Basics of Mechanical Engineering-1

Prof. J. Ramkumar

Dr. Amandeep Singh

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

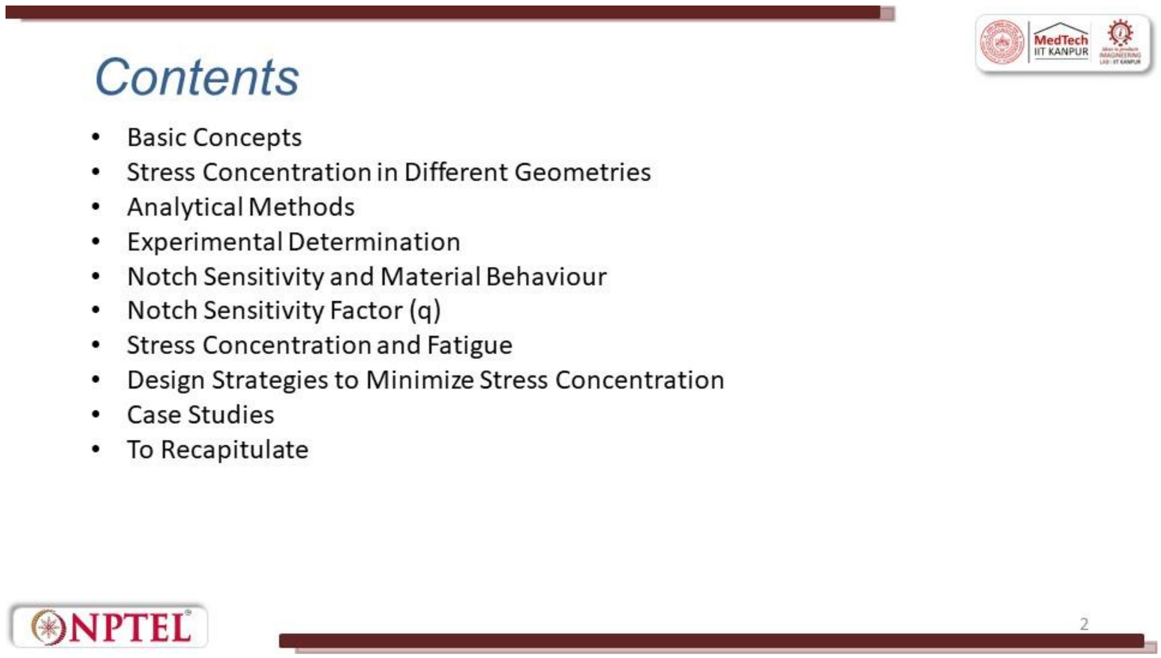
Week 08

Lecture 32

Stress Concentration and Notch Sensitivity (Part 1 of 2)

Welcome to the next lecture on Stress Concentration and Notch Sensitivity. When we talk about load getting applied on a structure or on a part, we always expect the load to be uniformly distributed. Many a times it gets converted into a point. So once it gets converted into a point, the concentration of the stress increases. This tries to create a major failure or an early failure of the part.

So the service life of the part or the product gets reduced. So in order to get out of the problem, we are trying to initially when design itself, we take care of that. So the importance of this topic is going to be enhancing the service life, improving the reliability of the part or product by understanding this concept on stress concentration and notch sensitivity. If you go back and look at our previous slides, we were discussing about fracture toughness test. So there we made a notch intentionally. So now you will see why is this notch very important.

