Failure Analysis & Prevention

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Lecture - 03
Fundamental Sources of Failure: Deficient Design I

Hello, I welcome you all in this presentation related with the subject Failure Analysis and Prevention. In the previous presentation, we have talked about the importance of the failure analysis and some major engineering disasters which have taken place in the past. And they underline the need of the carrying out the failure analysis, so that the suitable corrective action can be taken.

We know that, whenever any failure of the mechanical components can it takes place, then, we need to investigated systematically, so that the root causes of the failures can be identified in order to avoid the recurrence of such kind of failures, so but for failure investigation in which direction we should go?

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So, say we our the failure has taken place and it needs to be investigated in order to take the corrective action. So, what should be the directions in which investigation will be carried out? As you know, there the failure analysis will involve systematic procedure of investigation so that, the root causes can be identified, but what will be those directions in which investigation need to be carried out? So, to understand to have the idea about the directions in which failure analysis need to be carried out, we need to understand the fundamental sources of failure, fundamental sources of failure of the mechanical component. So, these fundamental sources of the mechanic failure of the mechanical component involve some of the bigger factors deficiency in those factors are in proper application of those things linked to the failure.

So, one is the improper design of the component. So, we know that, in light of the service conditions suitable parameters are used for designing the components so that, they can perform during the service. But, if there has been if in the design if there are deficiencies, then it will lead to the failure of the component. Another important factor improper selection of the material; although, selection of the material is a part of the design itself, but sometimes the material selection, if it is not done properly, then despite of having the proper sizing of the material, the material degradation property degradation in properties of the material lead to the failure of the components.

So, improper selection of material, this is another factor. And material has to be selected in such a way that, the force you will mechanism of the failure is considered for selection of the material and accordingly, suitable properties are considered for the design purpose. So, for improper selection of the material is the second one; third one is the improper manufacturing being applied improper manufacturing procedures being applied like say, a certain procedural faults are there or the something has been a specified in procedure, but something else is followed or care lessness on the part of the worker.

So, their various factors which are related with improper manufacturing and which become the cause of the failure; then, another one improper assembly, say, most of the engineering systems or mechanical systems are made of a number of components and all of them are assembled in a systematic way. But, if the assembly is not proper, then it will lead to the imbalance misalignment and which will lead to the introduction of unnecessary forces which can cause the failure of the components.

So, improper assembly of the system and then, we have like improper service conditions means, the system every system is designed to work under certain conditions of service. But, if it is I have used during the service like it is overloaded or subject with the lower temperatures subject to the too higher temperature than what is expected, then it will lead to the failure. So, improper service condition is another factor.

So, this is then, we have a improper maintenance every as most of the mechanical systems having the relative movement. So, they need to be properly lubricated in order to in order to have them in proper running conditions in order to reduce beer and friction and proper intercourse and paintings need to be done, so that, the corrosion from the environmental conditions can be prevented. So, number of things need to be done for maintaining the component in proper working conditions, but, if the maintenance is not proper, then, it also it will lead to the failure.

So, improper maintenance of the system can also lead to the failure. There is one additional point related with the material like, even if the material selection is correct, even then failure of the material failure of the mechanical component can take place. And this is the situation when the imperfections in the material itself imperfections in the base metal itself like for a particular application.

