Design of Machine Elements – I

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Lecture No - 28

Design of springs

we continue our lecture on design of springs and this is the lecture number twenty-eight you recall it that in the last class we discussed about the basic equations of a helical spring and derives are in important relationships and then we ah started talking about the design of springs under variable load just a very quick we visit to what we have done in the last class was something like this

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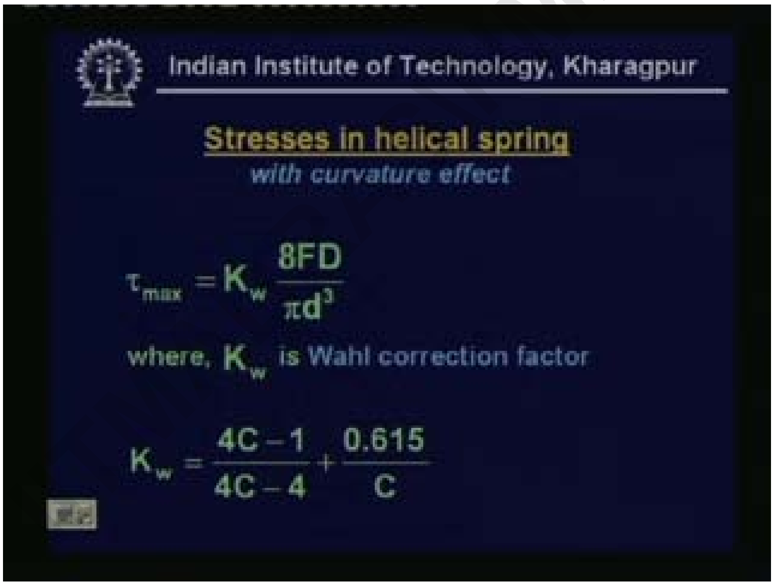

we found out the basically equation of stress which came out to be of this nature KW eight FD by pi d cube

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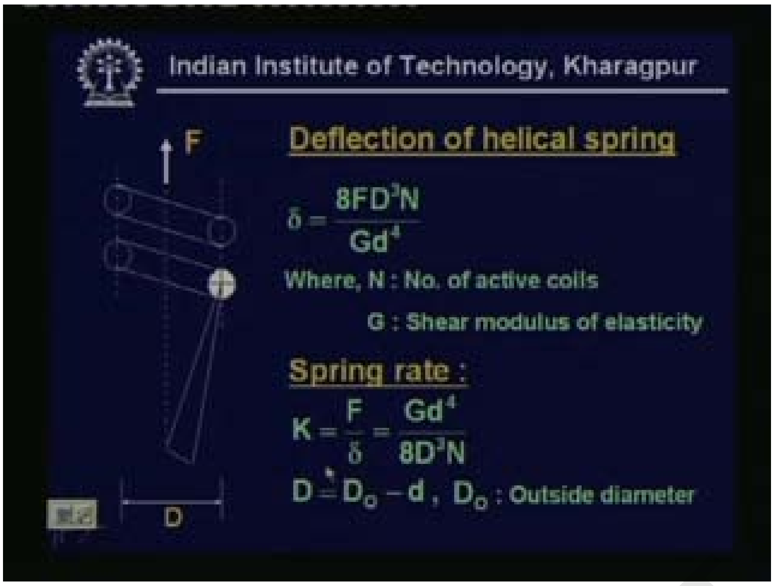

then we came down to find out the deflection of the spring and one thing we ah did not mention in the last class that is a very important spring parameter is called a spring rate which is defined as KF by delta and this delta is what we have obtained

so obviously the expression comes out to be Gd to the power four eight D cube N where D as you remember is the coil diameter

now here when we say coil diameter then please note that this coil diameter normally we will be referring to as mean coil diameter

what it means

it means from the if you look to this diagram from this extreme centre of the spring rate to the other ah the centre of the spring wire

so these distance is a mean coil diameter where we'll be referring to as D and that also referred in the last class also as D

so what is the relationship between the outside diameter so obviously very simple relation the mean coil diameter is nothing but D zero minus d where D zero stands for outside diameter

now this spring rate sometimes also is called as spring constant

so this was the basic equations what we have learnt and then we would

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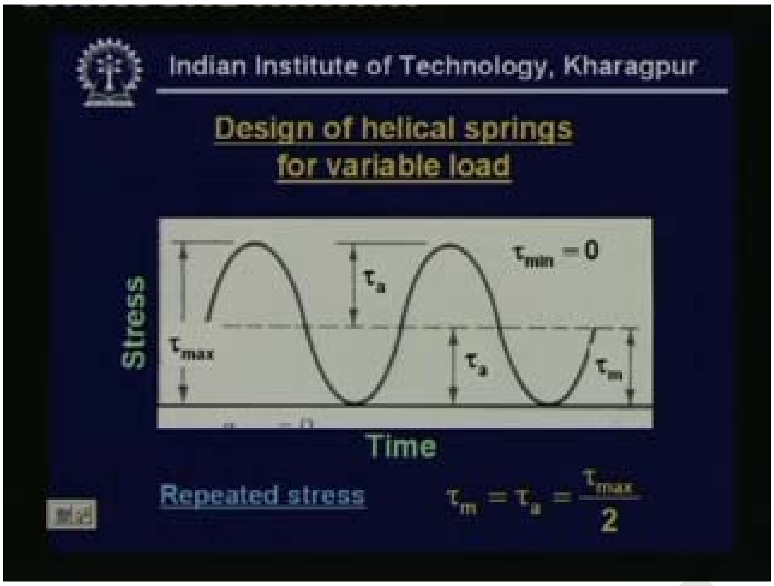

like to start with today's lecture whose preamble i have already given in last class that whenever there is a variable load onto the spring then how do we design in those cases

the first of all what we would like to know is that normally in case of the spring what happens that either it be a compression string or be a tensile spring or sometimes it is called an extension spring

see the force is always of one kind what i mean by one kind say it is an compressive then at the most what we can say onto a spring

this is a spring suppose ah suppose it is just in a position of holding a spring between two plates and we give some loading which goes to the maximum when it comes back means when it comes back to this zone

then it will be well it will be what sometimes like zero but not always but what i mean to say that if it is an compressive nature it will never go to a tensile in nature it will be always remain compressive

similarly if you consider an extension spring it will go to a some amount of extension and come back to a lesser amount of extension but it will never go to a compression zone

so looking into this fact normally what happens the spring materials are sometimes being tested what we discussed in the last class once again i repeat that it is tested under a torsion of what type

a torsion of repeated stress type means it goes to a maximum value comes down to zero it go so that always we are always having if we look into this board then you can see that it is coming to the maximum again going to the zero and it is like this particular phenomena is going out

so this is what precisely i would like to say is this is for the testing of the material