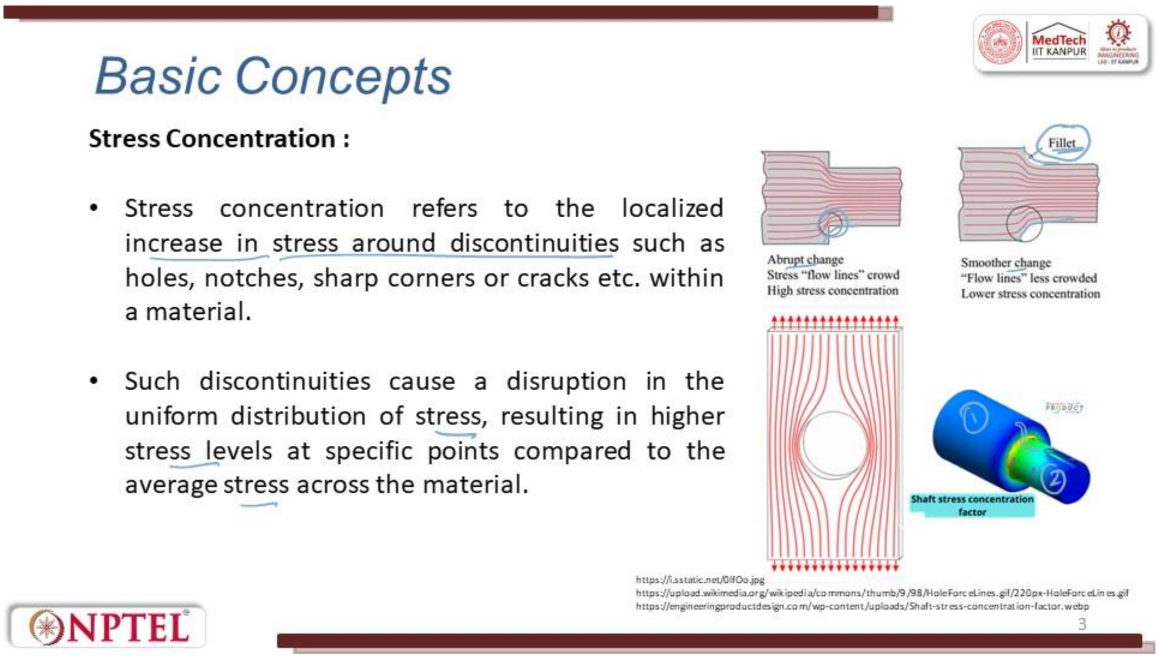


In this lecture, we will be covering the basic concepts, then Stress Concentration in different geometries. It can be a flat geometry, it can be cylindrical geometry. Why are always components made in a cylindrical fashion? Why is it not made flat?

Why is it not made square? So we will look into it. Stress concentration in different geometries. A small Analytical Method in understanding the stress concentration, then Experimental Determination. What you have designed for and when you do experiments, is it matching?

Then Notch Sensitivity and Material Behavior. It is not going to be the same for varying materials. For example, polymer has ductility. The notch sensitivity of it will be different. Ceramics have a brittle failure.

So their notch sensitivity is different. Then we will see a notch sensitivity factor called Q. Then Stress Concentration and Fatigue. Design strategies to minimize stress concentration. Case study. And finally we will try to recap.

