Design of Machine Elements – I

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Lecture No - 24

Design of Welded Joints-II

dear student let us begin the lectures on machine design part one

this is lecture number twenty-four and the topic is design of welded joints and this is the concluding part of {theles} ((00:00:58 min)) lecture on the same topic

let us recapitulate little bit what we have learnt in the last class

we we talked about different kinds of the welded joints different types of welding processes and towards the end we mentioned about the strength of the factors affecting the strength of these joints

now let us begin from ah the same place where we had ended in the last class [noise]

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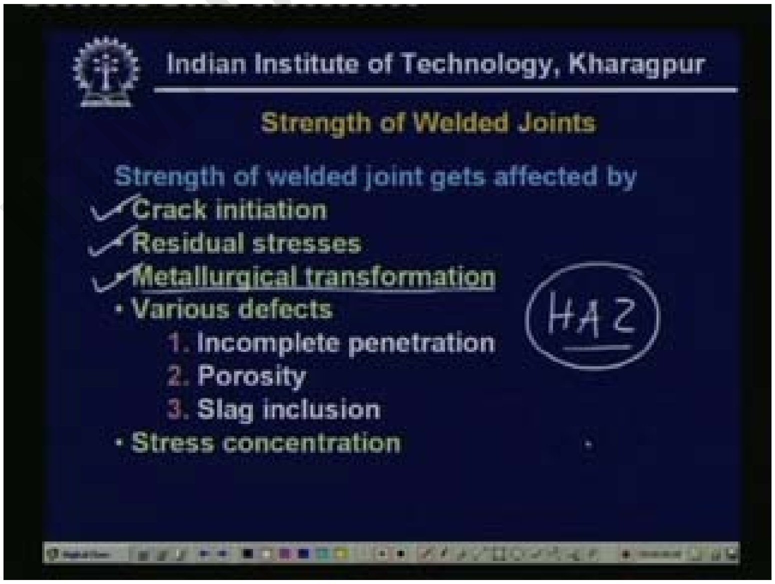

so this was the strength of welded joints we are talking of now [noise] the strength of welded joint gets affected by there are few criteria few things which affect the strength of the welded joint one is the crack initiation

now we mentioned that there are few causes of crack initiations that may be due to the incomplete the solidification contractions then there may be the cracks in the heat-affected zone then there may be cracks due to the residual stress or incomplete penetrations etcetera

so there are various reasons for crack initiations

then we talked of the residual stress

now because of the inhomogeneous or in non –uniform [noise] heating of the a of the weld melt that is the ah the parts which are which are to be joined by welding because of the non-uniform heating ah sometimes we get the stress

this stress is very dangerous because they may lead to the cracks as we i have told just now

then metallurgical transformation may take place near the heat affecting zone [noise] HAZ the ah the grain size becomes coarser because of the heating and that makes the strength low

so therefore the strength gets affected in the heat-affecting zone due to the metallurgical transformations

there may be a various defects possible that is because now welding could be considered to be a solidification or casting process

now all the defects present in the casting process will be present in the welding as well

so there may be incomplete penetration there may be porosity and there may be slag inclusions or foreign element inclusions which may also reduce the strength of the joint

and last but not the least ah the stress concentrations

the stress there may be certain ah um case ah some regions where the stress may be concentrated

so this will lead to failure if proper care is not taken

now these are about the strength of welded joints

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now let us look let us now start the design of welded joint

now for the sake of ah discussions we we ah have classified the design into broadly two parts one is the design for static loading and design for variable loading

now any joint is meant not only to carry static loading but some amount of dynamic loading also in machinery the presence of dynamic loading is ah um very obvious because it uh there are various movable parts and because of the movable parts the force may be fluctuating

so the variable loading is also very important

for the static loading we discuss in into of the two cases the butt joint and the fillet joint

now again fillet joint may be ah of two types one is parallel fillet weld one is transverse fillet weld

we also discuss how to design a {melte} ((00:04:55 min)) a welded joint which carries the torsional load such as the torsional stress will be taken by this joint

so this is what will be the ah subject matter today the design of static loading and the design for variable loading [noise]

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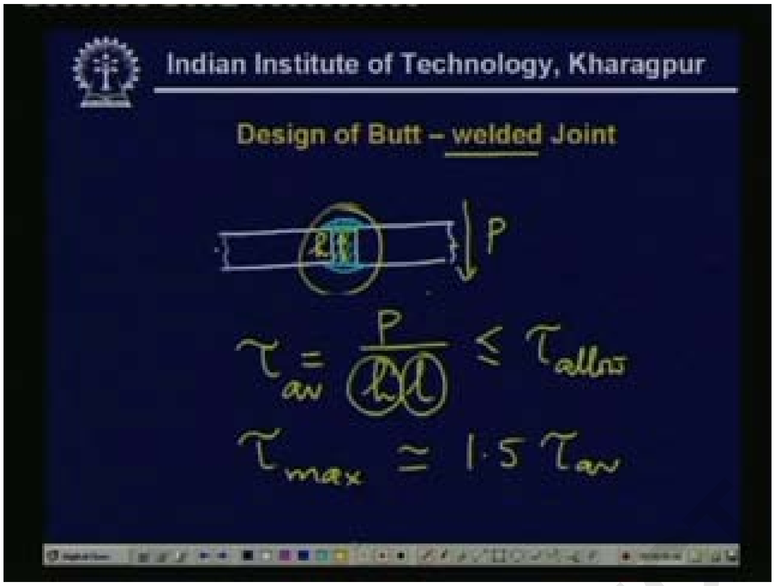

now let us come to the design of butt welded joint for static loading [noise] here if you remember butt welded joint

so there are two metal pieces which had to be connected by means of welding

so we introduce weld material here so this is the welded material

now this joint has to carry some load

it carries a load let us say P now definitely the maximum value of P will be governed by the tensile strength of this joint member

so the tensile strength that is sigma is equal to P divided by now the cross section area definitely the cross section area is this one h times the width of the plate or the length of the plate h l

and that must be less than equal to sigma allowable

now this is the design criteria we ah in design we want or we ah want the joint to carry certain load P we select l and we know sigma allowable from this fellow we design what is h

so this is the general design procedure

now this butt joint is now taking ah any longitude axial load

now suppose it wants to take transverse load so [noise] here instead we take transverse load P then definitely there will be the average shear stress then tau is tau average will be P divided by h times again l and that must be less than tau allowable[noise]

now here this is a average stress now we can find out the tau max if the cross-sectional idea is rectangular then we can get tau max which is roughly equal to one point five times tau average

so from this data we can design what will be the h of the ah of of the fillet or ah each of the butt welded joint or sometimes l or may be sometimes P max etcetera [noise]

now this is a square butt as if you as you remember ah from the last lecture that there are various kinds of butt joints