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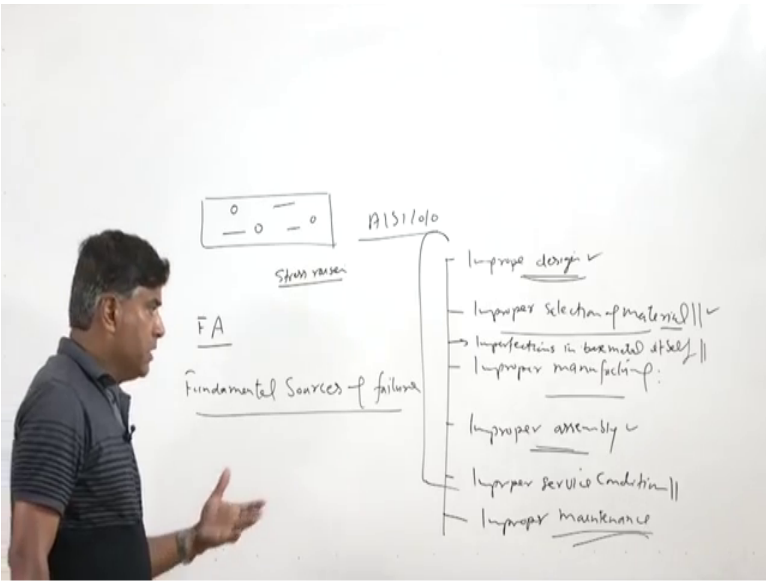

If the simple carbon steel like A I S I 1 0 1 0 steel is recommended and it has been selected considering the service conditions, but this is steel is having lot of inclusions or this is steel is the folks, this full of the gases present here and there then, these inclusions and the force will act as a stress research and will also act as a site of the weakness, where from cracks can easily nucleate and cause the failure of the component despite of proper design proper selection of the material proper manufacturing. But, the base material itself is weak, then, it will lead to the premature failure of the components of these are the fundamental sources of the failure of the mechanical component.

So, whenever any failure occurs, all these components need to be investigated and one by one possibility for each of the component is to be ruled out. So, will be first investigating in light of the service conditions whether design was perfect or not or what the whatever the material was of the selected the right kind of material was actually used or not. So, material confirmation and if there is any deficiency in the material itself, like a boosts or inclusions or cracks then, whatever recommended manufacturing process has been there that has been followed or not or over there any deficiency is a similarly whether the assembly procedure was collected correctly followed or not in similarly, the conditions under which failure has taken over corresponding to the conditions for which it was made or designed or not or it has been abused during the service.

So, all these components will be the suspect will be the suspected cause of the failure. And each one needs to be investigated to real out to rule out the possibility of the contribution of the factors or to identify which of the factors would have contributed towards the failure whether despite of everything, if even if everything is perfectly fine, but if the maintenance has been improper, then it also can lead to the failure. For example, like if there is an automobile and if the incorrect kind of the lubricant is used, then despite of the proper design of the piston cylinder crankshaft proper material, proper manufacturing, proper assembly and the normal the service conditions, it can lead to the seizure of the component or the failure of the ancient due to the use of the improper lubricants.

So, every factor is significant and every factor can lead to the failures. So, each one needs to be investigated for it is possible contribution towards the failure. So, now, we will see the first significant fundamental source of the failure which is the improper or the deficient.

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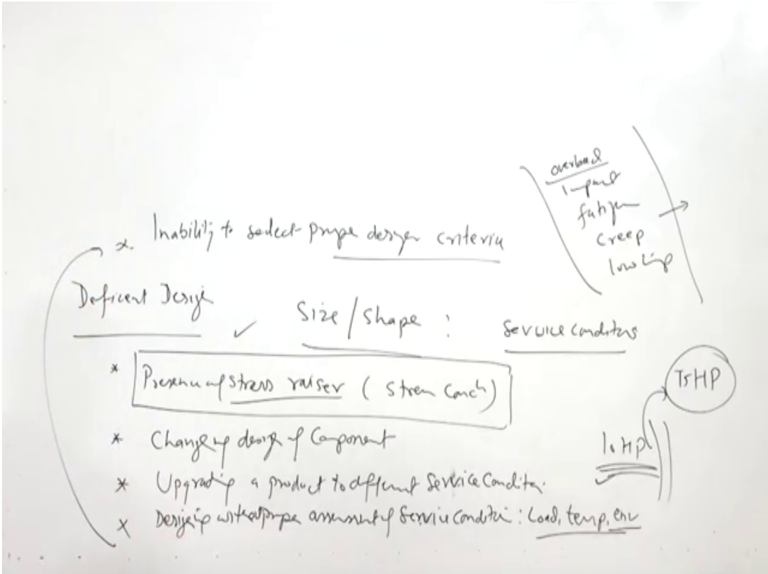

The design of the component, we know that, design basically of mechanical component involves the sizing and shaping identification of the size and shape of the component which needs to be manufactured considering the given service conditions like the load temperature the environment the type of load velocities etcetera. So, service conditions are kept in main world designing in a component for determine the size and what kind of size and shape will you fit for proper functioning and the proper life of the component.