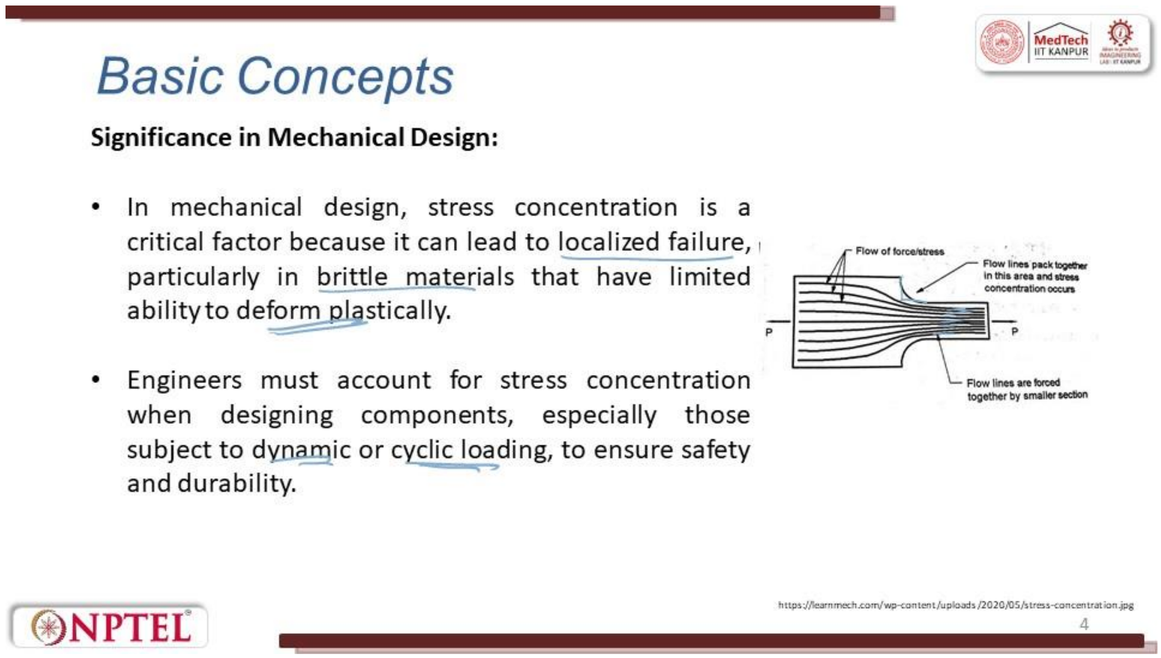


Stress concentration refers to the localized increase in stress around discontinuities. Increase in stress around discontinuities such as holes, notch, sharp corners or crack edge itself within a given material. So you can see here there is an abrupt change of stress flow lines crowded happening at a high stress concentrated point. So now how do we change this?

We change this by giving a radius. So you see here we are giving a radius. So when we give the radius in manufacturing, we always say fillet. Give a small fillet at the concentrated point such that the stress flow lines are distributed without abrupt change. So this is abrupt change and here it is smoothening change.

Such discontinuities cause a disruption in the uniform distribution of stress resulting in higher stress levels at specific points compared to the average stress across the material. So, when we have a same shaft material or when we have two different material, this can be one, this can be two. When we have two materials, when we try to press it inside or when we try to heat it and press it inside. So, all these things when we do, we always will try to see what is the stress concentration happening. Should there be a filleting given, right.

So, if you look at it, there is a stress flow lines are there, there is a hole. So, you see there how does the stress flow lines go around the hole.



Significance in Mechanical Design. Stress concentration is a critical factor because it can lead to localized failure, particularly in brittle materials that have limited ability to plastically deform. Wherever you have a ceramic material, we are more interested in trying to manage the stress concentration.

So you can see here these are the flow of the force or the stress and these are the flow lines. And the flow lines pack together in the area and stress concentration occurs. So here it would have been like this. There is a packing. Engineers must account for stress concentration when designing components, especially those subjected to dynamic or cyclic loading to ensure safety and durability.

So whenever there is a static load to a large extent, it is okay. Whenever you are going towards a dynamic load or a cyclic load, the stress concentration plays a very important role.

Basic Concepts

Significance in Mechanical Design:

- The stress concentration factor (SCF) quantifies this effect and is defined as:

$$k_t = \frac{\sigma max}{\sigma_{nominal}}$$

Exp
Empirical
FEA

Where

- σ_{max} is the maximum stress at the discontinuity.
- $\sigma_{nominal}$ is the nominal stress in the material.
- This factor is typically determined using experimental methods, finite element analysis (FEA) or empirical formulas found in engineering handbooks.

The significance in mechanical design, the stress concentration factor (SCF) quantifies its effect and is defined as Kt. It is a factor K_t .

$$k_t = \frac{\sigma max}{\sigma_{nominal}}$$

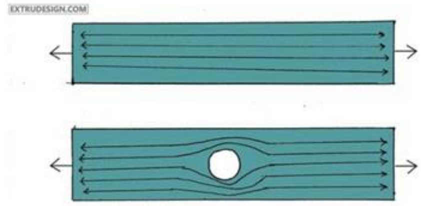
What is σmax? σmax is the maximum stress at the discontinuity. And $\sigma_{nominal}$ is the nominal stress in the given material. This factor is typically determined using experimental methods or finite element analysis or empirical formulas to get these values. So you can try to use experiments, you can do empirical.

See many a times experiments are very expensive or we do FEM, FEM, finite element analysis and then try to get the Kt factor.

Basic Concepts

Notch Sensitivity

- Notch sensitivity is a material property that indicates how much the presence of a notch or geometric discontinuity affects the material's strength and fatigue life.
- It describes the material's tendency to amplify stress concentrations, which can lead to premature failure.



https://extrudesign.com/wp-content/uploads/2018/08/Notch-Sensitivity-extrudesign.com-003_.gif

Notch Sensitivity. Notch sensitivity is a material property. That indicates how much the presence of a notch or a geometric discontinuity affects the material strength and fatigue life. It describes the material's tendency to amplify stress concentration which can lead to premature failure.