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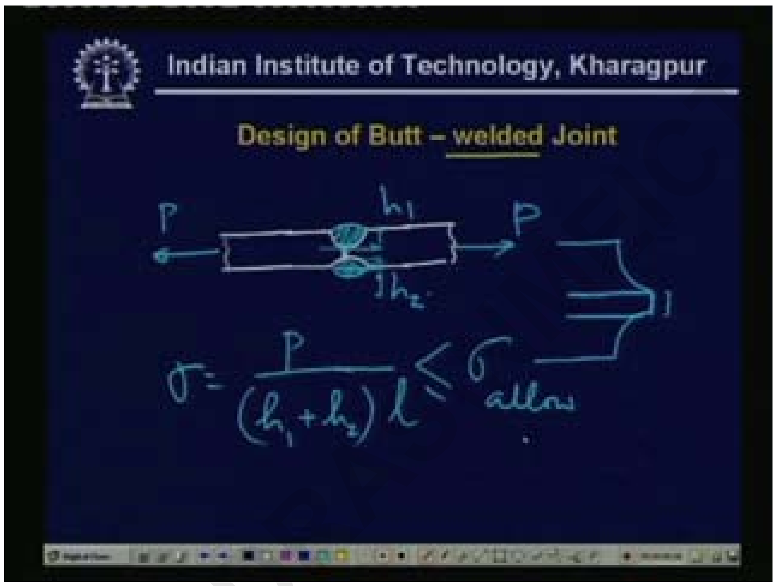

now if you talk of different kinds of butt joint then what you get [noise]

so this is let us consider ((double u)) (00:08:47 min) or j type butt joints and let us say ((double u) (00:08:49 min) here [noise] this is the two these are the two parts to be mated and we insert weld melt here [noise]

so now the effective cross-section is now reduced by some amount let us consider the same P axial load

now the effective cross section is now if this distance is h one and this distance is h two that is this part [noise] this part doesn't carry any load this one

so therefore sigma will be equal to P divided by h one plus h two times l and that must be less than equal to sigma allowable

so this is the design consideration of the butt welded joint

now it is very very simple ah the butt welded joint now when we come to the complicated case then we see that j the um complication arises because of the typical shape of the weld melt

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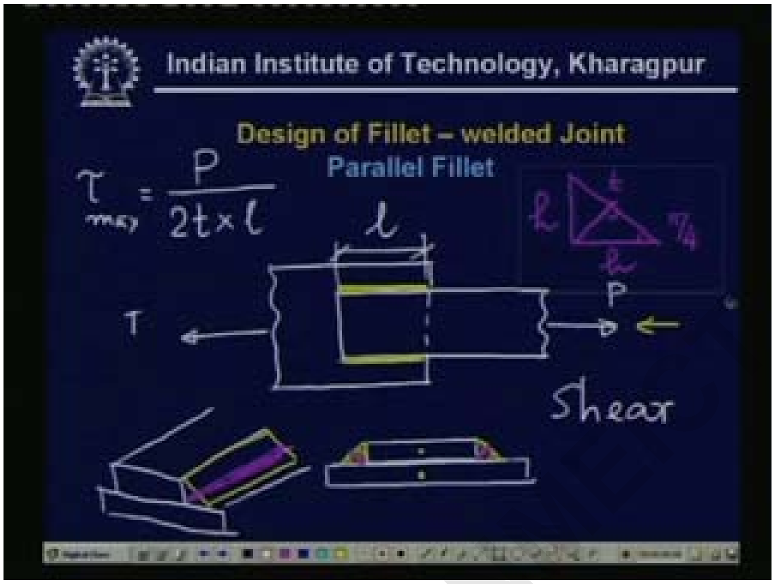

let us now go to the next topic that is the [noise] design of fillet welded joint

now we consider the parallel fillet

if you remember parallel fillets [noise] now here it carries a load P now parallel fillet is the fillet which is applied here that is the welding is done in these two places this is longitudinal fillet or parallel fillet

now what will be the design criteria for that

so if you look from from this side then it looks like there are two plates so like this and then the fillet joint

this is the fillet joint [noise]

now it carries a load P so the P is acting over here and there in two opposite directions the pointing the arrow here the direction is towards the reader or away from the reader

now if you want to design for the strength then what we have to consider the cross section where the ah joint is maximum vulnerable

and that is clearly the cross section here

it can be further elaborated with the help of a similar diagram [noise] now here is that fillet

now definitely the vulnerable cross section is here where the area is the least so this is now the part which is seen from that side and this is the three dimensional view and there and definitely when you look at the fillet then this is pi by four this is roughly of the same height and length and length is same

so therefore this length which is called the throat then t will be equal to throat will be equal to h by root two as you may verify

so therefore the the maximum shear stress here will be equal to now it has to fail in shear so we'll have to consider shear stress because this material is such that it fails in shear {fum} (00:13:41 min) in shear full mode

therefore we'll have to consider the shear stress

now the maximum shear stress will be equal to definitely[noise] tau max will be equal to force divided by total cross section area and here the total cross section area is t times the length here length [noise]

and there are two such welds which as symmetric

so therefore twice t l and t from this earlier relationship we can get that is equal to that is this part will be equal to [noise]

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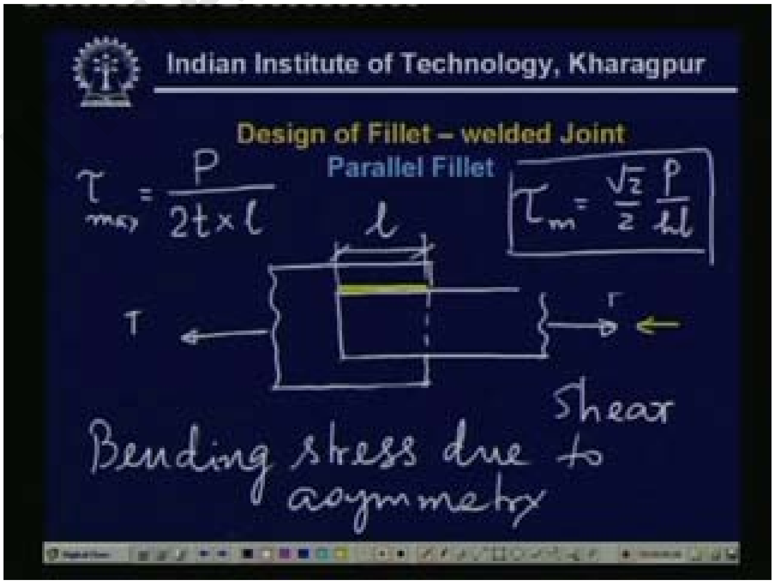

tau max is equal to root two by two P by h l

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now this is the formula which we use for designing the parallel fillet in the fillet welded joint

now what you see here the this is symmetrically placed

that is the these two mains of the weld are same in both sides

had it not been so that is if we had welded only in one place let us consider that suppose we had welded only [noise] the one place then what we get is there there will be a bending stress developed

now in this case asymmetry occurs and there will be bending stress developed

so there will be bending stress due to asymmetry [noise] and that is what we do not want because if we have bending stress then that may be very very large because the cross sectional area and the ah um rigidity the modulus {se} (00:16:12 min) sectional modulus is so small that the bending stress becomes very very large and the material may fail or the joint may fail

so therefore you want to avoid that we want the joint to be symmetric that is we do not want any bending stress to be developed in the weld joint

but suppose we have the structure that is the plate ah that is the plates which have to be joint the the if they have the asymmetric {con} (00:16:38 min) ah geometric

