear from statics that within one static body we can remove this load we can {rem} (00:09:41) we can shift this load from one point to the other provided we act some amount of couple or some amount of moment about the {nic} (00:09:50) new point

let us see what does it mean

if we remove this load now what we have done essentially is to take the load here so this is the load but now we have to add again a moment and what is the moment

the moment will be equal to we have to add the moment the moment is definitely clockwise and this moment M will be equal to P times the length of the arc and this is the distance if the eccentricity is e then this is nothing but M is equal to P times e so this moment has to be added

now the internal forces within the rivets will be such that they should balance not only the this external force P but also this external moment M

as we have discussed because of the direct load P each of the rivet will experience some shear load and which is equal to P divided by M and for four such rivets here we have P by four

now this is true for all the rivets

now we have to calculate the effect of the M now here we make an assumptions that is if you look at this riveted joint more carefully that is if you will enlarge it etcetera so this is this part which i have enlarge then the center of gravity is of course here

then we make the assumption that each one the load carried will be proportional to the distance from the center that is if let us say this is this is F two this force is let us say F one and this is perpendicular to this line joining the rivet the first rivet and the center of gravity

and this magnitude F one which is proportional to this distance if we denote this by O A B C B C and D then F one is proportional to the magnitude of F one is proportional to OA the magnitude of OB or magnitude of F two that is acting on this rivet is proportional to this length OB and the direction of this force is perpendicular to it to the line joining OB

similarly on C we have F three which is proportional to OC and direction perpendicular to the line joining OC similarly OD this way [Noise]

F four the magnitude is proportional to OD and the direction is perpendicular to the OD now here we make the {ub} (00:13:26) ah make these assumptions and with this assumption we can calculate further

what we see if we denote this by r one vector and this is r two vector r three and r four then we have the following relationship that is

F one times r one the couple about point O plus F two times r two plus F three times r three plus F four times r four this plus M will be equal to zero

now this is the balance of the momentum about the point O

now we have made the assumptions that F one is proportional to r one F two is proportional to r two let us denote the proportionality constant to be k

so Fi is equal to k times ri where k is a constant

now if you substitute this into this equations what you get is

k times r one square plus r two square plus r three square plus r four square plus M equal to zero

so this is the this is the equation which you get from this you can solve for k directly what you see is that the value of k now is

let us write down in for more legible form

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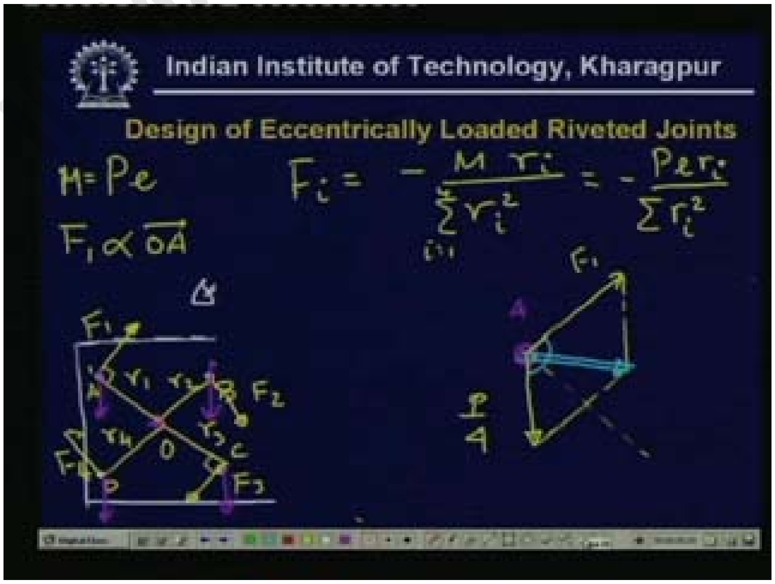

what you have then Fi is equal to [Noise] k which is equal to minus M divided by summation ri square i is one to four and times ri

and this is equal to minus Pe ri divided by summation ri square so this is now the force acting on ith rivet

now let us see uh {wa} (00:15:50) what is the resultant of this force

remember we have two two forces one is the force which is acting because of the shear the direct shear and each one is carrying same force and there will be the another force due to the turning actions

so therefore we have to look into the resultant of this force now the resultant will be different for different cases we study one or two cases here

you see for the first case we have ah now here on this let us say on the A that is the first bolt we have direct shear force which is equal to P by four

and we have another one which is equal to which is perpendicular to this distance and this is F one now we {sh} (00:17:01) should get the resultant force you get the resultant vector really so this is nothing but the resultant force

now you know very well the resultant force will be equal to if you denote this vector to be Fi so this is the first vector

you will have to calculate the resultant for each of the rivet so if you calculate that what you get is

[Noise]