- Notch sensitivity depends on factors such as ductility, toughness & nature of load (st/cy)
- Brittle materials has high notch sensitivity → failure)) → marshal out → Ceramic material
- Ductile materials distributes stress & so less sensitivity
- Notch sensitivity factor (q)

$$q = \frac{k_f - 1}{k_t - 1}$$

k_f ⇒ fatigue strength

k_t ⇒ SCF

Design ⇒ (k_t, q) any given material ↑ service life of Products ⇓ Polymer

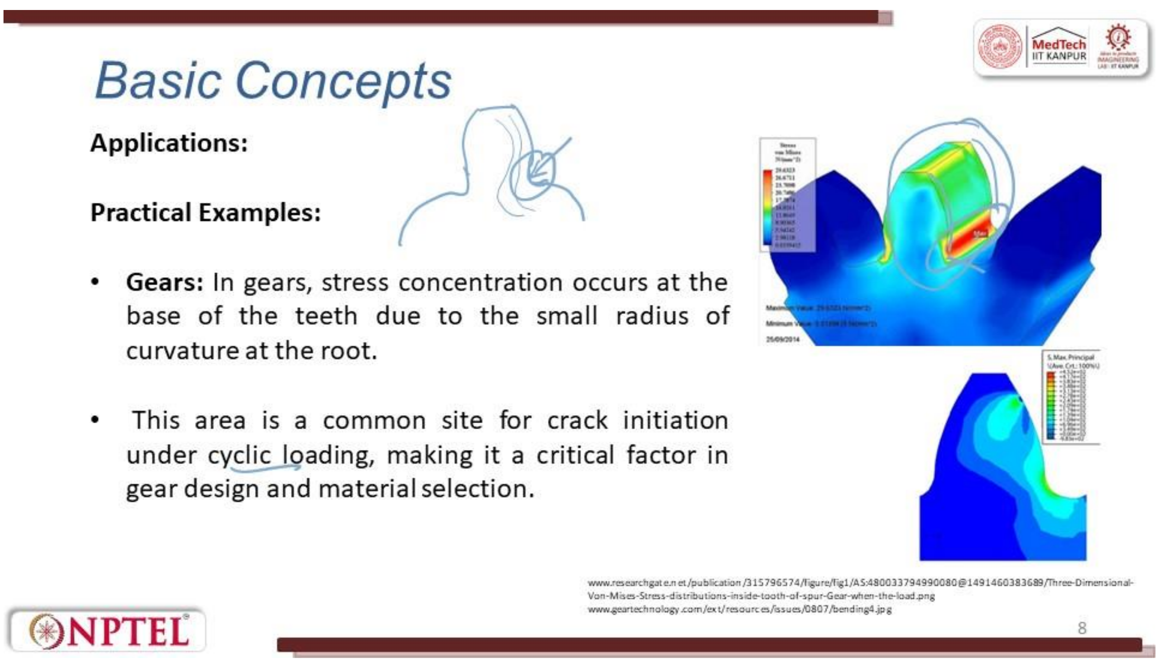
So Notch Sensitivity depends on factors such as ductility toughness and the nature of load static/cyclic brittle materials has high notch sensitivity. So, this leads to failure. On the opposite side ductile materials distributes stress and so less sensitive. So, this is why if you see in all the martial arts, they try to break ceramic material Because all you have to do is create a notch, create a impact, that is it.

So, notch sensitivity, like you have the stress concentration factor, notch sensitivity is also found out, there is a formula, notch sensitivity factor, that is called as ‘q’.

$$q = \frac{k_f - 1}{k_t - 1}$$

What is K_f? K_f is nothing but the fatigue strength. Fatigue strength and K_t is stress concentration factor.

Through this we try to calculate q. So when we try to design, we have to always look at K_t factor and q factor for any given material. Why? This will try to increase your service life of products. That is why you see many of the products are made out of polymer today is only because their stress concentration level and notch sensitivity factors are very good.