now ah that also describes that one thing that you can have any spring loading suppose a compressive spring loading if we consider ah then you can have something like that it need not go to zero always okay that means in this case as we have been referring to an positive
so it will be an tensile type of spring where we go for maximum tensile again we may release certain amount of tensile
so that means the space is released but it will never go to the other side this will never happen that is what we would like to say
so that is a reason what is happening that we will have a simple some changes in the variable load design for the springs in contrast what we have learnt in our earlier classes about the variable load design for general machine elements
where we have seen that we faced in in certain cases a complete reversal of cycle ah it was any general fluctuating stress or a repeated trip stress of the kind what has been shown over here
now here you can see that all these designations are all these things are designated as shear type
so what is this one this is a tau max and it comes out to be zero again i am repeating that if this is for what for the material test normally but the spring can have any sort of loading but of one kind that is a very important thing to talk about
so what we have the mean stress and the what we remember this one we called as stress amplitude so this tau a tau m remains to be the same thing as tau max by two
so if it is a material testing suppose then this tau max by two well just this tau max by two this one what we are getting can be retained something as see if it is an endurance limit then we go by tau e by two something like that
tau e by two also can come into picture [Vocalized-Noise] that means a maximum one we are going for a twist and then coming back to zero
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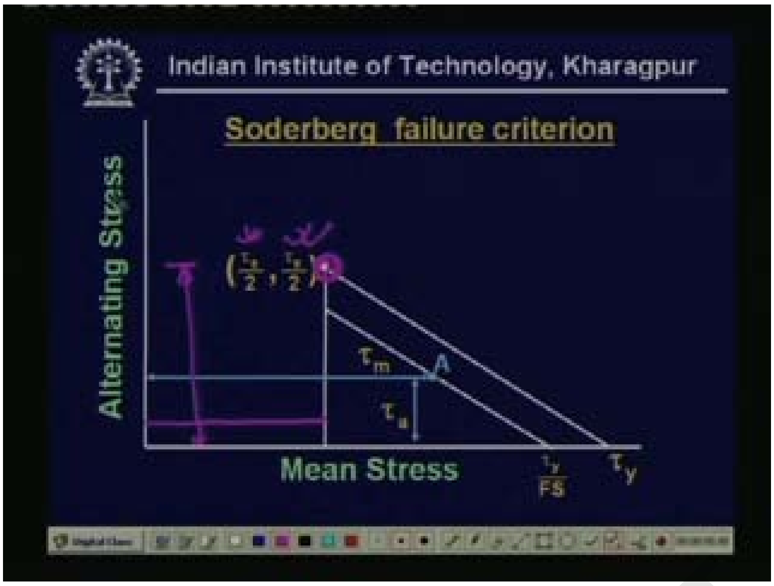

so looking into the fact what we find out in this particular case is the same Soderberg failure criterion ((bus)) (00:08:42) but what you can look over here that instead of the line starting over here what we have seen earlier we are we can find out the there is an the initial line is having a coordinate of tau e by two tau e by two

you remember in the case of Soderberg failure criteria when we did in the earlier case what we took about the material property

the material property was normally evaluated through the fatigue test undergoing a cyclic reversal okay

so in that case the cyclic reversal means what will be the value of the mean stress

the mean stress will be zero and a stress amplitude will have the value of sigma endurance and here what is happening as because we are having an repeated stress as just we have seen earlier so we'll be having the shift of the point like that we'll be having an mean stress of tau yield point by two and again we are having this situation just we are having the situation that is this is the mean stress for the material property which is shifted by this point

so this is the mean stress mean stress of these both are tau e by two tau e by two so this represent the mean stress and this represents a stress amplitude so this is a material property so once we go for that one then what we see okay

the rest of the Soderberg diagram is just shifted over here

so these as usual you can see we are having the tau yield point

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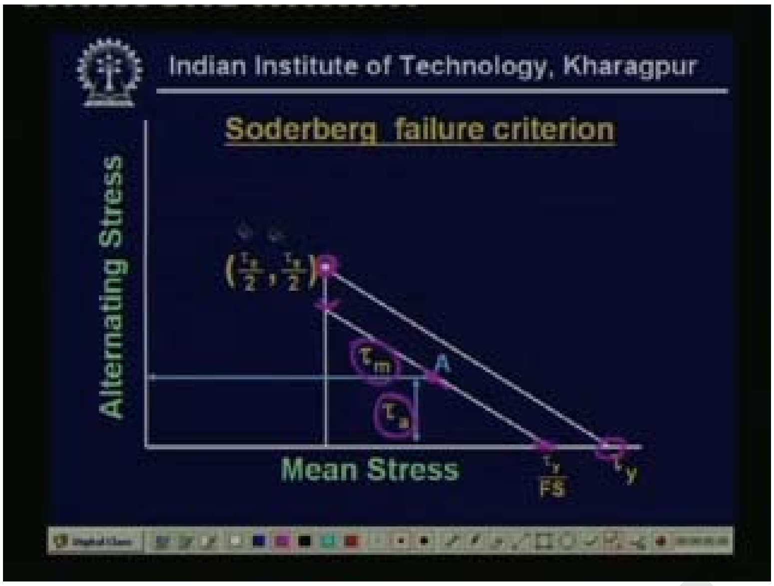

this is the stress amplitude part or the endurance limit but remember it is all for the shear values

now if we choose a typical factor of safety then obviously the line shifts as it is being shown over here and then what we get we get this line is a safe stress line

so any data point or the any failure any point falling onto this line beyond this one is safe and beyond this type we'll be considering to be not safe

so let us {con} (00:11:34) consider a typical design point over here as shown as A so what is a coordinate of A

the coordinate of A is nothing but the tau m

what is this tau m stands for the mean shear stress that is acting onto the spring and this is the stress amplitude what it is being acting onto the spring

so under this situation it is a very simple thing that we can think of a relationship as usual what we have done for earlier case