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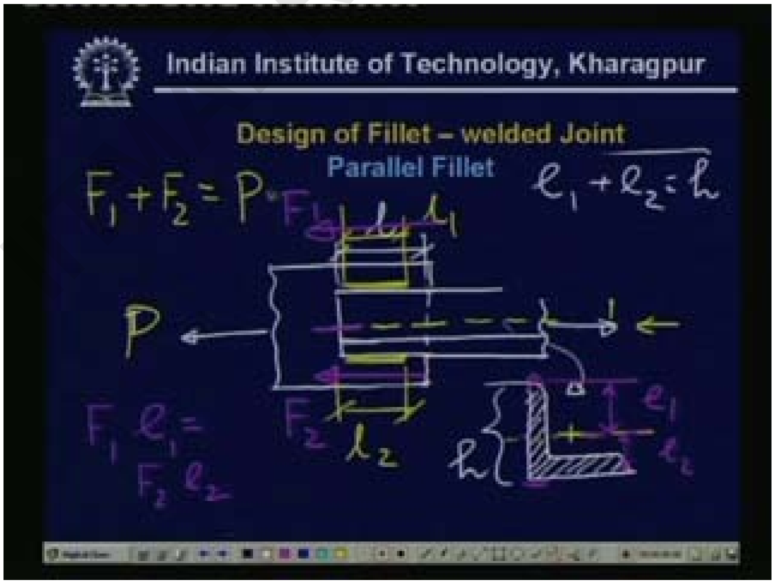

that is now we consider a case where where there may be asymmetry here

so if you look from this side the joint suppose looks like suppose we have l joint or something like that

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so this is the cross section of the plate [noise] this plate cross section is here we have the center of gravity somewhere here so this is the center of gravity

and now if you apply the similar joints in both sides again because of the asymmetry of the structure there will be bending stress developed

so we will have to make two different lengths of the weld welding now

so now we have to make [noise] so this will have length l one and this will be of l two let us say and l one and l two are not equal and this axis is the axis of the {geomet} (00:18:15 min) of this center center of gravity of this cross sections

then the the first condition is that the force taken by the weld if they are considered to be F one and F two that is F one plus F two must be equal to P which was applied there

so this was P and this was P and here we have the force taken by this weld F one and F two if you consider this distance that is welds are applied here and there

now if you consider this distance let us say this is e one ((centre)) (00:19:03) one and e two

now we want the ah the welds not to be affected by any bending stress

so now we have to select l one and l two such a way that the resultant F one and F two pass through the applications of P and normally we apply the load ah which passes through the centroid the centroid or the sectional centroid of this [noise] member

so now we have another conditions that is if you take moment about this axis it will be F one times e one will be equal to F two times e two

again we have this relationship that is e one plus e two will be equal to total height h is h

and then we see that F one and F two has have this relations that is if we now see that [noise]

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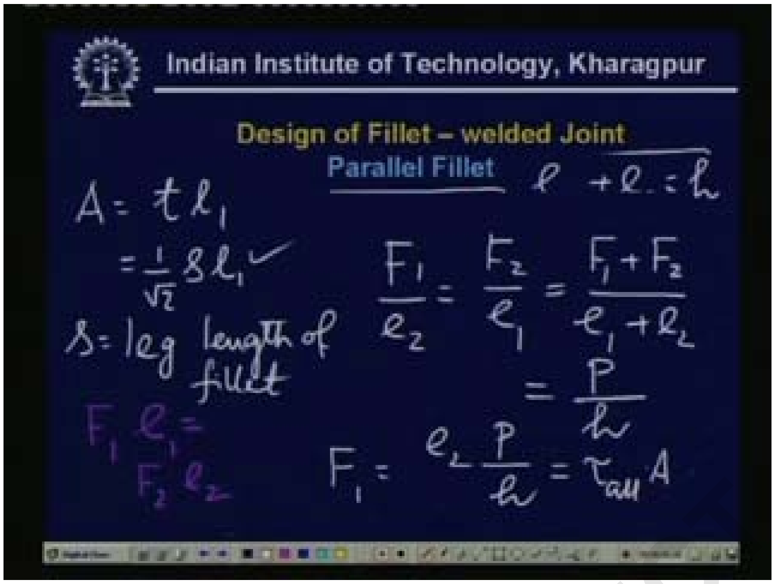

we have F one by e two is F two by e one and that is equal to F one by plus F two divided by e one plus e two

so this is equal to P divided by h

now we select F one to be e two times P by h and F one will be equal to the maximum load taken will be equal to tau allowable times root two divided by ah i'm sorry divided by the area[noise] times the area of cross section and this area of cross section is equal to [noise]

so this area will be equal to t times l one and t is if the leg length is [noise] is s then it will be equal to one upon root two s l one where s is the length the of fillet

so from this relationship we calculate the value of l one and similarly the value of l two

so this how the design is to be made

i emphasize here i stress again that the designs must be such ah so that the this welded joints do not have do not experience any bending stress

so this is very very important because bending stress is very detrimental for the joint efficiency or the it leads to the joint failure

so those this thing must be remembered very well

now this was about the parallel fillet joint

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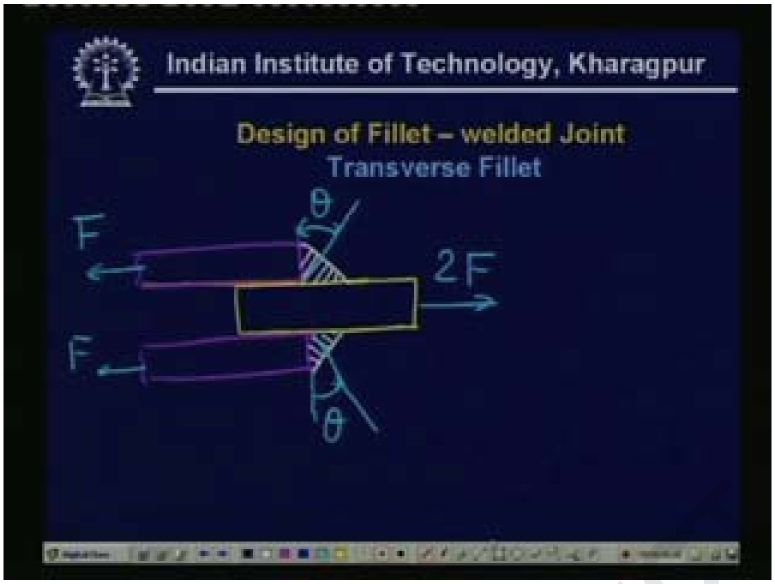

we are now going to come to the transverse fillet joint [noise]

so we are now going to transverse fillet joint which is of course it is known how does the transverse joint look like [noise] again we have similar configuration

we have let us say force P and here we have P and the [noise] transverse joint here the welding is made here [noise] now here the analysis becomes quite complicated as we'll see very soon ah

we take the example of a double transverse fillet that e that is a double fillet joint [noise] where there will be two such plates

now if you look at the cross sections it will be something like this is one plate

it is another two plates [noise] and we apply a force to F here this will be taken as F and F and the ((weldment)) (00:25:02 min) is here and there

so this is the welding [noise]

now if we have used the strength of material approach then we take a cut we want to find out the average stress at any sections

we take a cut let us say cut here two symmetric sections makes an angle theta we take the cut and draw the free body diagram

the free body diagram will look like [noise]