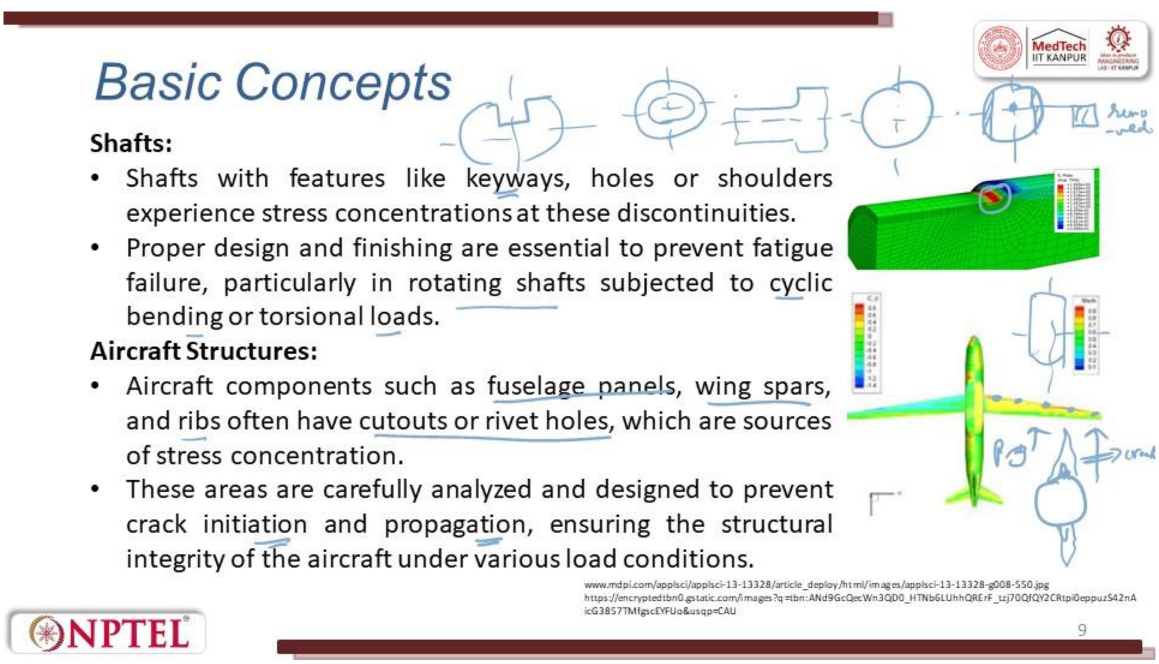


So let us see some of the applications. Many a times if you see gear, when you see a gear, you see how the stress gets distributed. Wherever it is red, it is relatively higher stresses are getting acted. When gear-gear meshes, there will always be stress concentration at the end of the teeth when it is getting attached with the gear, right. So, this portion will have a huge stress concentration. In gear, the stress concentration occurs at the base of the teeth due to small radius of curvature at the root.

So, now people what they do is they have a gear. Now, this radius is very important when we go for the next gear, next teeth, right. This radius is called as a Root radius. If the radius is too small, then you will have more concentration. Because once the radius is smooth, the flow lines will be easily getting changed.

So once the flow lines are getting, there is not much of accumulation of stress flow lines. So because of that, the failure does not happen. This area is a common site for crack initiation under cyclic loading. When the gear keeps on meshing and going, like nowadays the gears run at 5000, 10,000, 50,000, you have spindles which are running today at 1 lakh rpm, 5 lakh rpm. So when we are doing so, there will be gears which are meshing with another gear.

When meshing is happening it is a cyclic load. So under cyclic load making it a critical factor in gear design and material selection.



When we look at Shafts, we always try to see a cylindrical shaft. Sometimes when see cylindrical shafts are always done because it is manufacturing also I see.

Sometimes because of assembly limitation what we do is we try to make a shaft like this. So that means to say this portion, the shaded portion will be removed. So then what you have will be something like this. So when we have this, there is a discontinuity. So, when we do a shaft design, we have to be careful.

Why are we doing a shaft design and where is a shaft exhaustively used? When we have a motor, the motor rotates, right. This motor will always have the output of the motor will come to a shaft. This shaft in turn will be attached to a coupler and then you will have a mechanical component getting attached. So, there the shaft design becomes very important.

For locking with a coupling and many other applications, the shaft design is always an important role. And on top of it, if there is a coupler, if there is a shaft which is rotating, this is a rotating part, this is a cylindrical part. So, there has to be some locking mechanism. Only for that, we always make a keyway. So, keyway is a slot on the shaft and then on the keyway, you put a key.

So this will try to have a positive drive. So positive drive is it tries to communicate the rotation to the other end, the next end where both rotates. Shaft with features like keyway, hole or shoulders experience stress concentrations at these discontinuities. Keyway is you have a shaft. So you have a keyway made, right.