So,, but if the sizing shaping determination of this aspect is not correct, then it can lead to the failure and that failure comes up due to the various factors with regard to the design of the mechanical component the first one like, the presence of the stress raisers. This is one of the most common cause of the failure due to the deficient design presence of the stress raisers and these stress raisers of course, will be causing the a stress concentration and increasing the localization of the stresses and so, localized failure will be triggered.

The second factor, I will elaborate each of the factors at length. Then, second factor is about the changing the design of the component without giving proper consideration to the various possibilities which can happen if the design is changed. So, changing design of the component for a given service conditions without proper consideration is to the various factors and which can lead to the stress concentration overloading or exposer to the conditions for watches for what it has not been designed, so that change in design without proper considerations to the various possibilities are related with a service conditions.

Third one is like one particular component has been working fine for very long and it has a very good record of the service and encouraged with that performance if we are upgrading the same for the different design made for different kind of the system, then that can also lead to the failure.

So, upgrading a product to the different service conditions which are like say a more serious service conditions like something has been designed for the 10 there is a nut and bolt assembly or there is washer (Refer Time: 12:45) or number of components which are there for the 10 HP engine and if a if some of the components has been working very efficiently effectively for long without failure with this kind of system and then, if with encouraged with this performance of particular item associated with the 10 HP engine, if the same is upgraded further like say, 15 HP engine, then it can lead to the failure of the component much earlier than it what was stimulated stipulated.

So, unnecessary up gradation of the certain parts without considering the without giving full thought to the various possibilities which can happen during the service under the most severe conditions it can lead to the failure.

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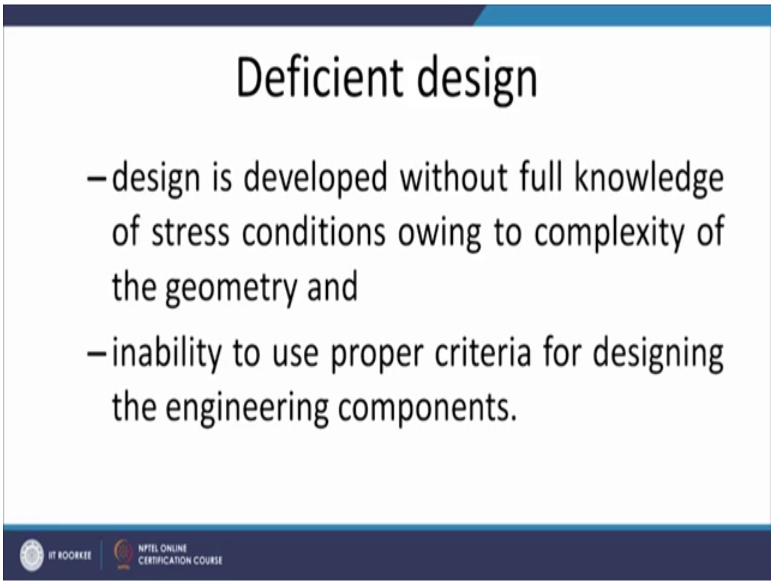

The next one is the next factor is about the design developed without full knowledge of the stress conditions. So, this one is like designing without proper assessment of service conditions, without proper assessment of the service conditions like sometimes it becomes difficult to identify what will the maximum load, what will the minimum load, what will be the temperature conditions. For example, and automobile design for the normal ambient conditions, if the same is used under the very sub 0 conditions, then it may not survive under those conditions.