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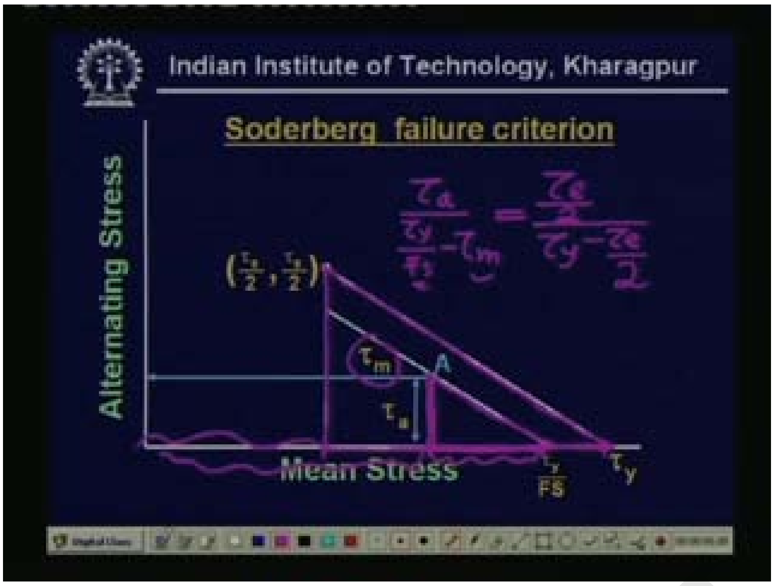

so look carefully that we'll be selecting this triangle okay and another one if we select this triangle then what we see these two triangles are similar triangles from the basic geometry

so if this is so so then what we can find out then we can find out a relationship

that is this is what this one is tau A means tau stress amplitude divided by this one so what we can write down is something like this this tau a divided by this side

so how much is this distance

this distance we can see is tau yield point by Fs minus these zone so what is this zone this is nothing but tau m so using the similar triangle property what we do what we find out from these triangles

similarly this value is tau eight point by two divided by how much this distance okay so what is this distance

this distance is tau yield point minus again this distance so this is tau eight point by two so this becomes your simple relationship between the stress amplitude mean stress material property like shear yield point and shear endurance limit value and of course the factor of safety

so if we arrange these equations in a proper manner then what we get we get something like this that means this was the original figure

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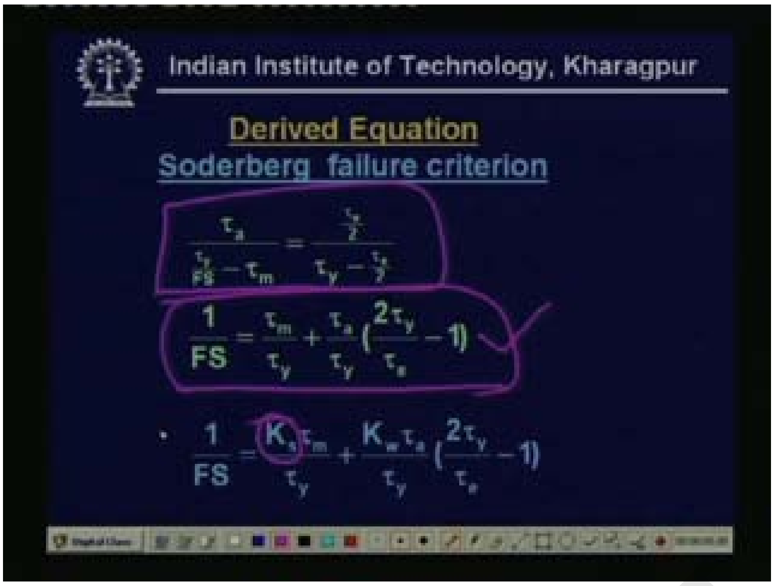

so if we consider this one you can see the same expression what we have just written comes out be like

this so this is the one we got so if you arrange then we get an equation of this nature and we can rewrite this equation in various forms and we will be also finding in several other literatures this same expression may be retained in an different way but the basic understanding remains the same

now you understand that the same equation has been modified by one factor Ks what is this factor do you remember

this factor is shear correction factor what we learnt last time and this is the wall correction factor which takes into account of what curvature and the shear together

now you can see that it is customary that the mean stress of the stress tau m is being multiplied by the factor Ks where as this stress amplitude tau a is being multiplied by the wall correction factor Kw

so what we get we get a relationship something like this that one by Fs equals to Ks into tau m by tau y Kw tau a tau y into two tau y tau e minus one

so we consider the expression what has been shown here as the form of the equation what we get for the Soderberg failure criteria for variable loading

so now you understand that this particular expression will be utilizing for designing of the springs when it is undergoing a variable load or a fluctuating load whichever you may call it just look into one aspect next is that

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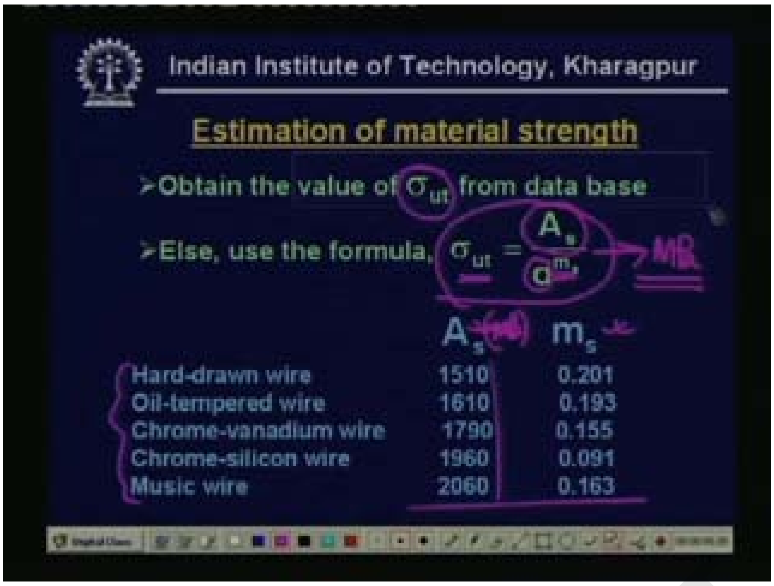

well this is what you can see is the estimation of material strength

now this is a very important aspect what is being done in design of the this particular spring is that

whether you go for a design under static condition or a design under a variable load situation you have to have the knowledge of the shear yield point property or in case of this particular variable load design you have to know also the endurance limit for shear

now what it has been seen that ah most of the materials are being tested for tensile strengths that is a very simple type of experiment and we get a quick data and regarding this we had already discussed earlier

so what is the thing what i would like to point out is that mostly we have the data for the material for the tensile strength

so from those data we can find out what are the situations or the strengths coming due to the tensile test that is mainly the yield point in tension and the ultimate point in tension test

however as you can see that we require the shear values of the corresponding strengths in tensile ah one has to undergo on or undertake an experiment to find out the actual data or to find out from various experimental data collect it together to get an knowledge of what should be the values from the ultimate strength values to the yield point value i mean shear point values

so first and foremost thing is that one has to find out the value of what we consider is this particular one what is the value of sigma ultimate

now the best way of finding out the sigma ultimate is this thing that you find out from the data base

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what is data base means standard design hand books and other sources where use experimental data for the {sese} (00:21:00) simple tensile tests are available from which you get the values of sigma ultimate and then you try to find out the values of the shear corresponding shear values

now in case of the spring design it has been observed that this sigma ultimate values are quite sometimes dependent on the wire diameter of the spring

hence from the experimental results sometimes ah formula of the type what has been debited over here is being used

what is this particular formula

you can see that sigma ultimate equals to a constant A divided by wire diameter to the power another experiment

now for some selected materials which are commonly used for the spring design the values of As and ms are given over here

so we can see that these values one five one zero one six one zero etcetera and this is the diameter to the power this particular value will give you a stress in ampere okay

this values will give you a stress in ampere that means this particular one should be in MPa

ah and then you you get the corresponding values of the Ams ah well that means let me write it little clearly that means