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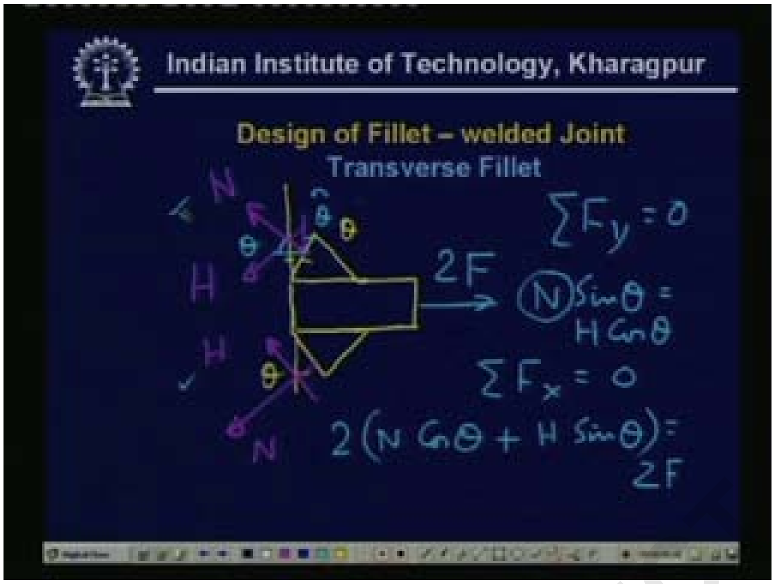

so now we draw the free body diagram this angle is theta this angle is again theta and there will be no force here and there are these other forces the normal force because of symmetric there will be the same normal force there and there'll be the horizontal that is the {par} (00:26:38 min) parallel force let us denote this by H H

now if you write down this angle then it becomes this angle

you see this angle is theta so therefore this angle becomes theta

and if you write down the equilibrium equations then it becomes the equilibrium equation becomes something like this

equating the vertical force that is balancing Fy to be zero we get N sin theta is H cosine theta

and equating the horizontal force to be zero we get N cosine theta plus H sin theta and there are two such things so therefore twice will be equal to twice F

now if you just manipulate a little bit what you get if you substitute the value of N here because we need both N and H if you substitute the value of N then what you get [noise] what you get is

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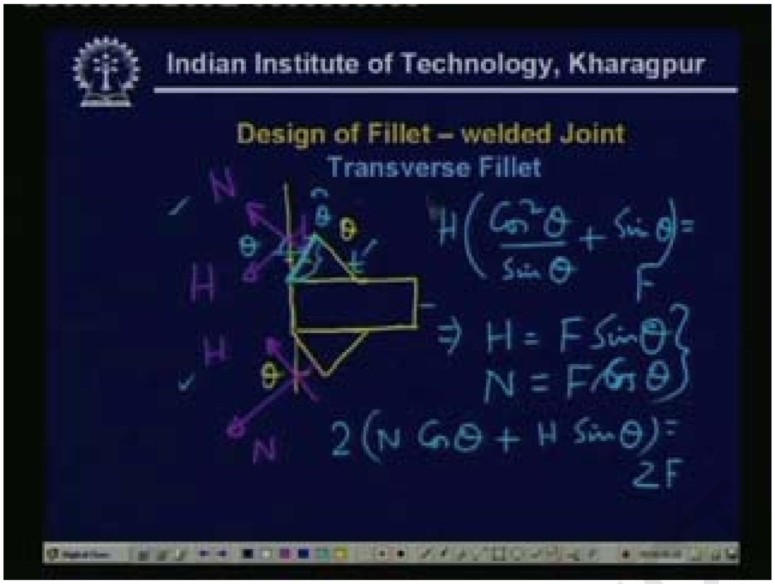

seen here that is H if you substitute the value of N which is equal to H cosine theta by sin theta so therefore cosine square theta by sin theta plus sin theta will be equal to F and that gives H is equal to F sin theta

now and N will be equal to N is given by the same formula that is N by H is equal to cosine theta by sin theta therefore N is cosine theta

so this are solved

now we have to find out the area of cross sections here the area is the length times this length that is the throat length or ah i should not say throat but the length here

let us denote this by t prime

what is that t prime

so that comes directly from the ah if you consider geometry let us consider little bit details [noise]

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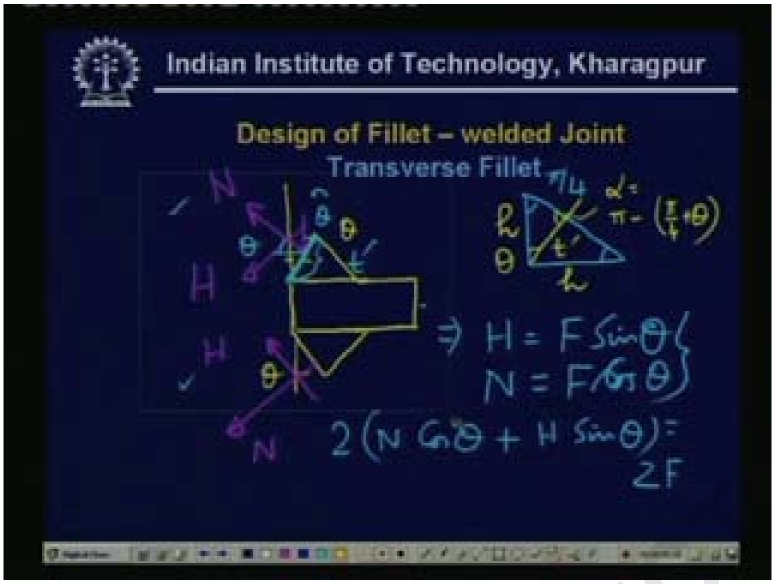

what we have there is if you consider this part that is the fillet section originally it was this angle was pi by four

now we had taken a cut at angle theta say about this angle alpha will be equal to pi minus pi by four plus theta and if you use the ah the sin law of the triangle here this height this length h this is h if this is t prime then we have the following relationship that is