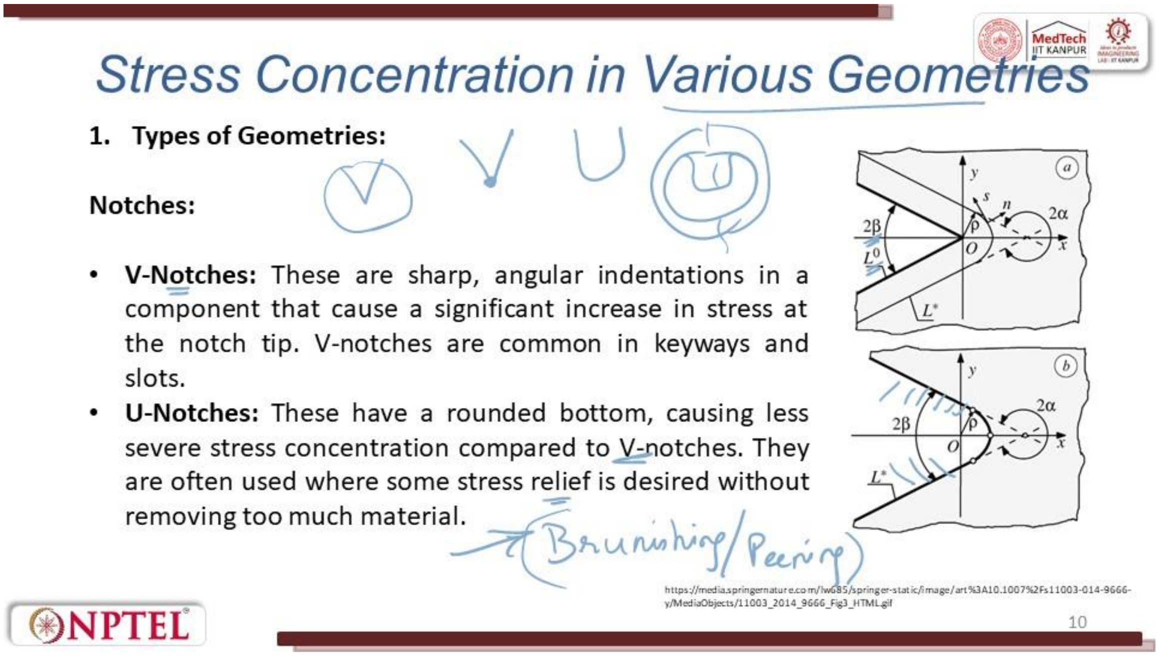
You have a shaft, you have a hole made, right. You have a shaft, you have a shoulder made. So at these places there will be discontinuity in the system. Proper design and finishing are essential to prevent fatigue failure, particularly in rotating shafts subjected to cyclic bending or torsional load. Cyclic bending means it goes up and down.

Torsion means the resistance, right. Torsion, rotation, torsion load. So this comes exhaustively sir. Nowadays the shafts are made out of plastic. The coupler is made out of plastic.

Shafts are made out of steel. Coupler are made out of plastic. So all combinations are coming up today such that they make sure that the stress concentration is not transferred to the shaft. Aircraft structures. So when we aircraft components such as fuse large panel, wing spar, ribs etc. often have cutouts or riveted holes, which are the source of stress concentration.

These are the spots for stress concentration. These areas are carefully analyzed and designed to prevent crack initiation and progression. So when the hole is there, the crack can form like this. This crack can go on driving it. So crack initiation, that's what they say.

Crack initiation, prevent crack initiation and crack progress. This is crack. And the direction is progression. Under various loads.