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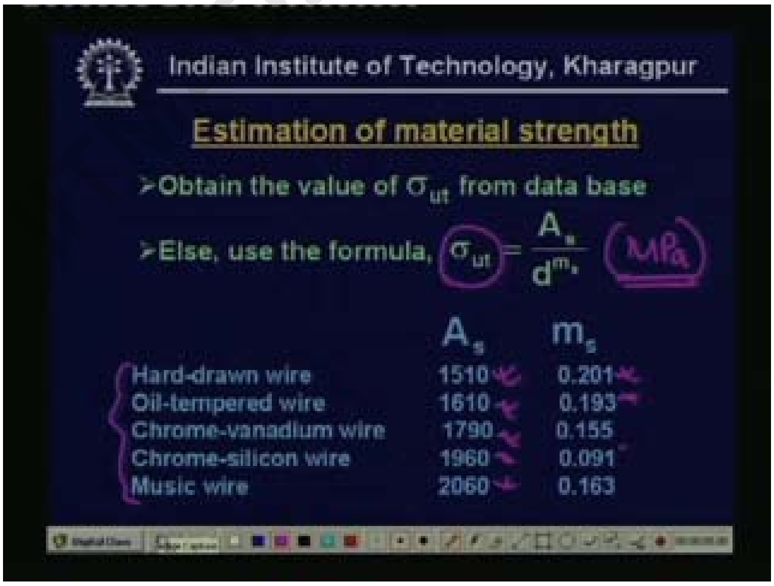

what you get that this using these constant what we have given over here and corresponding exponents this sigma ultimate will have a unit of ampere now in this case what one can do is that utilize this expression to find out the value of sigma ultimate or else as we have told that you get from some data base source and take the value of the sigma ultimate

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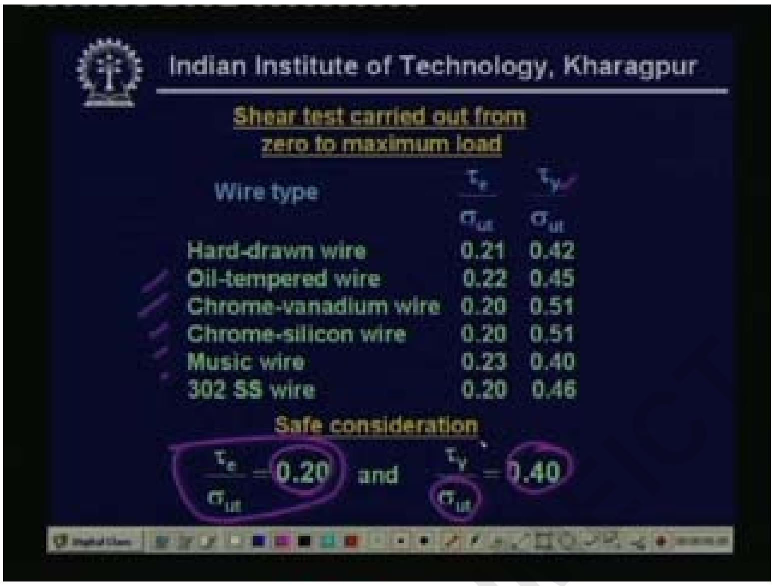

now here comes another relationship that for all these materials for which for all those materials for which you have found out these values of sigma ultimate this for all these values what we have got for the sigma ultimate

it can be equivalently utilizing these factors we can obtain either the endurance limit value or we can get the yield point value

please note that for all these cases the shear stress carried out from zero to maximum load means that repeated stress experiments have been carried out and from which the values of yield point has been derived and this from the experimental fact such table can be prepared and one such example has been given over here which shows you can see onto this board that this shows that if we consider such relationship then what you get that tau yield point by tau ultimate is point two one for hard drawn

for oil tempered wire it is point two two chrome

vanadium point two zero chrome silicon point two zero

music wire point two three and the three zero three stainless steel wire it is point two zero

and the correspondingly if you want to find out the yield point value then what you get

these are the ah constants point four two point four five point five one etcetera etcetera

now you can see these list is not an exhausted one for other materials what you have to find out you have to find out in the similar manner the values of the yield point and the endurance limit values okay when you very well going for the design for the variable load

now ah this comes out to be a very important fact in the design that the choice of the material strength or how to determine the material strength

as you know the best will always ah would be to have a real test carried out and in case it is not possible then one has to resource to this type of data base and get the corresponding values

now the extensive data base is beyond the scope of this lecture one can {ja} (00:26:47) just go through the reference hand books on this particular matter and get those values

well ah as a very rough estimation or ah you know ah just an first hand ah consideration here we have tried to give you a safe considerations

just looking at this particular data or the this constant one can very well say that the tau endurance means tau e by sigma ultimate is simply point two and tau yield point by sigma ultimate is simply point four

may be this is safe means this is a very conservative design but any way one can just roughly one can use this values to have an design approximations

so we have gone through this one we have gone through this one well

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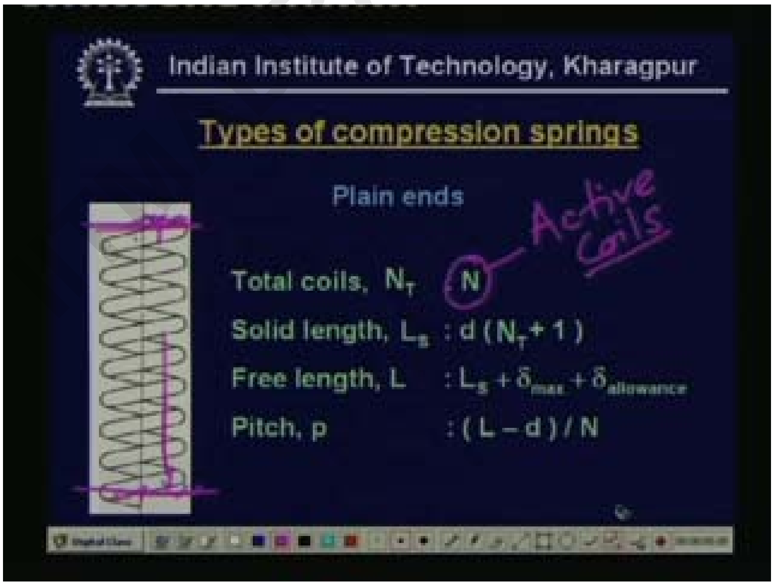

next comes the types of compression springs those are normally used

we know that two types of compressions two types of springs are normally used one is an compression spring one is an extension spring so when we talk about the compression spring normally we'll be having two kinds ah four kinds of compression springs one is the plain {lane} (00:28:28) plain end and other one if you can see is the plain and ground end