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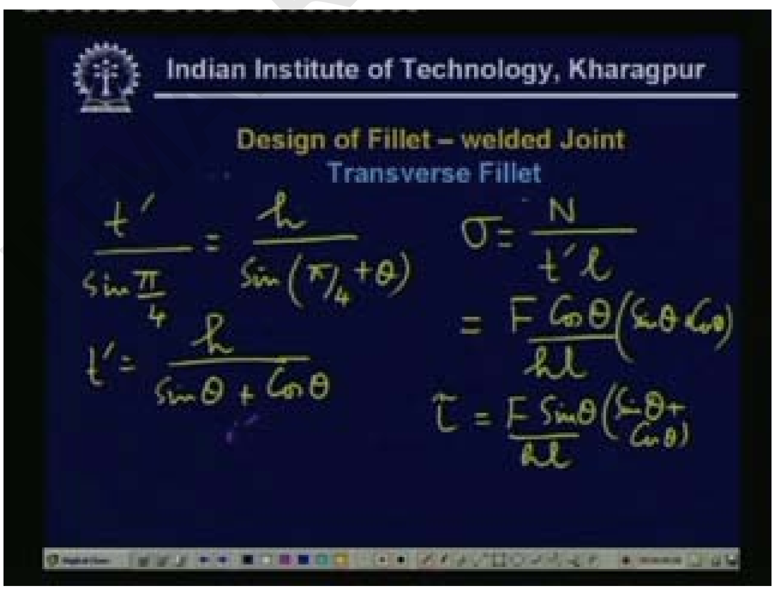

t prime by sin by pi four is h by sin pi minus pi four plus theta will be equal to pi by four plus theta

so therefore t prime will be equal to h by sin theta plus cosine theta so if you want to calculate now the maximum shear stress or normal stress across that sections then you get the following relationship

what you now get is [noise] the normal stress will be equal to N divided by the area that is t prime times l length

so this is equal to as i discussed F cosine theta times sin theta plus cos theta divided by h l

you have tau is equal to F sin theta [noise] i am sorry plus cosine theta divided by h times l [noise] i am sorry

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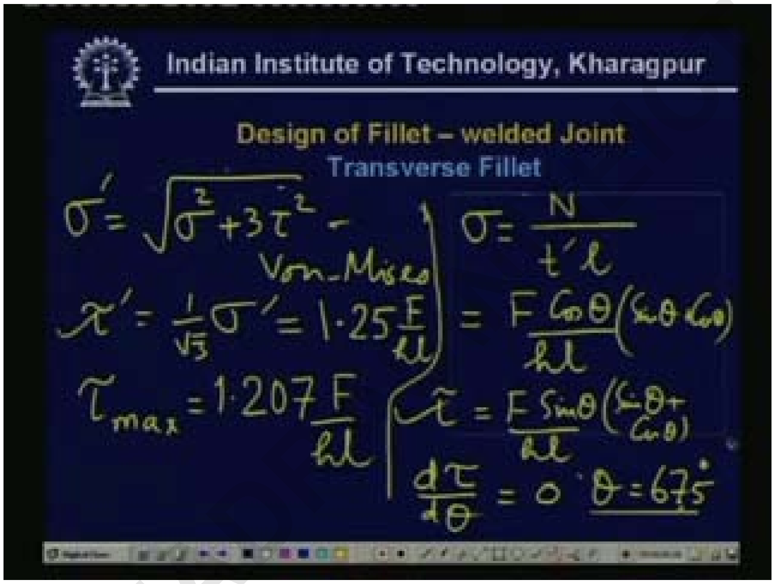

then from this relationship we can find out the Von Mises stress [noise]

the Von Mises stress will be equal to equivalent stress is square plus thrice tau square the Von Mises

we can get tau is one upon root three the equivalent shear stress in the Von Mises stress ((test)) (00:32:40 min) failure criteria we can have tau max as well

from this relationship if you know this tau here then what you get tau max first we'll have to differentiate d tau d theta and that to be zero

then gives the relationship between theta [noise]which is equal to you'll see if you carry this calculations then theta becomes sixty-seven point five degree and if you carry out this relations then tau max you get you substitute value of theta in tau here and you get the maximum value of tau to be approximately equal to one point two zero seven F by h l

this is about the tau max and if you calculate the same for the Von Mises stress that is the Von the Von Mises stress again it appears in the same angle theta equal to sixty-seven point five degree and that becomes almost equal to one point two five F by h l

so this i leave ah to you to calculate that but what is important is that having done all this stuff what we get is that is the average value but it seldom matches with the ah experimental result

experiment uh was carried out with the photo elastic apparatus photo elastic experiment was done and it was found that it is very very difficult to find out any match that is um there is practically no match between the strength of material approach and the reality

so after some discussions and many research it was arrived that if we consider for the design purpose if you consider the same ah thumb rule that the the maximum chance of failure is near the throat then the following ah following relationship could be obtained which is

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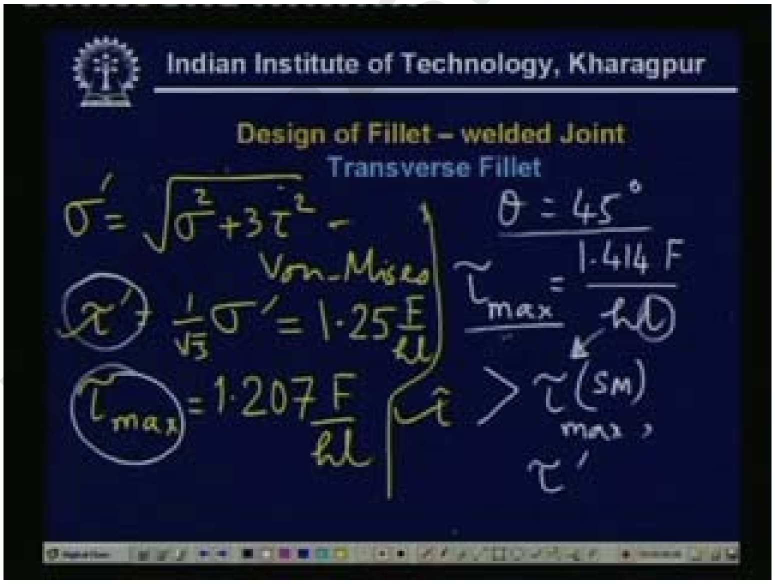

now here we consider that ah the maximum failure chance is at theta equal to forty-five degree instead of sixty-seven point five degree

but if we {con} (00:35:12 min) if we neglect the normal force normal force on the on that particular sections then what we get get tau max is one point four one four this is square root of two F divided by h times l remember h is the length of l is the length the joint and h is the leg height of the fillet weld

now you'll see that although this is a thumb rule and here the assumption is that the stress is uniform over the cross section making an angle theta equal to forty-five degree

and we have neglected if we neglect the the normal force on that particular sections then we get tau max equal to this value and this is of course greater than the tau max obtained here from the strength of material approach

so this is tau max with strength of material approach or may be it is greater than even tau prime which is the corresponding shear stress in the Von Mises failure criteria

so this is very very conservative result we which we have for this transverse fillet

now this is normally used in practice okay

now here ah although this is this is um a almost a thumb rule this is no way ah an accurate theoretical result but of course it is very very useful and this is the unified formula which is it is called the unified formula

so let me write down this formula again which will be the basis of calculations for the strength of welded joint for a transverse fillet weld