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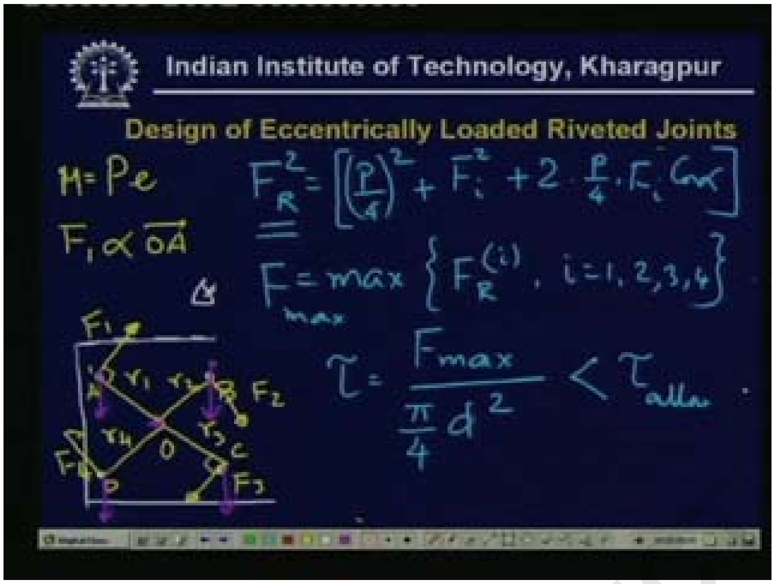

the resultant FR will be equal to this is P by four square plus Fi square plus twice P by four times Fi cosine alpha which is the angle between these two forces

so therefore for each of the bolt you will have to carry these calculations you will have to make these calculations and you will have to find the highest the largest Fr that is the rivet which has the largest shear of the load

now you will have to design the rivet such that the stress in the maximum stress in the bolt is below the allowable limit

so with the help of these calculations you first calculate you first calculate what is the maximum of FR i where i equal to one two three four there are four such cases

so you get this maximum force F F max and then you calculate the stress

now the shear stress F max divided by pi by four d square and that must be less than tau allowable so this is the design criteria for eccentrically loaded riveted joints

now now let me ah repeat again we make the assumption that whenever we have eccentrically loaded joint the turning action around the center of geometric center of gravity of the ah of the of the riveted joint will be such that the force in each of the rivet will be proportional to distance from distance of the rivet from the center and the direction will be perpendicular to the line joining the point the center of gravity and the corresponding rivet so with this assumption we make this calculations we find out the maximum force in ah such rivet assembly and then with the maximum force we calculate the shear stress taken by the maximum shear stress taken by this bolt and hence we calculate the corresponding diameter that is we design the joint

so this is the design procedure for eccentrically loaded riveted joints

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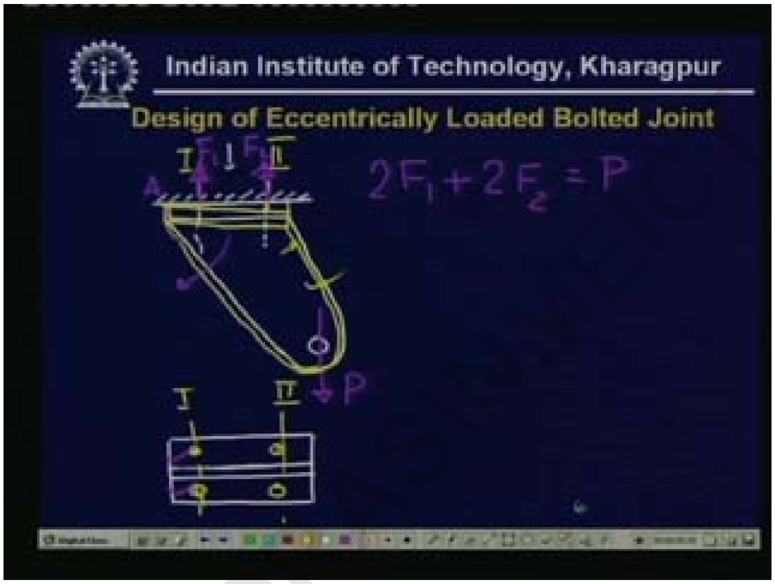

now let us go to the design of eccentrically loaded bolted joint

here we have few {ca} (00:20:51) two cases distinct

first let us take the example here consider this kind of bracket

there are bolts here so if you look from this side top you {ve} (00:21:20) you will see

now these are bolts let us say cross section one section two so there are four such bolt one and two and the load is acting here there is a load p acting now you see [Noise] what will be the effect of P

now the P will introduce tension in the bolt bolted assembly

so each bolt will carry some tension but the tension will not be uniform because there is a distinct in tendency for this bracket to rotate about this point let us say point A so it’s a {chan}