So, designing with without proper assessment of the service conditions, so this is especially with regard to the load, temperature and environmental conditions in which component can be exposed during the service. So, if this is not kept in mind properly, then it can lead to the failure. And the last point related with that design is here that is inability to use proper design criteria for designing a particular mechanical component means, in ability to select proper design criteria which means, we are not actually able to appreciate the service conditions whether the failure will take place due to the overload under the static conditions or failure will occur due to the impact failure will occur under the fatigue load conditions, failure will occur under the crib conditions at high temperature or failure will occur under the low temperature conditions.

So, what parameters we should select? If that is not considered properly, in selection of the suitable parameter or criteria for designing, then also it can lead to the failure. So, we need to see what are the possible mechanisms by which can by which failure can take place and accordingly, we need to select suitable design criteria, so that, it can perform successfully during the service. Now, will come to the first point will we will go through we will go through the things related with the stress raisers in detail and in which way it can contribute towards the failure.

Thereafter, will talk about the failures when the design is changed without giving full thought about the various possibility is related with the service or upgrading a part of the product part for more severe service conditions. So, first we need to understand what are the stress raises is.

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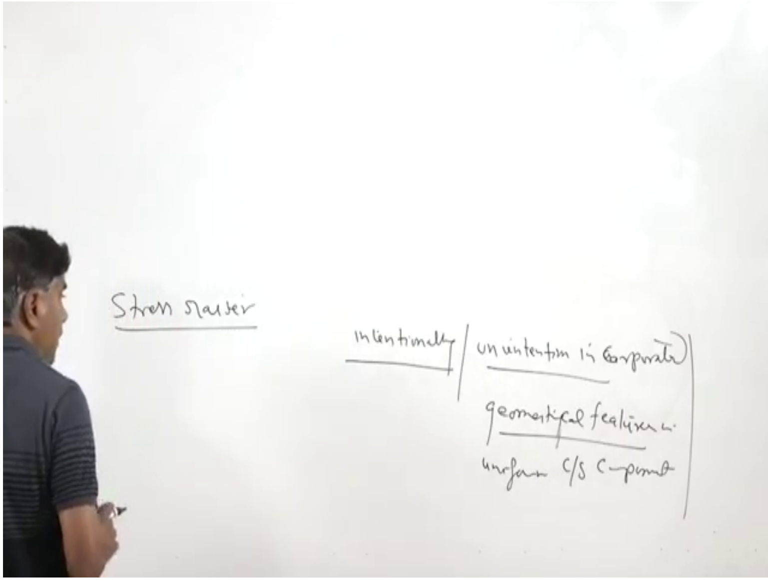

Stress raisers are, we can say either intentionally or unintentionally incorporated geometrical features geometrical features in a in a uniform form cross section components. These are basically termed as stress raisers. Whether sometimes, these are intentionally added for realizing various functionalities, but a many times, these happen un intentionally due to the defect formation crack development during the manufacturing or improper of imperfections in the material itself. So, either intentional or unintentional, if the geometric features are present in uniform section of the material, then this will act as stress raiser. So, what happens when there is no stress raiser?