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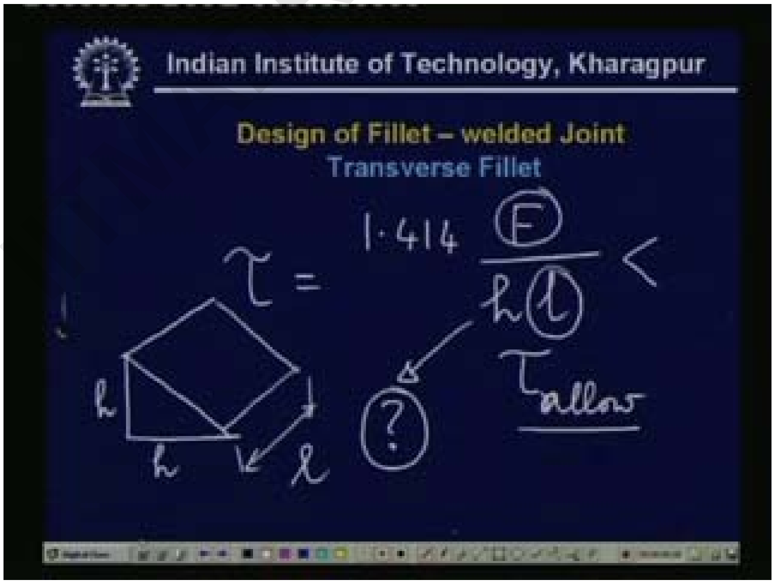

so we have this unified formula that is tau equal to one point four one four times F divided by h times l where h is the length and l is the total length of this weld now this formula will be used and this will be lesser than tau allowable

so now what are the design criteria design data [noise]we want to have this joint which can which is which should carry the load F ((with no)) (00:37:53 min) tau allowable

we decide some value of l and then we design the joint for particular edge

so this is the design parameter which we get from this following calculations all right

so this is about the design of fillet welded joint for the transverse fillet [noise]

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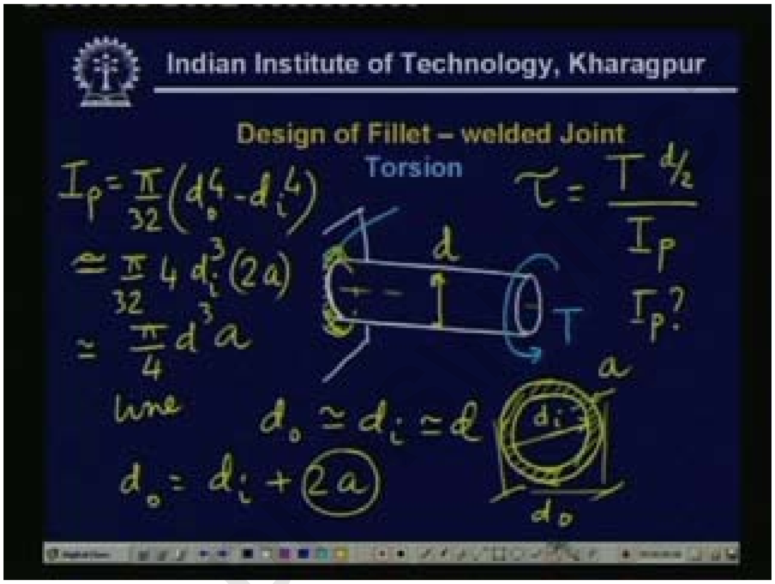

our next discussion is the design of fillet welded joint for torsional torsional ah joint

that is here we consider this is roughly the and the weldment is given here so here is the weld and the torque is applied here

we want to design this welding welded joint

so what will be ah the dimensions of this weld this particular portion

now if you look closely into this joint what you see here is the following

if we look there [noise] but again we consider the most vulnerable area and this is definitely this portion

so therefore the torque the shear stress will be maximum over this surface then how to calculate the polar movement you remember the formula that is t it is shear stress due to torsion will be equal to t times c if you consider the diameter to be d then d by two divided by Ip

now what will be the polar movement

now we want to find out this Ip now Ip could be find found out if you make some assumptions and the assumption is that because compared to the diameter of this of this member the thickness or the width of the weld welded joints this weld welding is very very small

so therefore if you consider the welding to be a line now you consider this entire welding to be a line element

that is the thickness is so small that we consider it to have almost no width at all

that is now we have if you look the cross section then here the circle [noise]

now if you consider this inner diameter d i and outer diameter d o and if you consider this to be very very small then d i

if if the thickness is let us say a then d o will be equal to d i plus twice a

now if you calculate the polar movement then the polar movement becomes Ip will be equal to pi by thirty-two times d o four [noise] minus d i four

and this if you consider a to be very very small then this is approximately equal to pi by thirty-two four times d let us say i q[noise] times twice a

so that is approximately {mately} (00:43:09 min) equal to pi by four d now d i if this is very very small then d o is almost equal to d i is almost is called a average diameter

so this is d q times a

so this is now the polar movement for this thin strip

now normally what is given in the table is the polar movement for per line

so now we take a to be unity

so what we get in the handbook is that we take Ip to be sometimes we call Jp

now here if you consider the this cross section then what is now your a is nothing but the throat length that is a is t if you use the same connotations

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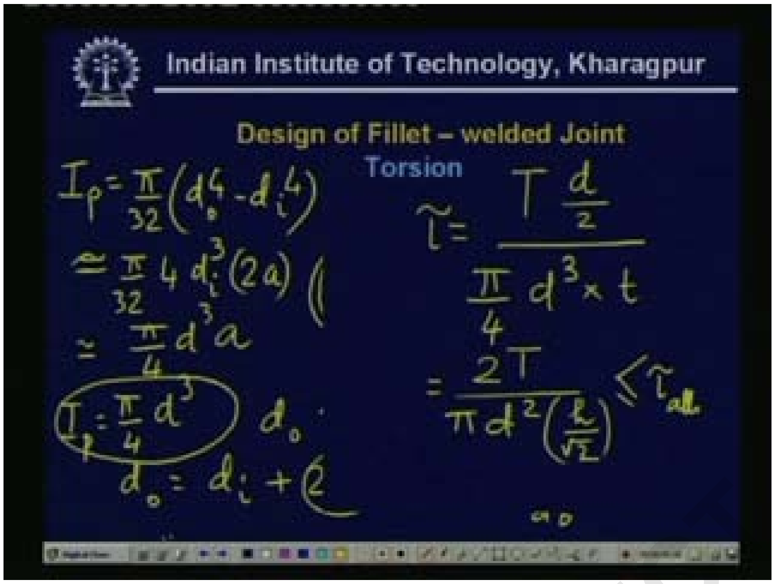

now we know the shear stress due to torsions which is equal to[noise] tau will be equal to T times d by two divided by pi by four d cube times t and if you use the same notations then this will be equal to T

so this is twice T by pi d square times

this is equal to h by root two and this is the shear stress due to torsion and that must be less than equal to t allowable [noise]