(00:22:21) there is a tendency that it will rotate about this point because of this load so therefore the tension in the bolt will be unequal

now again what we see ah now how to calculate the load ah the tensile load in the member

we make ah the static equilibrium that is let us say that each of the bolt here carries load F one and F two

now if you write down the static equilibrium equation then F one there are two such one and two

two F one plus two F two will be equal to P [Noise] and that is the only static equilibrium equilibrium equations we have for this case

now this is statically indeterminate problem therefore because we have two unknowns and one equation only so it cannot be solved by means of pure statics only

so we will have to {t} (00:23:24) take help of help of now the ah kinematics that is the flexibility of this member now if you take the {con} (00:23:34) consideration of flexibility we have to we make the assumptions that here this body is a rigid body this bracket is a rigid body

so therefore it when it rotates suppose it rotates then because of rotation it will be it will come to some this kind of position ((is of)) (00:23:57) because it has rotated so this was the original position and this is the final positions

now it has rotated therefore there is a small deflections of these two bolts there will be some elongations of this bolt

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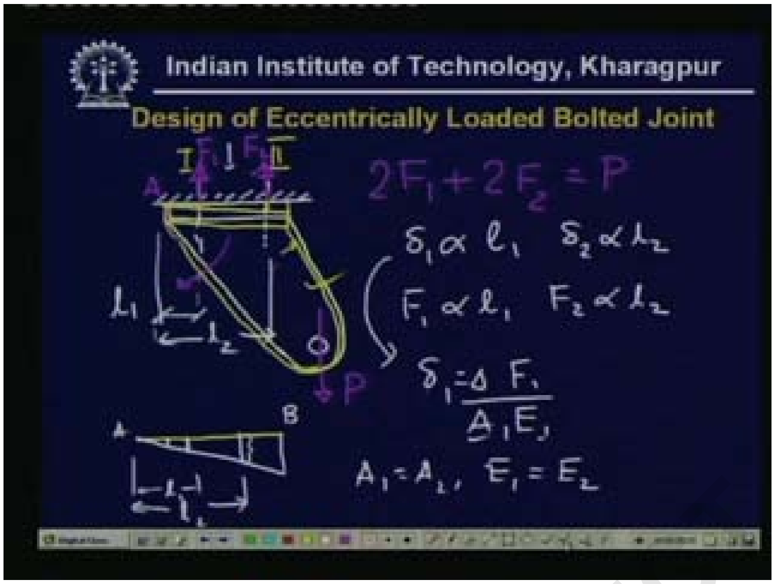

if you draw it elaborately then what you see here initial this was the initial line and after that it has rotated here

so now if you denote this length length from this point to that point by l one and from here to there l two then what you get is that this is l one this point A and point B

so this is l one so and this one is l two

now the delta that is delta one that is the deflection of this is now proportional to this length l one that is clearly visible because this is a rigid plate so this angle is constant so tangent of this angle will be equal to delta one delta one divided by this length l one and the tangent of this angle will be again equal to delta two which is the deflections of this bolt divided by delta length l two

so therefore delta one {wilb} (00:25:42) is proportional to l one and delta two is proportional to l two

then if you use the {u} (00:25:51) use the hum Hooke's law then what you get is that

F is F one ultimately could be written is F one is proportional to l one and F two is proportional to l two

that is clearly visible because delta one is nothing but Young's modulus times the original length let us say delta is the original length and the deflection is ah the extension is delta one so the strain is delta one divided by capital delta which is equal to Young's modulus i am sorry this is this has to go down

so this will be equal to stress which is equal to F one divided by A one and E one

now if you consider A and E are same that is A one equal to A two and E one equal to E two then what you see is that F one is proportional to delta one and delta one is proportional to l one

so therefore F one is proportional to l one and F two is proportional to l two

so that is that comes from a very simple calculations

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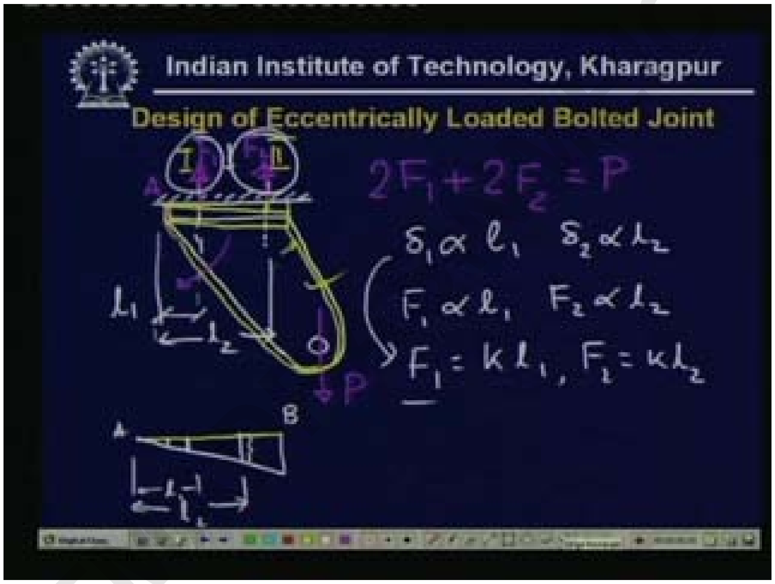

now what we can have is [Noise] that we can use the this considerations that is F one is proportional to l one if you consider the proportionality constant to be k

so therefore F one is k times l one and F two is k times l two

so in that case you can get the F so in this case you can find out F so {tha} (00:27:57) thus we arrive at the ah at the different loads in the bolted joints

so this is one example where the load is acting now ah load is acting such ah such that there is always tensions in the bolt

now we come to the second example where the load is acting such that both the tension as well as the shear force will be developed let us see