then square and closed ends and then squared and ground ends

each has got its own{mer} (00:28:46) ah own merits and demerits but let us go for that what we mean by all this nomenclatures what has been shown in this board

now total coils will be the number of coils what you can find over here

now then why especially the total coil code has been used

sometimes what happens that some that we will be seeing just after sometime that just for a better sittings sometimes you grind off this portion grind off this portion and you get a total coil of this nature

so once you get this one then you can see over the length although there are some other coils present over here but those are not counted

so in other words what you mean to say is that only those coils which are really taking up the spring actions are called the N and this is termed as active coils

so active coils are those coils which are taking part in the particular spring stress or spring nomenclature when we are defining means these are the mainly responsible for springing actions and other coils may be present but due to certain amount of manufacturing just like that grounding and etcetera

these will not contribute to the total spring in actions

so we understand that there will be one term called active coils and wherever you find this particular one is written as N then you understand this is always the active coil

so we understand that this one total coil so in case of plain end as because there is no other manufacturing {conse} (00:31:06) considerations the total coil is simply the same as number of active coils

what is solid length

solid length is that length means

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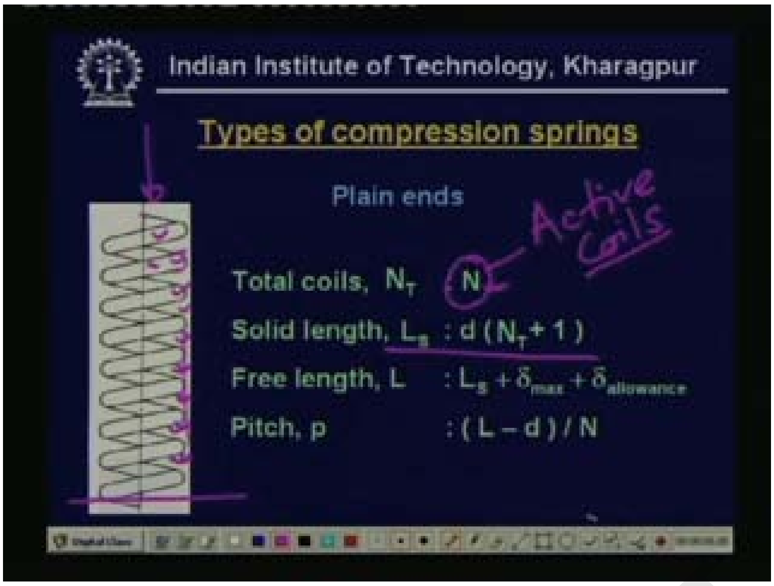

if you just take up the spring and put a load over here and press it in such a way that all these gaps are disappearing means entire this coil this coil this coil clashing with each other and makes a solid body

so that is what we call as a solid length so in this case the relationship between the solid length and the total number of turn is given over here for this typical plain end that solid length is equals to d is a spring where diameter into Nt plus one

so that is it is understandable so these are the number of coils which is having d so d into Nt and plus one as i told you to take care of the other coils which may or may not be actively taking part although we can see it is taking actively part all the end calls but still for the this parts all together add up to another value one so we get this solid length as as it is given over here

what is free length

the figure over here what is being debited is purely the free length

this is the free length means you just keep the spring as it is then the length it will show up is the free length

so what is free length

this is the solid length

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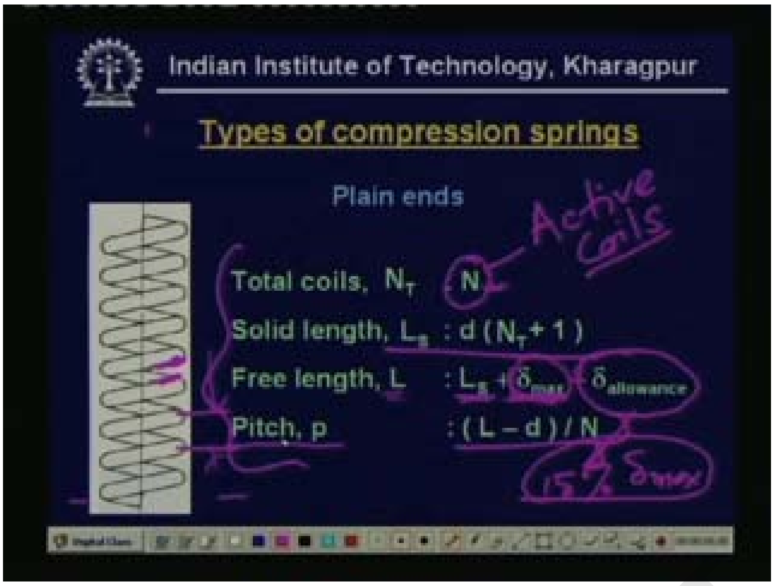

and this is the solid length plus delta max what is delta max
it's a maximum amount of compression it can have is a delta max and that means that delta max plus solid length will give you the free length but any way always people consider certain amount of more length called allowance
what is this allowance meant for so that in design we'll be considering this delta max if this delta max is to the fullest extent then what will happen
this coil and this phase of the coil will clash with each other so that means there could be some amount of wire taking place due to this clash of the wires
to avoid that what you understand that means you give certain amount of clearance so ah this particular d allowance is meant for that and this is normally fifteen percent of delta max
but any way there is no such definite situation that can guide us that what should be the allowance but i am giving you a just an guideline that fifteen percent of the allowance ah fifteen percent of the delta max is the allowance
so this is what we get and then you come down once again to the pitch so what is this pitch this is L minus d by N
so you understand the pitch just like an screw you this is a pitch what you get for the coil so that is L minus d that is free length minus d by N that gives you the total nomenclature of a compression spring having the plain ends
i need not to repeat for all other springs but you can see the next one will be for plain and ground ends where you can see total number of coil is N plus one solid length here it becomes d into Nt
free length is as usual but pitch is L divided by N plus one
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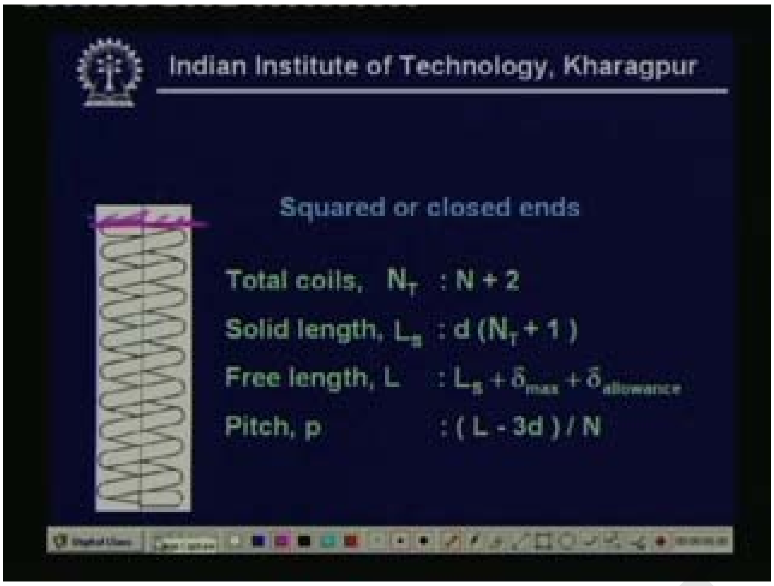