so we know how to design the fillet weld for a torsional member

for many other cases ah you can find out the the polar movements for a thin strip and then use the similar formula

here again the assumption is that the stress will be or the failure will be governed or failure will be ah most probable in the throat area

so here in the throat is that place where the stress gets maximum values and we design from the throat according to the throat cross sectional area

now this is about the fillet welded joint for torsions

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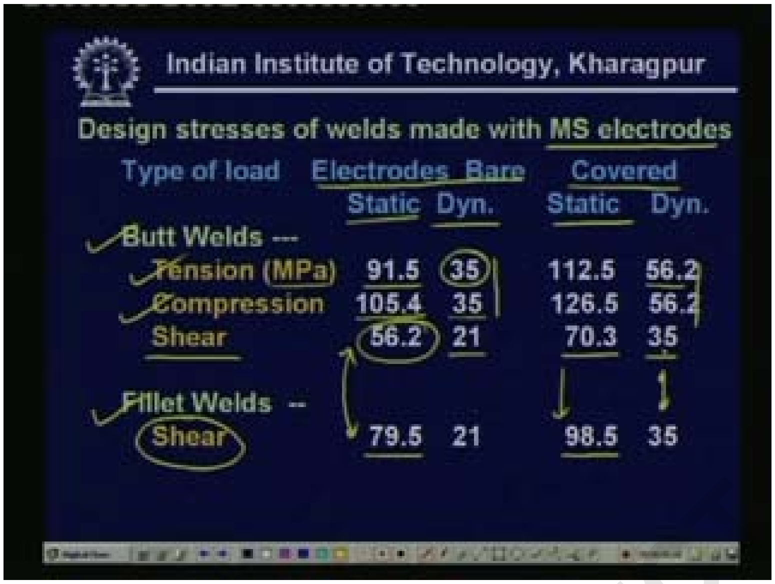

let us look at at the design stresses of weld made with mild steel electrode

now here the strength because of analysis is very {diffi} (00:46:36 min) difficult for welded joint

so we make lot of {experi} (00:46:39 min) experiments and with the help of those experiments we measure the strength of welded joints

now again the experiment in reality it will depend on not only the properties of the the base metal but also the properties of the weld metal

and it is the electrode which also affects what type of electrode there may be bare electrode or may be covered electrode

now if you have a bare electrode then the chance that chance exists ah that there may be some contamination of ah oxygen which may leads to embrittlement [noise] if it is covered then this chance is less

so that is ah reflected here you see if you consider a butt weld then the tension value here is ninety-one point five everything is mega Pascal but the dynamic stress

now here we ah know that because of the fluctuating stress the failure probability is more

so when we have the dynamic load then we'll have to make the allowable the allowable stress quite low

so that is taken care of by the fatigue ah stress concentration factor as well

so if it um if it design not to break then we'll have to have this ah endurance limit which is sufficiently low compared to that of the static loading now in tension we have ninety-one point five but in dynamic loading it is thirty-five

if it is covered then for the static loading it is one hundred twelve point five and for the dynamic loading it is fifty-six point two

for the compression this is naturally quite large and is larger compared to the tension this is one hundred five point four and for the compression it is again thirty-five similar value

now here it is observed that for both compression and tension if the loading is dynamic then of course it makes no sense to talk of uh tension and compression if the loading is completely reversing because ah half the in half the cycle it will be in tension half the cycle it will be in compression

so they are equal in both cases

for the shear again it is sufficiently low and for the dynamic stress this is twenty-one for the covered electrode static stress it is seventy point three and for the dynamic load it is thirty-five

for the fillet weld normally we take only the shear because fillet welds as i have discussed in the last ah two or three design criteria that we take the shear stress of the fillet into account and shear stress is for the static loading seventy-nine point five which you see it is large compared to that of the butt weld

but the dynamic stress is almost the same for the covered electrode this is ninety-eight point five again you'll see it is higher value then that of the butt weld but the dynamic stress is the same

so these are the roughly the design ah the design stresses of welds

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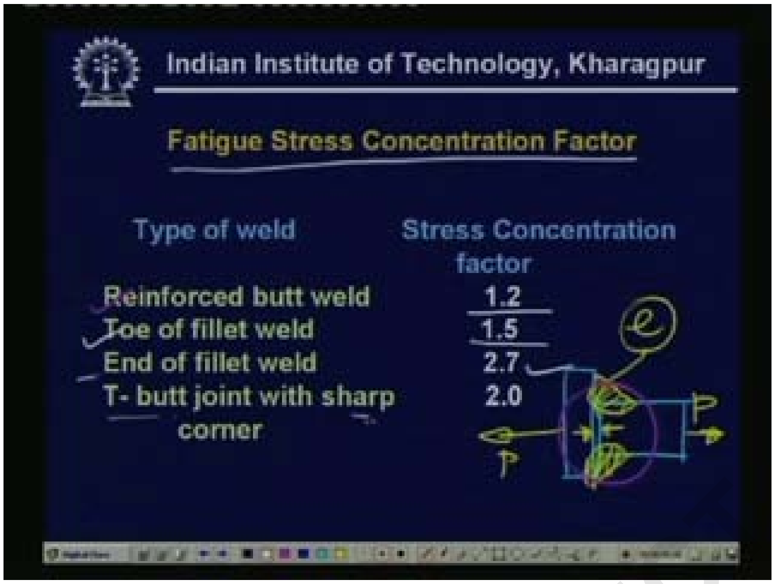

now we come to the fatigue stress concentration factor

now there may be stress concentrations you see if you consider the butt weld the weld[noise] and if you have a weld here

so there may be a stress concentration because of that abrupt change in geometry you see here the thickness is quite large compared to that

so therefore if you consider the force P here the stress distribution will be somewhat like this

the stress concentration factor because of the abrupt change therefore it is advisable to machine this off we normally do not leave this as it is one good practice will be to grind it

so this is how we make this joint

now these are the this is one such case the stress concentration occurs there may be stress concentrations due to various other reason

suppose there is incomplete fillet if you consider this case that is suppose we have this fillet here

now you see when we want to make two fillets here then definitely there will be a gap that is that cannot be avoided because of the some error so this gap e which is nothing but which is nothing but a crack if you consider the loading

that is if you consider the real joint then this is nothing but the crack

so therefore stress concentration will exit over here

so there is large stress concentration over here so these are the there are various other possibilities of stress concentrations

now what you see here the typical a figures showing the fatigue stress concentration factor

stress concentration is not that important of the static loading but for fatigue loading for the dynamic loading it is quite important

for the reinforce butt weld it is one point two

for the toe of fillet weld is one point five end of fillet weld two point seven and T joint T-butt joint with sharp corners definitely we want to avoid the sharp corner and it has a uh {fac} (00:53:03) stress concentration factor two