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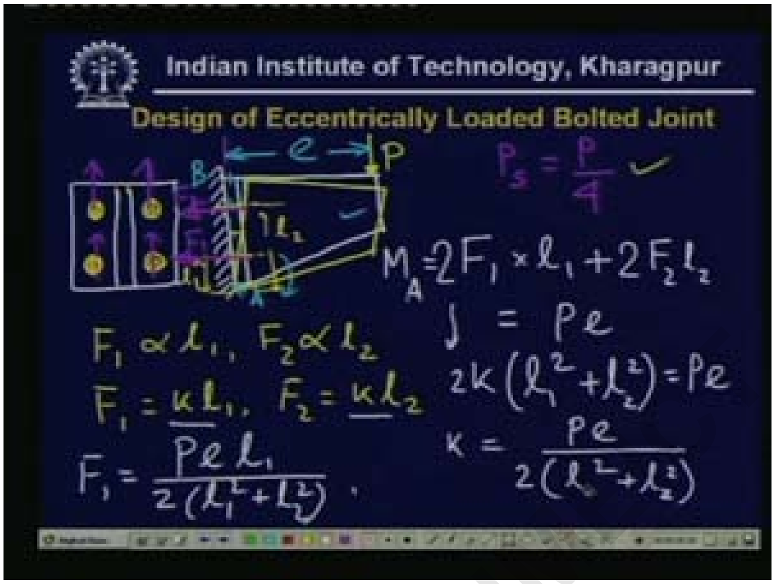

let us come to the next example

here we have [Noise] now here and we have let us say again {simil} (00:29:19) some kind of arrangement we look from this side then we have this bolt

so there are this four bolts the load is acting over here so therefore you see the direct effect of P will be to introduce some shear force here so each one each of this bolt will carry some shear force

now the shear force will be equal to P shear will be equal to P divided by four because there are four such bolts

now what is the effect of this eccentricity

let us say that there is a distance e from this plane to that of the applications of P

now because of this eccentricity it will try to rotate about this point okay if this is A and B so there is a tendency that it will rotate about this point

now because of this tendency of rotations so there will be elongations this is enormous tensile force will be developed in this bolt and again if you consider the rigidity of this member that is if it ((teals)) (00:31:11) for example here this way so this is the tilting it is very much exaggerated but the point is that now the rigid body dynamics that is rigid body statics ah is not enough and we will have to consider the deflections that is the elongations of the bolt we will have to consider the strength of material approach

so therefore we make these assumptions that this is a rigid body rotations now this body the bracket is relatively rigid compared to that of the bolt so the bolt gets extend where as the rigid body gets only rotated

and here again if this length is l one and this is l two what we have is that l one that is this force again from the same calculation as before this force on this first bolt that is this bolt again will be

F one which is proportional to l one this is why because we see

delta one the elongation of this bolt that is of this bolt the elongation will be delta one and this is proportional to l one and that is because this angle is constant

again the tangent of this angle will be equal to delta one delta one divided by l one again the tangent of this angle will be also equal to delta two delta two divided by l two

so delta one and delta two are proportional to l one and l two respectively

now again if you use the Hooke's law you get that F one and F two are proportional to l one and l two

if you use this proportionality constant to be k then what you get is

F one is kl one F two is kl two

now you have already used the equilibrium equations force equilibrium equations only we are left with the moment equilibrium equations

let us use the moment equilibrium equations now if we take the moment about this point what you get is that F one let us consider this direction of this force is here F one F one and F two

then we have F one times l one the moment about point A F one l one plus F one times l one because there are two such bolts so twice F one l one plus F two times l two again twice of that this is equal to the external moment which is equal to P times e

now if you in if you use this relationship that is F one and F two are proportional to l one and l two respectively then what you get from this equation is [Noise] twice kl one square plus l two square will be equal to P times e

from this you calculate k which is equal to

Pe divided by twice l one square plus l two square [Noise]

once we have calculated k then we have calculated F one because F one will be equal to k times l one

so this is equal to Pe l one divided by twice l one square plus l two square

and F two will be equal to similarly F two will be equal to Pe l two divided by twice l one square plus l two square