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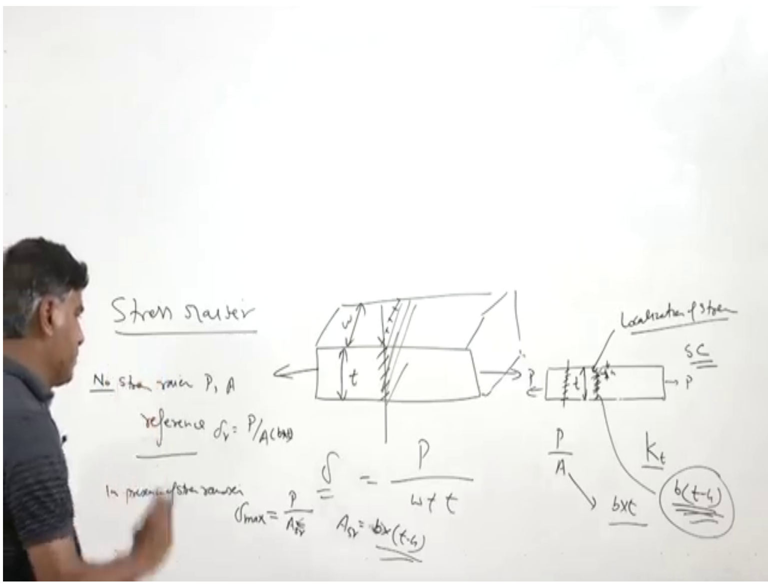

In that case, like say there is a particular section having the uniform cross section there is a particular component having uniform cross section and it can be subjected to the bending load torsional load or axial load. So, when axial load acts in is longitudinal load, load acts in along the axis then the magnitude of the stress across the section will be uniform. So, like say if the load P is acting and the cross-sectional area like say, this is the thickness and it has some width like this. So, this width needs to be multiplied to determine the value of P.

So, P is the load and width into t will give us the stress visual acting and this value of a stress will actually be uniform all along this section. But, if any geometrical feature is introduced like say a in the front view if you see the load P is acting and some geometrical feature is like this is introduced, then at the location where the special geometrical feature has been introduced or it is unintentionally present, then it will be leading through the localized increase of the stresses. This is called localization of stress or means, the stress is are increased in very localized manner at particular location where, these are present and this localized increase in stress is basically is termed as a stress concentration S C and it normally it is represented as a word like K t theoretical stress concentration we will come to that subsequently.

So, if we take any cross section here, where there is no stress raiser, then the load can be determined the stress can be determined by simply the load divide by cross sectional area which can be simply obtained from the width in to the thickness for rectangular section. But at this location, where we have a stress raiser like say that this thickness is h this thick that the depth of the stress raiser is h. So, in that case, load resisting cross section area will be somewhat lesser.

So, the load resisting cross sectional area for this particular cross section will be reduced by which magnitude like say, width is same, but t minus h width with. So, load resisting cross section area in this case will be reduced. So, t is this thickness and the h is the depths. So, t minus h in to b that is the width of this component so that will give us the reduced cross-sectional area or reduced load carrying cross sectional area and which in turn will be increasing the stresses at this particular location.

But here, again the stress magnitude is not equally distributed all along the length all along the thickness it is more localized in near the near the location where a stress raiser is present, so that, localized increase in the stress where a stress raiser is present actually becomes the cause of the failure in number of cases. So, in the case when there is no in a material when there is no a stress raiser.

For a given load, for a given cross sectional area, we find the nominal stress or it is also termed as reference stress like say the sigma r we can. So, P by A will give us simply the reference stress or the nominal stress, but when there is a stress raiser, in presence of stress raiser in presence of a stress raiser, the stress is will be high. So, the maximum stress in presence of a stress raiser sigma max will be load is same, but the load resisting cross sectional area has been reduced. In this case, it was b in to t, but it will be reduced to A. actually, in case of the stress raiser will be reduced. So, with the stress raiser this magnitude will be equal to this A as r is the area when there is a stress raiser will be equal to w b into t minus because the t is the thickness and h is the depth of the stress raiser.

So, this will be causing the localized increase of the stress is it is indicating just the geometrical dimensions of the stress raiser and the ratio of the maximum stress.