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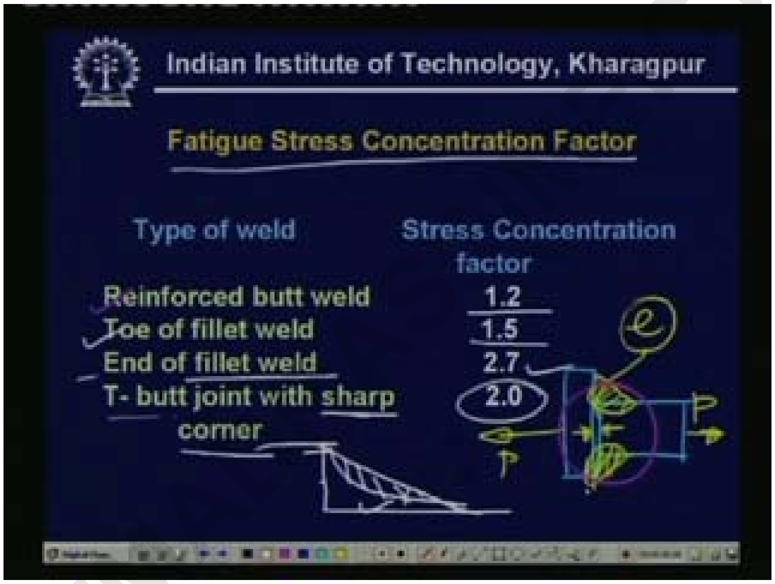

now there are various techniques to avoid the stress concentration factor

one is to make the leg size that is the uh the weld that is fillet weld apparently unsymmetric if you make this leg this length much larger this length much larger than that then definitely there is a gradual variation of geometric change in geometry therefore the stress concentrations may be more

then another technique is to make this contour concave and that also reduces the stress concentrations

so there are various techniques of stress concentrations removal

now let us come to the conclusions

what we have learnt we have learnt the different ah kinds of welded joints and how to design them

now designing is very difficult and we use the thumb rule that uh it is only at the throat where the stress {concent} (00:53:55) stress is maximum and we designed the welding from the or considering only the throat cross sectional area

so there are various ah literature available if you read ah if you have a chance to look at some of the text books you will find many such design ah um problems given you solve them

okay

so this is ah as for as the welding joint is concerned

and i end here today

thank you very much

Preview of next lecture

Lecture No-25

Design of Joints With Eccentric Loading

this is lecture number twenty five and the topic is design of joints with eccentric loading

now in last few lectures we have learnt many facts many ways how to design a joint

now this joints are of two types non permanent types and permanent types

for non permanent types we had the examples bolts nuts assembly and for permanent types we had ah riveted joints or welded joints

now in all types of joints we have studied so far we have used the load which passes that directly to the center of the gravity of the joint

now ah in many cases it happens that the load as some eccentricity from the center of the gravity or the center of the joint

now what happens then this is very very important because lots of structures have this kind of loading namely for example ah um the tower crane ah which has loading definitely eccentric

so in those cases the eccentric loading of the joint is very important and hence we'll have to concentrate on the designing of such joints when we have eccentric loading

so in this lecture we are going to study how to design a joint which has eccentric loading

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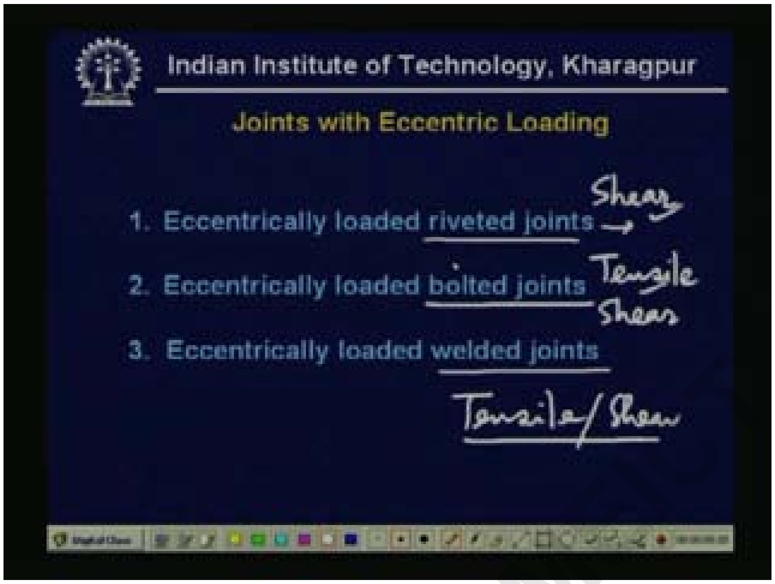

let us come to the joints which we have studied so far

and here in this lecture we are going to study how to design a joint when ah the joint is a riveted joint you all remember what is a riveted joint

and it is permanent type joint the ah the most of the applications where riveted joints are used the load passes load is applied such a way that this riveted joint acts primarily on that shear

so this is the primary force primary loading which is ah applied to the riveted joints

sometimes it can take some tensile load but normally we have ah the shear ah shear loading

similarly the bolted joints will normally take the tensile load primarily tensile and welded joints could be tensile or shear load

now [noise](00:56:50 min) here in this lecture we are going to study the eccentrically loaded riveted joints first then how to design eccentrically loaded bolted joints and last eccentrically loaded welded joints

so now come to the design of eccentrically loaded riveted joints

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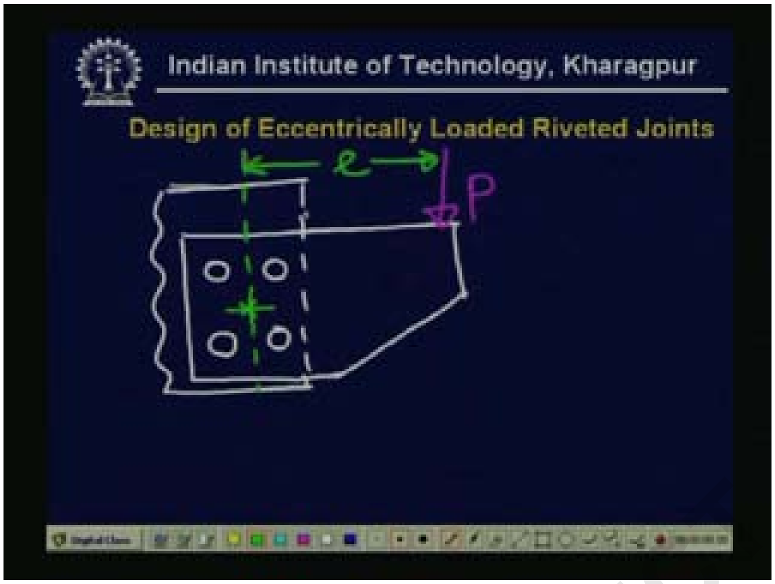

now let us consider a riveted joint let us take this as the structure[noise] and we have a riveted joint[noise] so let us take this as the joint

and then [noise](00:57:39 min) there are few rivets take for example there are four rivets these are four rivets and we have a load which is passing by here

so the eccentricity will be measured from the centroid of these four rivets and that is given by this distance

so this is the centroid and this is e the eccentricity of the loading

now you see what happens due to this

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