now let us sum it up we have

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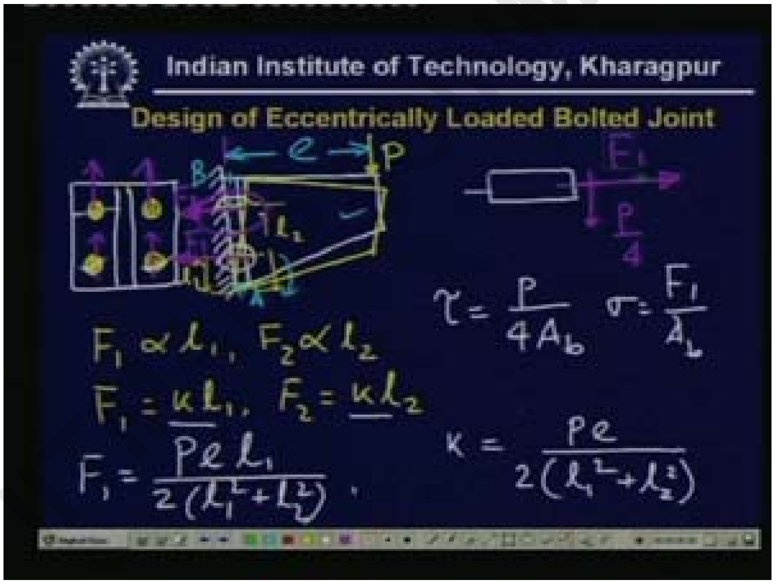

we have now a situation where in a bolt there are two kinds of stresses

if you consider this bolt the first bolt that is this one here this is the bolt now we have the force P by four as well as so there will be the shear stress developed which is

tau equal to shear stress will be shear stress is P by four times A bolt so this is the shear stress developed and there will be the tensile force the tensile force is again F one which is given as Pel one by twice l one square plus l two square

definitely F two is much larger compared to F one

so therefore the tensile force will be larger for the second bolt this bolt

so when we consider the ah when we when we have to find out the the cross sectional e of the bolt that is when we want to design the bolt then we will have to consider the maximum of this stresses

so we consider the second bolt the first bolt ((gives)) (00:37:18) then the tensile {uf} (00:37:20) stress F one divided by sigma will be equal to F one by A bolt but F one is less than F two

so therefore the maximum tensile force will be taken by the second bolt and we will have to consider the design with with uh the second bolt itself but not the first bolt

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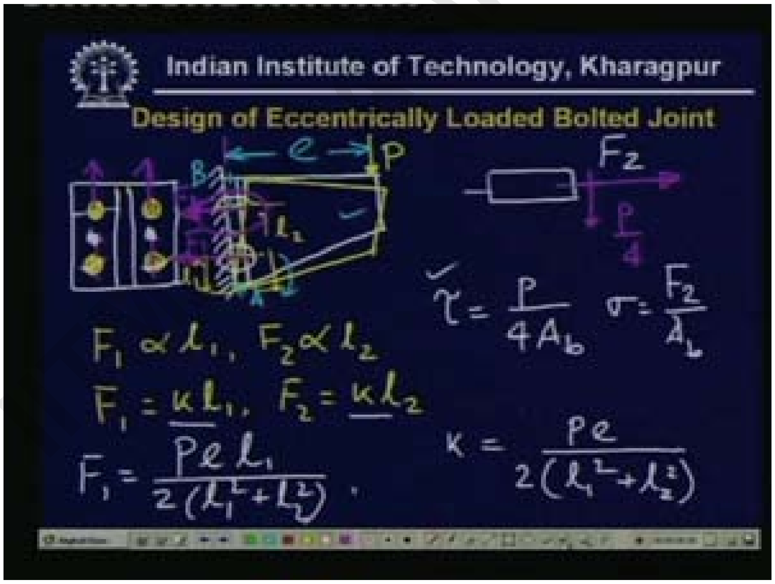

so if you consider the second bolt what you get is the same shear force but here F two tau remains same sigma becomes instead of F one we have F two and divided by Ab

now we have uh the case where the bolt is subjected to both shear and tensile force now normally as i said the bolts are ah not meant to carry the shear load primarily the bolts should carry only tensile load but if sometimes the shear load occurs then we will have to relieve the bolts of the shear load if possible

so that is done by say ah adding some kind of other bolts dowel pins etcetera so this should take off the shear load as small as possible

so if you increase the number of bolts over here then the shear load may be decreased so this is done

the shear load is um well reduced as far as possible but if ah if further is not possible then we will have to consider the effect of the shear stress as well as the normal stress

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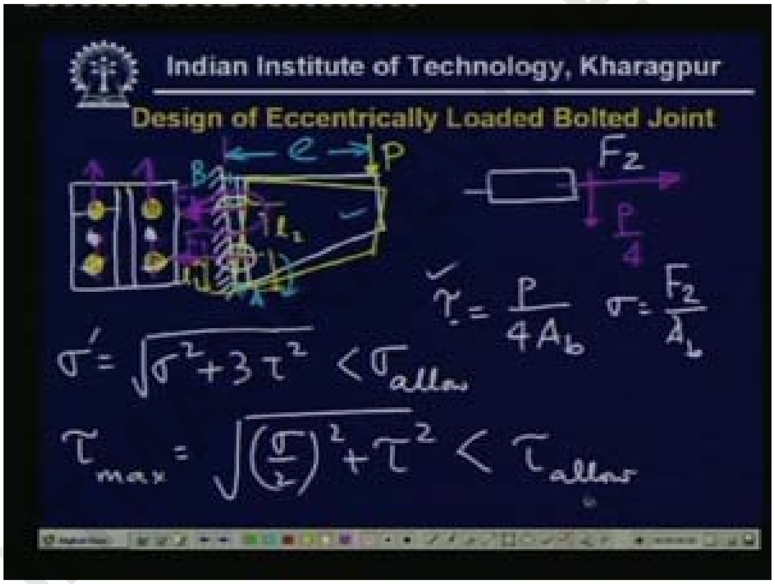