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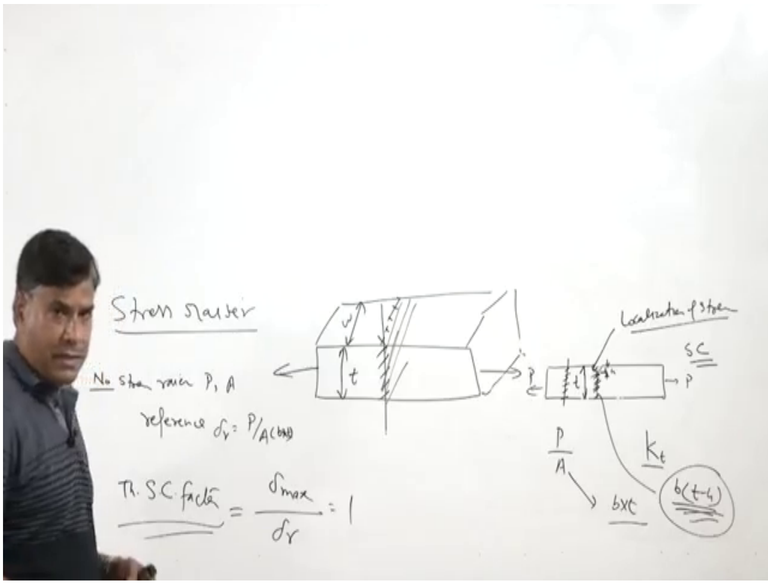

Due to the stress raiser and the reference stress that is the sigma r this ratio is termed as theoretical a stress concentration factor. Normally, when there is no stress raiser, this ratio maximum stress and reference both are equal. So, it is 1, but whenever there is a stress raiser, the maximum stress is will be high or greater than the references stresses and then stress concentration factor will value will be obviously, more than 1.

So, we know that, if the stress raisers are present, then they will cause the localized increase in the stress and that will be termed as stress concentration. This is what we can see here in this diagram when there is no stress raiser.

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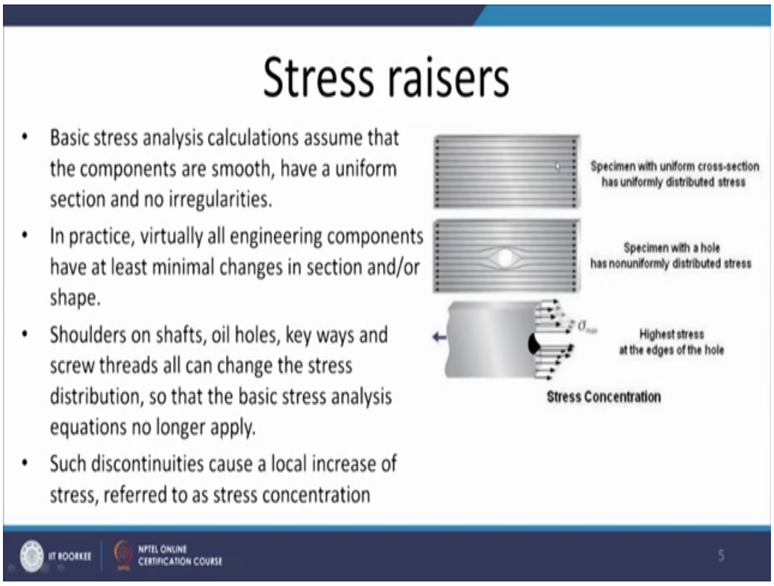

Stresses are uniform and this stress flow lines are equally distributed, but whenever there is a like say in this particular case, when there is a hole and around the whole the stresses are more steps for lines are more localized there more crowded indicating that stress is more localizing. And this kind of a stress distribution can be seen in the third diagram where, more stress magnitude is higher near the edges of the whole as compared to the distance away from the stress raisers.

So, this kind of the stress raisers are invariably present in most of the engineering components to realize various functionalities, and that is why, these are integral part of the most of the mechanical designs, but we need to take care of such kind of the features in such a way that, the stress concentration remains within the limit and they are easily accumulated without causing the failure of the component.