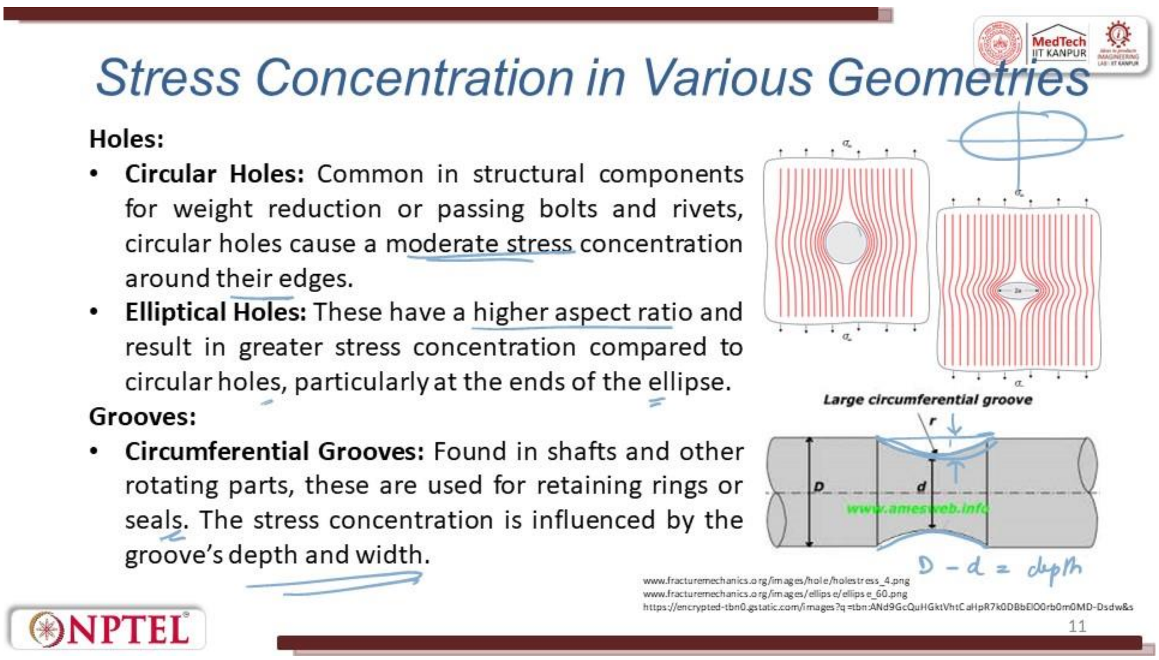
The Stress Concentration in Various Geometries. You can have a V notch, U notch. V notch, these are sharp angular indentations in the component. Thus, that causes a significant increase in the stress at the notch tip. V notch are common in keyways and slots. When you have a shaft, they always try to have a V notch.

When you have a shaft, they try to have a U notch. V notch is easy to make because the tools are sharp and you just cut across. You can do a shaping operation. You can do a milling operation you get. But U has advantage compared to V.

U notches, so you see here V, we always specify all these things. What is the angle which is there and what 2 beta is the angle and this also we specify what is the angle L naught. We specify and then we try to do the geometry. These are all important for stress concentration. U notch, these have a rounded bottom causing less stress concentration compared to V notches.

They are often used where some stress relieving is desired without removing the material. So, sometimes what we do is we also try to do an operation called as Burnishing. So, we try to press the material or we try to do peening. Sometimes we do roller burnishing. With some geometry we try to do peening.

So all these things what it does is it tries to create a radius and also introduces compressive strength. So the machining process plays an important role of introducing compressive stress on these elements.



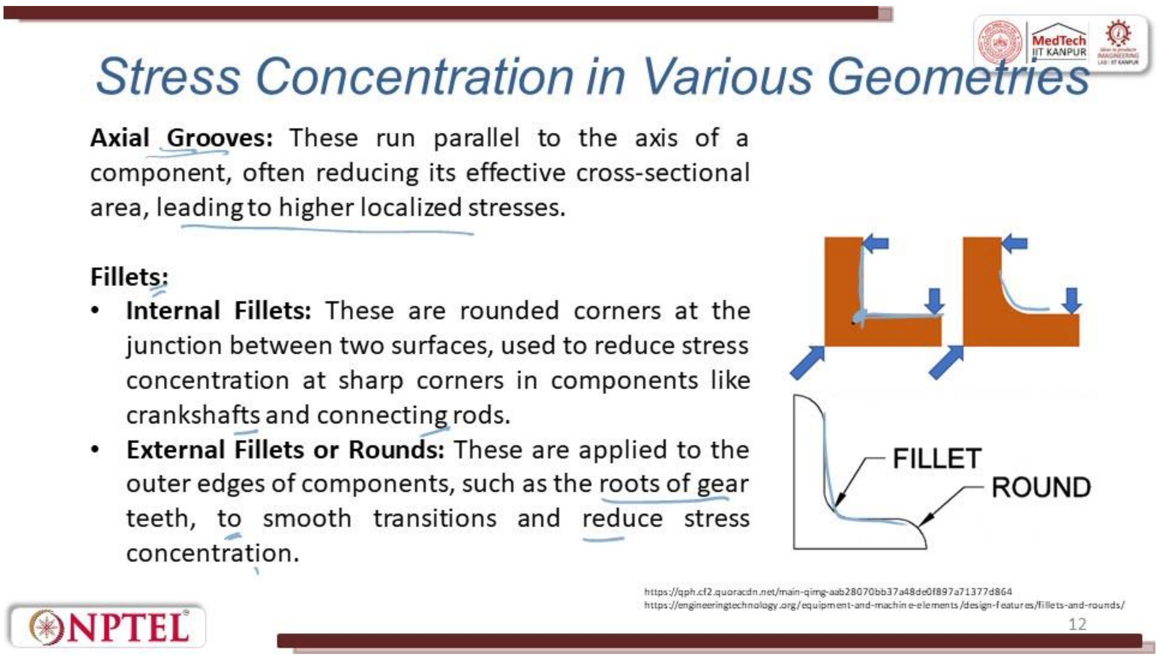
Holes can also be thought of. Look at it here, different geometries. We studied V notch, U notch. Then we are trying to look at circular hole, elliptical hole. Circular hole are commonly made because we have a drill, we make a hole, so you get this geometry. Common in structural components for weight reduction or passing bolt and rivets.