we have the shear stress and the normal stress and then we calculate [Noise] the ((von mises)) (00:39:16) stress you know that when we have both the stresses we can calculate sometimes the ((von mises)) (00:39:29 min) stresses which is equal to sigma square plus thrice tau square

this is one failure criteria where the uh material fails if this is greater than if sigma allowable

another failure criteria is the maximum shear stress which is tau max will be equal to sigma by two square plus tau square and this must be so these are the two criteria by which the ductile material will fail if it is made of brittle material which seldom {hap} (00:40:17) happens then we will have to consider the maximum principal stress

and that is given by the balloon formula that is sigma by two plus under root sigma by two square plus tau square and if the material is brittle nature then this should be less than ah allowable [Noise]

so these are the few failure criteria's which you will have to consider but the main {importa} (00:40:54) the important point is that here ah the bolts are subjected to both shear stress as well as normal stress

and you when you have to calculate the normal stress you will have to make this assumptions that the bracket is ah more rigid compared to that of the bolt so therefore the bracket actually rotates about one of the points but the bolts will get elongated

and the force will forces will be ah found out accordingly using the geometrical relationship

so that must be clear this is again a case where statical ah statically determinancy doesn't exist so this is statically indeterminant problem and we will have to take the help of ah the help of flexibility of the members

now this is about the design of eccentrically loaded bolted joint remember i repeat we have design we have considered two cases

in one case the load is acting such a way that the bolts are entirely under tension there is no shear force as you have seen from the first example

in the second example the bolts are now under shear because of the direct action of this force and it is again partly under ah tension because of this eccentricity so eccentricity makes the uh joints um hum the design of joints quite complicated as you might have uh understood by now

so this is about the {eccentricit} (00:42:29) eccentrically loaded bolted joint [Noise]

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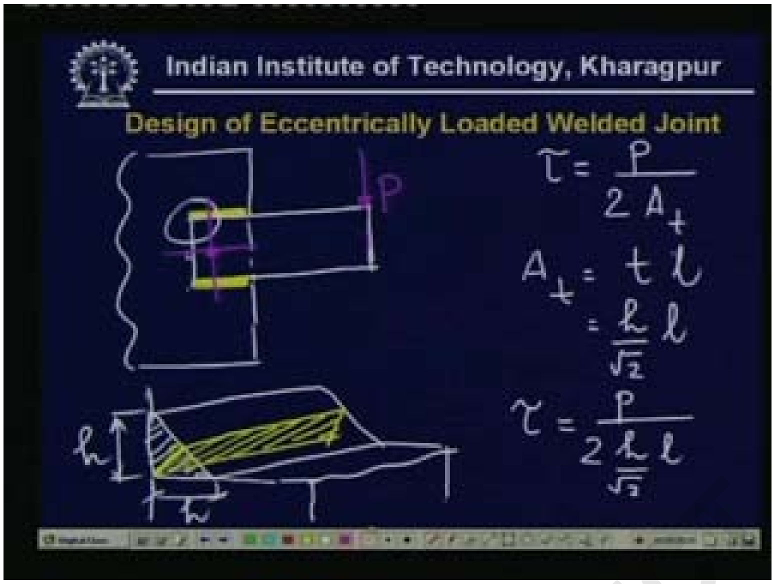

now we come to the third case where we have the eccentrically loaded welded joint

there are again few examples we take one by one

let us consider the case where a plate is welded to a structure now the welding can be done in various ways the welding may be this side that is it may be it may be a ah transverse fillet welding

there are two kinds of welding one is butt welding another is fillet welding normally in this case we use the fillet welding

there may be again two types of fillet welding one is transverse fillet and another is the longitudinal or parallel fillet

let us say that here this is in parallel fillet so we have the fillet joints here fillet joints over here and the load is now eccentric loading and in this directions

remember in earlier classes we have studied the the design of this joint this welded joint in that case the load was along the along these directions but now instead we have load in the other direction

so what is the effect of that that is what we are going to study

now you see here if you look little bit closely then what you see the fillet weld looks like this so this the plate and this is the welded part so this is the fillet and the critical section is the section of the throat that is this section so this is the critical section and the failure may take place in this section itself

now [Noise] when we consider the eccentrically loaded joint what you see that in addition to the shear force there will be then two cases

there are two kinds of stresses the direct shear force direct shear stress and what is the direct shear

stress the direct shear stress value is equal to tau will be equal to P divided by twice because there are two such welds divided twice area of the throat