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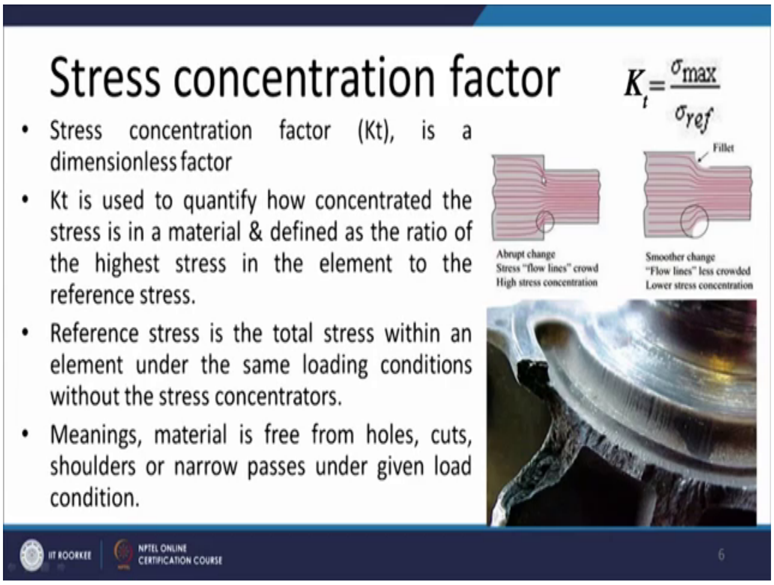

So, what I have said earlier, like the stress concentration factor can be obtained from the ratio of the maximum stress to the reference stresses and it happens the stress concentration. Mostly happens at the locations wherever there is a change in cross section. So, like say, here the cross section is uniform. So, this stress flow lines are uniformly distributed, but since at this location, there is a change in cross sectional, change in cross section is taking place. So, here what will see what we can see the stress flow lines are more localized and what is seen in terms of the increase in stress magnitude? Again, the stress flow lines are like say, at distance away from, they are more they are by an large uniform.

But the stress magnitude is more. And we can see this diagram here in this particular location where change in cross section is taken place has caused the higher stress concentration which ultimately leads to the failure of the component. So, this is what has been explained in this slide.

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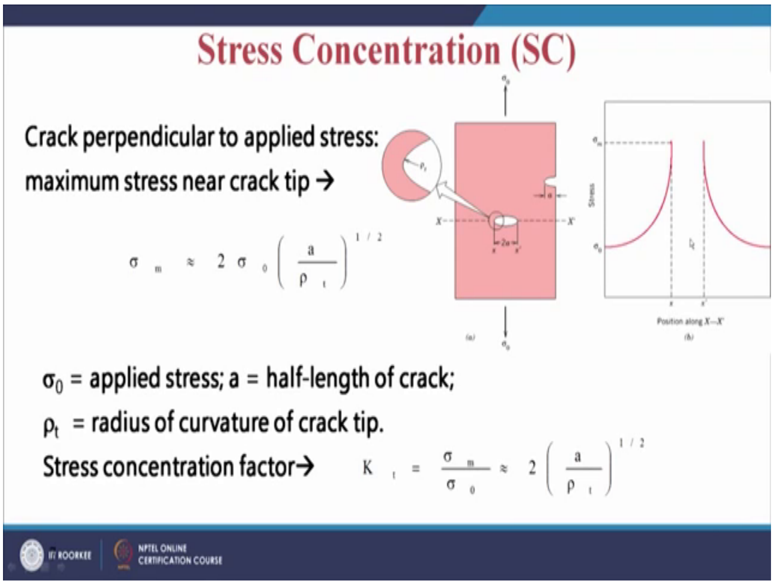

The same thing we can see now, as there is additional aspect like the geometry of the a stress raiser. So, in this case, if we see, like say, this is a simple plate of a particular dimensions like say, there is a width v and maybe thickness t that will be there. So, which all though it has not being explained here, but like in this plate is having the stress raisers of the 2 types one is stress raiser is inside and another stress raiser is at the is present at the surface.