next you go to the squared or closed ends see earlier what is the squared end and closed end and the plain end the difference lies over here

earlier the spring head was going like that now here if you ground it then plain and ground but in this case what you can find out that the last coil is not going in the proper manner

it is being pressed to make a make a some sort of flat end and this is what we called a squared end or closed end

now if you look at the next one then you will be finding out the square and ground end so there will be having something like this

this means something like this you have squared it again made it and ground it so that it can properly sit in the sitting coil

so what we get this is the squared and closed end and

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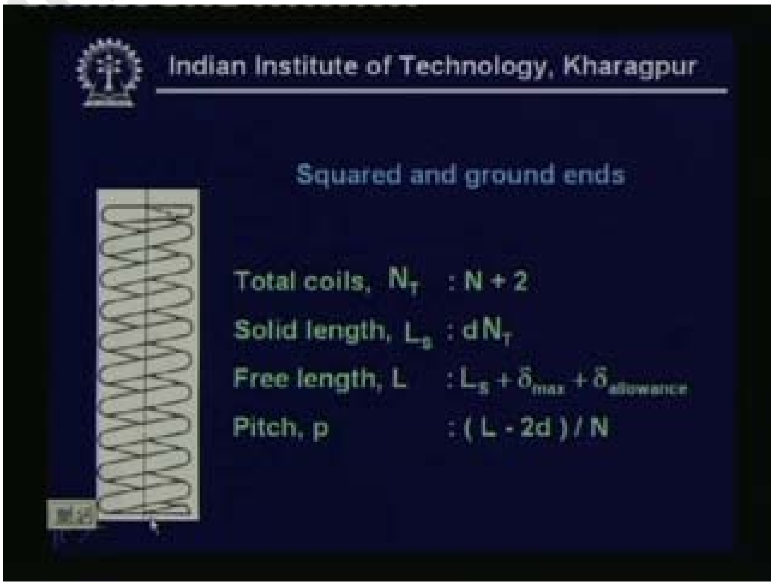

next one we get squared and ground end already i told you that that one in the earlier slide so this is the picture of what you find out by the squared and ground end compression springs so this are the four types of compression springs normally is used in design and you have learnt that what are the nomenclatures of a spring that is the total coil solid length free length pitch etcetera

we have talked about these springs of the compression type

now next we will go to learn more about the other type of springs that is the extension springs

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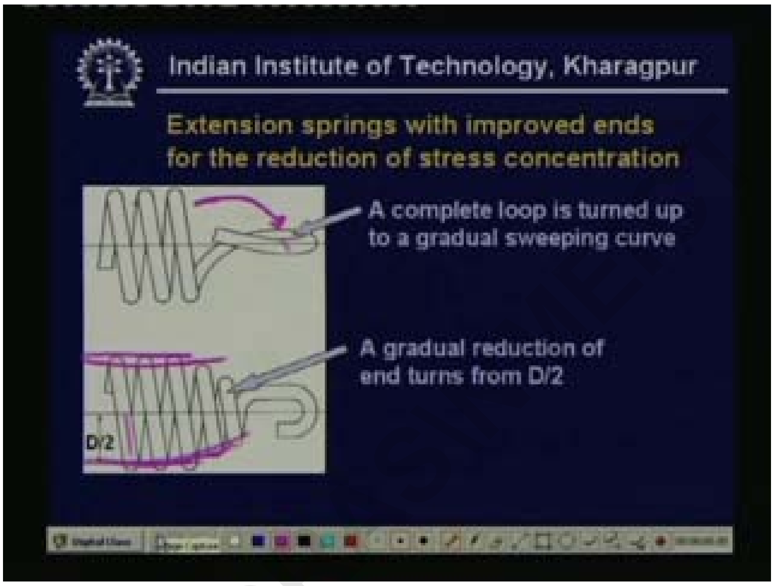

so you can see a part of an extension spring with a hook which is this is the what we call this is the hook okay and this view is shown over here and this is the spring body in the extension spring

now you can see the simple relationship is a body length Lb is given by d into N plus one where N again stands for the active coil and free length is the Lb the body length plus the hook diameter so only two nomenclatures to define the extension springs

now one of the situation that come into picture is that this hook

now this primary this hook are hooks are unavoidable because as you know that the spring has to be held at some location so to hold the spring at some location what you require that you require some sort of a hook or a bend onto the spring heads to facilitate holding of the loads

now a typical hook has been depicted over here but by putting such hook what happens certain amount of stress concentrations comes at this bend zone and these are substantially weaker zone compared to what off we can see for the other spring bodies so one has to take care to see that while designing the hook one should take the steps so that the stress concentration is reduced

now here you can see the same extension spring with little modification or improvement which has been incorporated so that the stress concentration is reduced at the heat zone

now you see that in this case what is happening a total loop just like this loops what is happening a total loop is just turned up that means by some means it is purely turned up to this zone and this makes a what has been it has an by gradual sweeping curve

so anything going in a very gradual manner as we know that stress concentrations will be highly released

so this is one way and another way please look at the board that you can see that this is the mean coil diameter okay and this D by two means the radius so from this radius if you can see that gradually if i just join this lines then you can see that gradually there is a reduction of the radius

so this was D by two then gradually it is reduced and then you make a hook like that

so that means a gradual reduction of n terms from D by two to a some form like this also a way by which you can relieve the stresses in the tension springs

so now we have learnt two types of {sp} (00:41:23) helical springs one is a compression spring another is a extension or tension spring and we have also learnt about what their constructional features and the nomenclatures