and what is the area of the throat

if this leg size is h normally the fillets will have equal dimensions this is ah it will ah this is this is forty-five degree angle so therefore the At will be equal to throat times the length

if these two lengths are equal then of course area will be equal to t times l and this is equal to h by {ro} (00:46:33) root t root two {t} (00:46:36) ah root two times l

and therefore the shear stress will be equal to P divided by twice h by root two l

so this is the direct shear force which is acting on this joint but what will be the effect of eccentricity

we see that eccentricity will try to rotate this entire plate about some axis and what is that axis thus this axis is nothing but the centre of gravity that is the geometric centre of this welding

that is there are two welds and we can define {als} (00:47:16) always one centre here which is the geometric centre

how do we define this geometric centre

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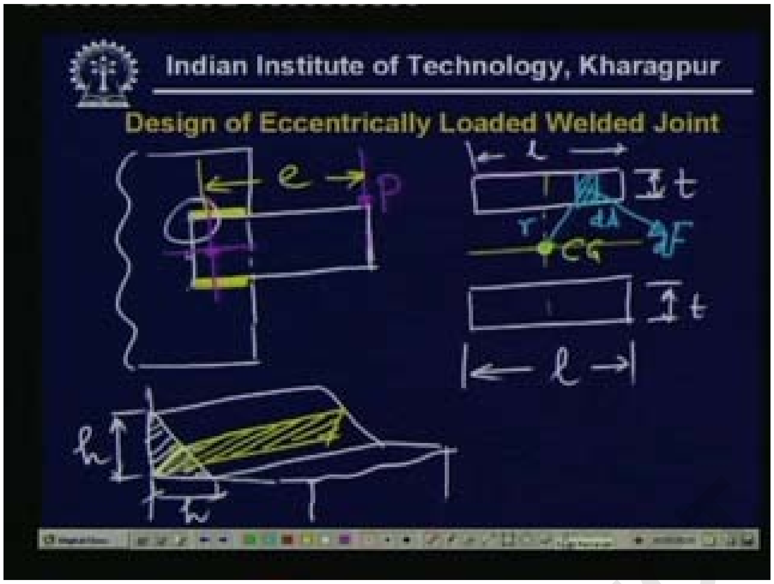

which is again based on the throat area what we do here we repeat the entire picture entire welding in terms of the throat area

so here the length is l and this one we look at in the in this plane this is throat area plane now this is t similarly this is t and this is l (( )) (00:48:16)

then the geometric centre will be equal to definitely because of the symmetry this will be the centre and this is the cg of this welding

now because of the displacement shift from the cg by some distance e eccentricity say there is a tendency that this will rotate [Noise] then how do you calculate the shear stress that is the secondary shear stress because of this rotations or torsion

now we again have to make some assumptions again the assumptions is that here when it rotates we get the force for every area there will be some force

so let us say for a distance r from the cg let us consider the small area dA

we assume that this force again is proportional to the uh distance from the cg to that area of course this assumption is almost similar assumption as ah that of the Po torsion torsion of a circular shaft we make these assumptions that the shear stress is proportional to uh that is varies linearly from the distance ah um from the radial distance that is um that is linearly with the radial distance that is it increases gradually as you go from the centre of the shaft towards the periphery

similarly similar assumptions is made here we make the assumption here that this force is now proportional to that is F or let us say dF that is the small force acting over the small area dA is proportional to the distance r

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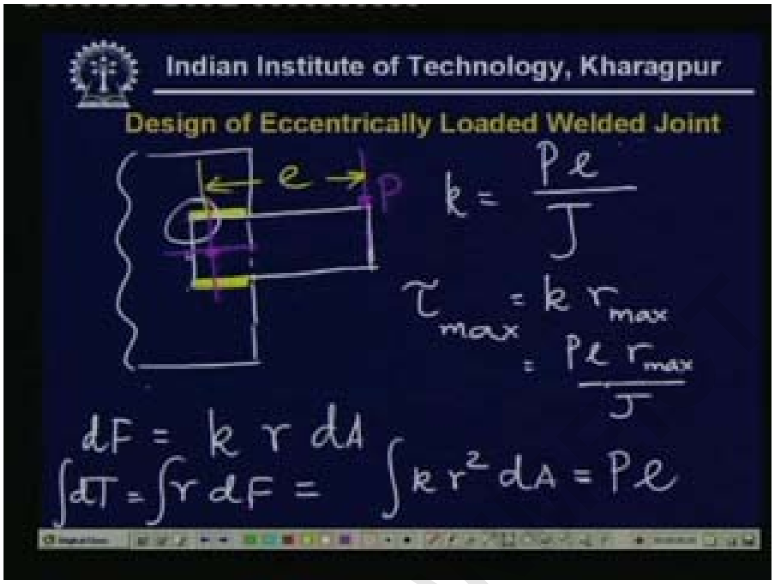

so therefore we can write down that is dF the magnitude is proportional to this is the proportionality constant proportional to r [Noise] ah and the area of course cross section in a sense we say that the stress is proportional to r