So, whenever the stress raiser is present at the surface, it is more dangerous as compared to the stress raisers when they are present in the inside. So, a stress raisers present at the outside it is depth is taken as a and when the stress raiser is present inside, then it is length is taken as it is length is taken as 2 a and a is the half crack length. So, a is the full crack length. When it is open for open cracks and a is the half crack length, when the when the crack is inside and another feature is.

So, the length of the crack is one of the aspects that affect the stress concentration. The second one is the crack tip radius. So, since both cracks will have their own tip where the crack will be ending and that cracked tip radius is a rho t this is also very critical very important like say, in this plate if we have a crack here, outside crack and there is another crack which is present at the sides.

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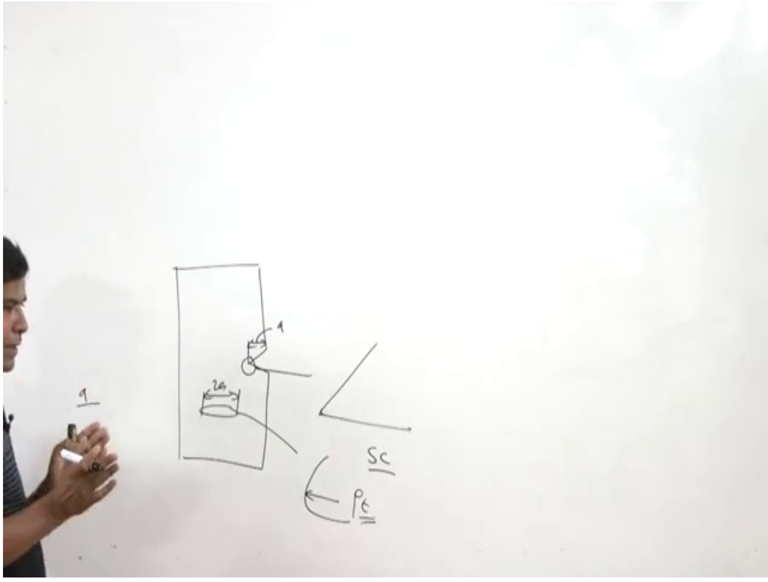

So, that the radius at the tip that which we can see like if it may be very small or if it is very tip defined tipped then, radius will be too low or it will be 0. So, whenever it is 2, it is small. Then stress concentration is very high, but when the tip is a rounded or the tip is having radius like this, then it will have somewhat lesser stress concentration. So, that tip radius is termed as rho t.

So, the length of the crack that is a or the 2 a for the internal cracks is used. So, a is the half crack length for internal and a is the full crack length for the external crack or the surface the crack exposed to service surface and the rho t is the crack tip radius and for this kind of a situation, that stress concentration or the maximum stress near the crack tip can be given through this equation like twice of sigma naught or this is a sigma reference is stress and within the bracket here a is the crack length and rho t is square root of the a divided by rho t.

So, this how this is how we can calculate the maximum stress. And if we see the stress concentration stress concentration, then stress concentration can be of stress concentration factor can be obtained from the maximum stress divided by the references stress or the nominal stress. And this factor is coming out to be the twice of a by rho t square root. So, this and according to this equation, if we see this stress distribution the sigma naught is the nominal stress or references stress and as we move from the crack tip from one side crack tip to the another one there is a continuous change in the stress magnitude and stress increases it reaches to the maximum stress.

So, the stresses are maximum; so and in vicinity of the crack tip stresses are high and both side and the crack stress magnitude at the both sides will be too high. And so, it will be a these are the locations where the crack nucleation and growth tendency will be maximum to cause the fracture. So, stress concentration is one of the most very common reason for the failure of the mechanical components, especially, if the proper care and the proper radius has not been given to the stress raising elements or the stress raisers.

Now, I will summarize this presentation. In this presentation I have talked about the in general, what are the fundamental sources of the failure and what is the importance of the stress concentration in the failure of the mechanical component.

Thank you for your attention.