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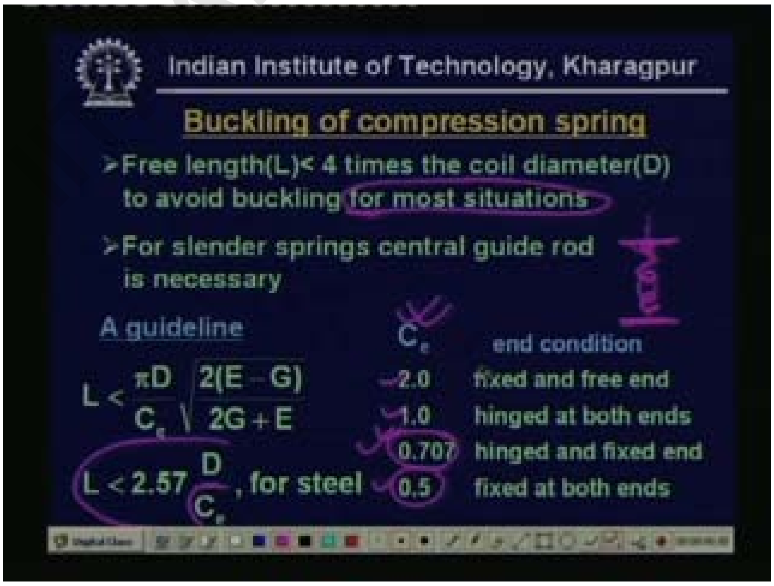

now here another important situation comes into picture is that Buckling of compression springs by now ah after going through the basic courses you have learnt about buckling what is this buckling

it is some sort an instability that is normally shown up when a long slender bars or column something like that are applied with compressive type of loads
so the similar situation comes whenever you consider a spring body
if the spring becomes too slender and quite long then what happens that it sways away side wise and what we call normally as a buckling failure
means ah if we look to a spring of this type and it is an compressive of whose is the buckling will take place for a compressive type of spring then what happens
if it is an instability it is the buckling is occurring in an instable situation then what happens something like this means a spring takes up a shape like this so this is what is normally called buckling of the spring
so what is the idea the one of the idea what we try to learn in this particular buckling of the compression springs that when you are designing
if you find that free length is a ah i think ah this ah this should be ah not less than please (( ))
(00:43:54) if the free length is roughly four times the coil diameter to avoid that mean {fred}
(00:44:02) free length ah excuse me excuse me it was okay
that means free length should be four times the coil diameter less than four times the coil diameter to avoid buckling for most situations
please note that i am just using the word most situation because just i will explain it after some time
now in this case what is happening for slender springs central guide rod is necessary means if we find that the after calculations the spring is likely to buckle then one has to use a guide rod passing through the center of the spring access so
so about which the spring should compress and i mean the compression action of the spring should takes place along this particular guide rod
now [Noise] as a guide line ah you can see the L the free length that should be this one
it should be less than pi DCE you understand this a E and G has a standard meaning of the last modulus of the elasticity and shear modulus of elasticity
and in case of steel if we use a value of E to be what two hundred Gpa and ah G to be eighty Gpa then you get a relationship for the steel material that L is two point should be less than two point five seven D by CE where CE are the this CE are the end conditions what has been given over here
now fixed at both ends means what that means something what are the you have pushed i mean you are placing some sort of plates through which it is being the spring is being

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compressed so you get a point five hinged at one end and there's a plate at one end this is a point seven zero seven and hinged at both ends and fixed at one end and free at other end so that's the reason if you look for all the engineering applications that mostly you will be finding out ah this situations that's the situation i have used the word the free length should be less than four times the coil diameter to avoid buckling for most situations

it is not always but roughly as a thumb rule you can see it but it requires such checking for each and every individual spring whether the buckling is taking place or not

so you always keep in mind that any spring you design you compute its free length and have a check for this relationship taking up the values of the end conditions what has been given over over here

so this is an very important aspect because if there is an buckling then obviously the design either has to be changed and if it is impossible to change the design due to certain other constraints

then what we have to use you know you have to use a central guide and once we use a central guide obviously the machine component design has to take a another shape so a check for buckling is also very important

now let us see another aspect of the design of the springs that is what we called as spring search or the determination of the critical frequency of a spring

now what is that normally if this particular phenomena can be ah explained in the way that if we

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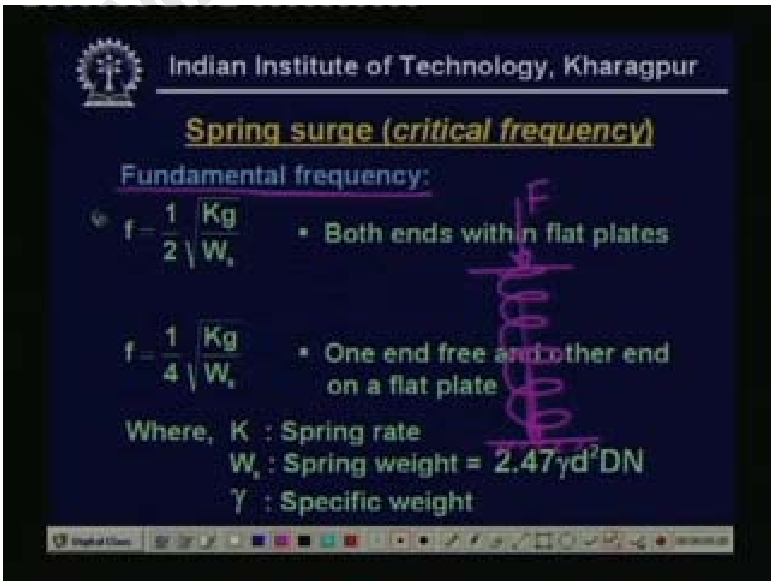

say give a load onto this spring some F load is given onto the spring then what happens whenever a load is applied then a some sort of just be to this particular movement of this

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spring say a wave travels across the spring and then it again goes back and this type of phenomena continues
something like that if you see ah in a closed body or ah in a closed water body if you put some sort of disturbances the way the disturbances goes towards the end or towards the wall then again return
so similar situation happens whenever a forcing function acts onto a this particular spring
now this particular situation is called the surging of the spring in the sense that if this particular travel of the wave becomes equal to the natural frequency of the spring
then immediately there will be an resonant frequency and you know this will be determinantal and there will be a failure of the spring or likelihood of a failure of the spring then what the what the design is predicting okay that means before the design predictions the failure of the spring may occur this is actually called a spring search
so what is the idea that means once you have designed a spring then what you have to take into here that you find out the critical frequency of the spring
and if this critical frequency is different then what is your actual operational frequency then the chances of resonance is less
now you know ah there will be there {ee} (00:50:50) there is a natural frequency which we call as a fundamental frequency and it will have other frequencies what we called as that first natural frequency then we can have the second natural frequency like that
so other modes also can be calculated but normally what happens that it is of the interest that you only take up the fundamental frequency calculate for the fundamental frequency and use a judgment to predict the operational frequency of the spring
now in this case we will see that this fundamental frequency what it is being given over here which is of our interest all right
now this particular fundamental frequency can be okay can be obtained by the relationships what we can see is that f equals to half root over K into g by Ws and another one is f equal to one fourth root over K into g by Ws
so first expression explains for both ends within flat plates and the second expression that is this particular expression
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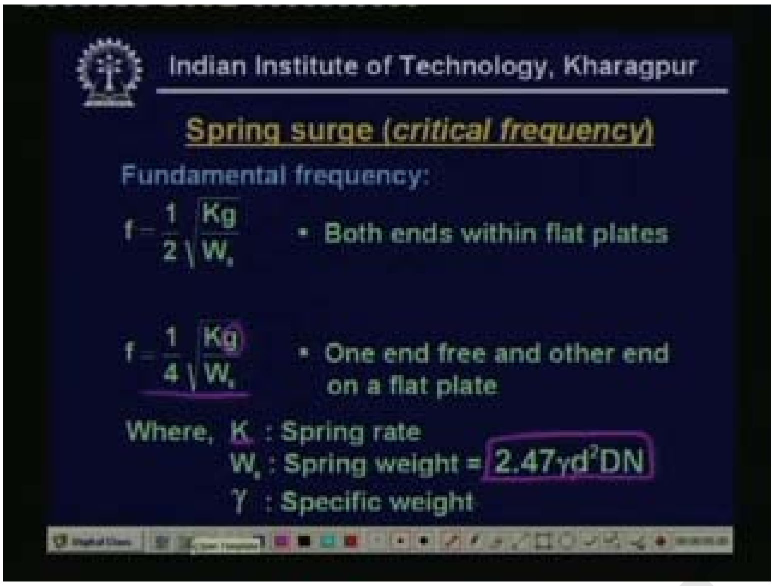