and the force is of course will be also depending on the area of cross section so this is the total force acting on this infinitesimal area dA

so therefore the net torque will be equal to T which is equal to

dT will be equal to r times dF the direction is again important direction is such that it tries to rotate so therefore this direction direction of this force is perpendicular so this line the direction of this force dF is perpendicular to this line this vector joining cg to that infinitesimal area

so therefore the total torque will be equal to [Noise] r times dF so this is the torque uh over this infinitesimal area hence the total torque will be equal to the integral of this and that could be written as

k r square times dA and this is over the entire area now this is again if you calculate it then then this will be equal to your this will be equal to the torque external torque this is Pe from this we calculate k

now if you write down this in details what you get is

k will be equal to the torque Pe divided by integral r square dA which is nothing but the J of the total throat area

and hence we can calculate the maximum shears the shear force that is the shear stress will be equal to the maximum shear stress tau max

which is equal to k times r max k times r max

so therefore k is equal to Pe r max by J

now J how to calculate J

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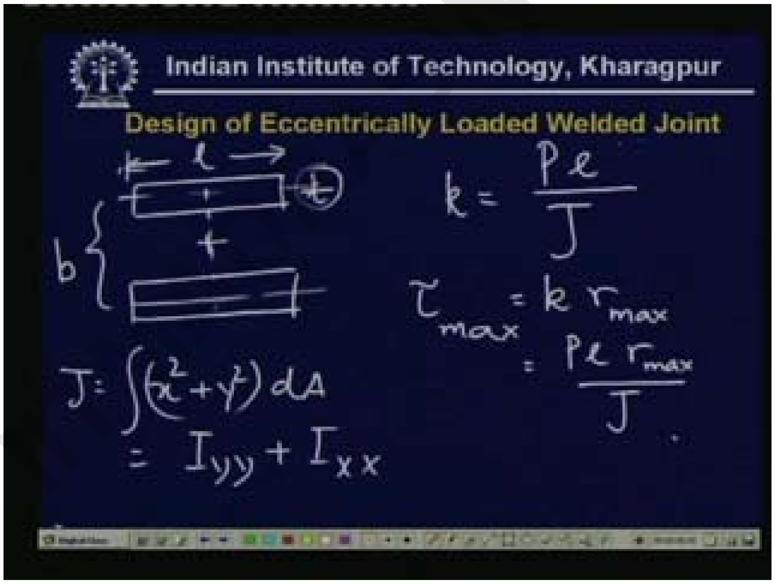

J is very easy to calculate you know the geometry of from the geometry of this we know these two ((weld mill)) (00:53:55) if you have you have t then l

and this distance is total height this length is equal to say b from this you can calculate J

and J is nothing but so J is r square dA which is equal to x square plus y square dA and this is nothing but Iyy plus Ixx and Iyy and Ixx the second moment of area of these rectangles are {ec} (00:54:48) easily known

remember T is taken to be very very small compared to the other dimensions

so therefore the higher order terms containing t are sometimes neglected

and in the book what you get there are some tables which are available which which ah which contains the value of J for unit thickness that is we consider the t to be unity but ah um of course this unity is again very small thing so therefore we neglect when we have (( )) (00:55:19) order terms and what you get the value for unit t

now whatever then if you have this relationship what you have to do is just take this data and multiply by the throat length

which is equal to root two h by root two h is the leg of the uh or the height of the fillet weld

so if you do that then you get J then tau max will be equal to Pe r max divided by J

what you have now is that {ta} (00:55:50) you have tau max the direction of the force you cannot add vectorially two stresses but you can add vectorially the the forces

so what you can do over a small cross sectional area you can calculate F uh that is the force dF due to the load the ah uh the direct shear stress and and the shear stress the due to the torsion

and then again you add vectorially and find out the maximum shear stress and using the maximum shear stress theory you can find out (( )) (00:56:22) the different design parameter

so this is roughly the way how to calculate the ah {ve} (00:56:28) welded joints when there are eccentric loading

so let us {cap} (00:56:31) recapitulate what we have learnt

we have learnt how to calculate the uh design uh how to calculate the strength of joints with eccentrically loading for riveted joints

here mainly the shear stresses exists

in the bolted joints there may be cases where the ah uh only the tensile force appears or there may be cases where both shear force and tensile force appears and in eccentrically loaded welded joints there is the case where the ah shear stress will appear

sometimes we can have tensile stress force but they are we are not going to discuss them

so um this is all about eccentrically loaded joints

thank you very much

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let us begin lectures on machine design part one this is lecture number twenty-six and the topic is design of joints with variable loading

in the last few lectures we have learnt how to design ah the {s} (00:57:42) joint for strength for various static loadings

now in the last class we have learnt how to design the joint for eccentric loading

and in this class we are going to study for the variable loading

now variable loading is very important for any machine components

in structural ah joints ah normally the loading is static but in machine components there will be invariable some movable parts and because of this movement there will be the forces which are normally ah fluctuating in nature so these are to be taken care of while designing a