describes the formula for fundamental frequency when one end is free and other end on a flat plate

in this case what you can see is that this K we call the spring rate so that we have already learnt earlier Ws is a spring weight and this particular expression of the spring weight is given by this particular formulae two point four seven gamma d square capital D into N

so here you know d is the wire diameter

this capital D is the coil diameter N is a number of active terms and gamma is a specific weight of the spring material

so that will give you the weight of the spring so you substitute the value of the weight of the spring over here

you must be knowing the K value that is the spring constant or the spring (( )) (00:53:37) and the g you can find g is the known oscillation due to gravity

now how this two point four seven gamma d square DN it is coming it is very simple idea of what we get is like this

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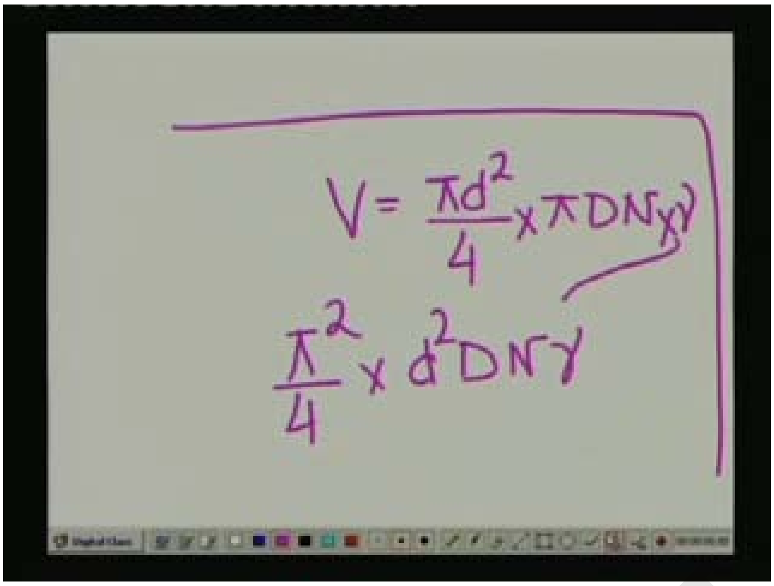

you just compute the volume of the spring how we we get the volume of the spring cross sectional area okay so pi d square by four into total length of the spring what is the total length of the spring

this should be pi D one length multiplied by capital N

so that will be capital N is the number of active coils so this becomes the volume of the spring and once you know the volume of the spring you multiply by the gamma that is a specific weight

so what is this idea so that means this specific weight you you know that this specific weight we consider as rho into g rho is a density of the material and g is acceleration due to gravity so that means this expression you get like this so once you get it so this is the this comes out to be pi square by four multiplied by d square capital DN gamma

now you please note down that ah one has to be very careful about the units what you prescribe because this is the situation it is coming like this

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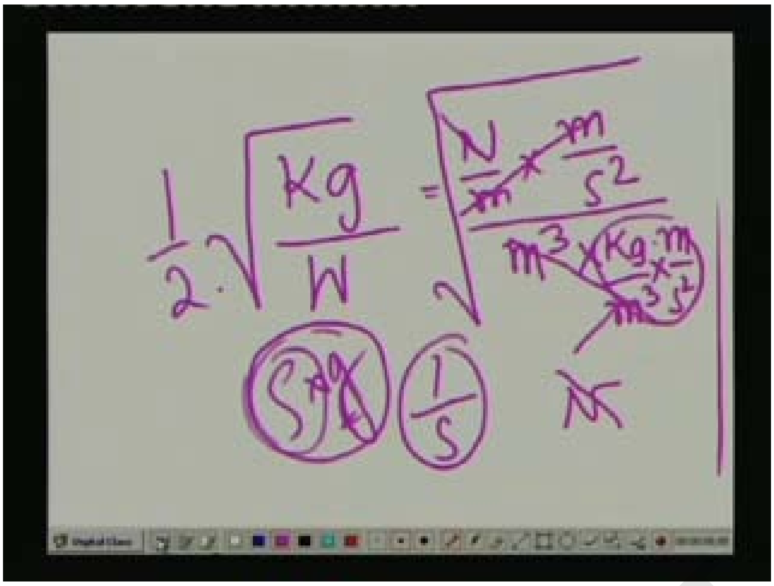

that you have got root over Kg by W this one is K Newton per meter g meter per second square now ah well half or one fourth may be there say half divided by this is W

so that means what you do you find out the volume volume is meter cube density is Kg per meter cube and again you will use the g meter per second square

so that this meter cube cancels this meter cube cancels

Kg meter per second square is invariantly Newton this Newton this Newton cancels

so under root becomes one upon S so this is the unit what you get so here ah normally rho simple rho won't what

rho multiplied by g this is a mistake you all of you know but still i am just giving you a ah this particular caution that sometimes we miss this one so that the unit correspondence ah may not be correct

so this {re} (00:56:55) this expresses that what we get is that this K ah this particular one ultimately pi square by four is nothing but this two point ah four seven and this is the specific weight so this is not mass but this is the weight

so once you find out the fundamental frequency then normally what you do is that you take the operational value of the spring at least fifteen to twenty times less than the natural frequency

so this will {ens} (00:57:35) ensure you that the spring search won't occur and ah if you take about this value margin of around this value then not only the fundamental frequency but other modes of frequencies will also can be taken care off

so this the more or less the ideas what we concentrate for the design of the springs and next thing what we will be doing is that you'll be taking up a simple example to illustrate the how we design a typical spring

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so that we can take up in the next lecture

thank you

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