Circular holes cause a moderate stress concentration around their edges because they do not have an edge. So they always try to create a very small moderation on the stress concentration.

So we always try to do a hole in the component. Elliptical hole, they are very difficult to make. These have a higher aspect ratio because it is an ellipse. And results in greater stress concentration compared to circular holes. Particularly at the end of the ellipse.

Where do we use? We have very particular applications for elliptical holes to be made. But generally we do it with circular holes. Grooves. These are grooves. Circumferential grooves found in shafts and other rotating parts.

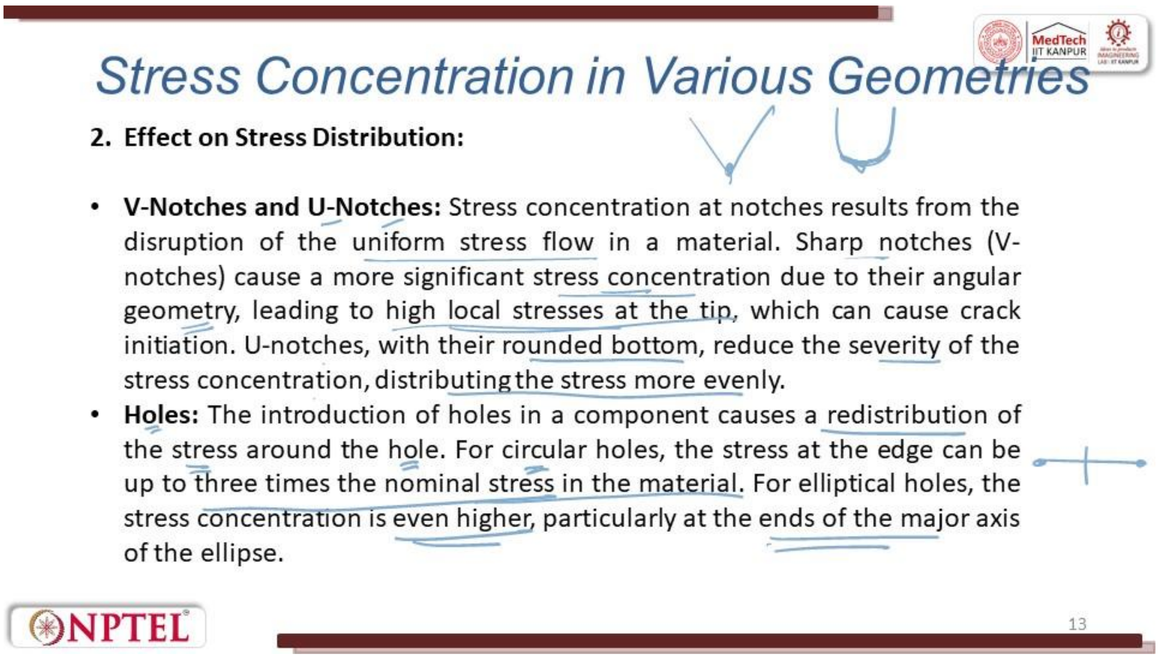
These are used for retaining rings or sleeves. The stress concentration is influenced by groove depth and width. This is groove depth and width. So, you see that there is a D minus d will give you the depth. And then this radius R will try to give you the widths.



Axial grooves are also there. These are Axial grooves. So Axial grooves, these run parallel to the axis of the component. Often reducing its effective cross section area leading to higher localized stresses. These are also axial grooves are also there.

Fillet is one thing which we always give. Fillet is nothing but radius we give. Internal fillet, External fillet. Internal fillet, these are rounded corners at the junction between two flat surface used to reduce stress concentration at the sharp edge. So, there is a change of geometry.

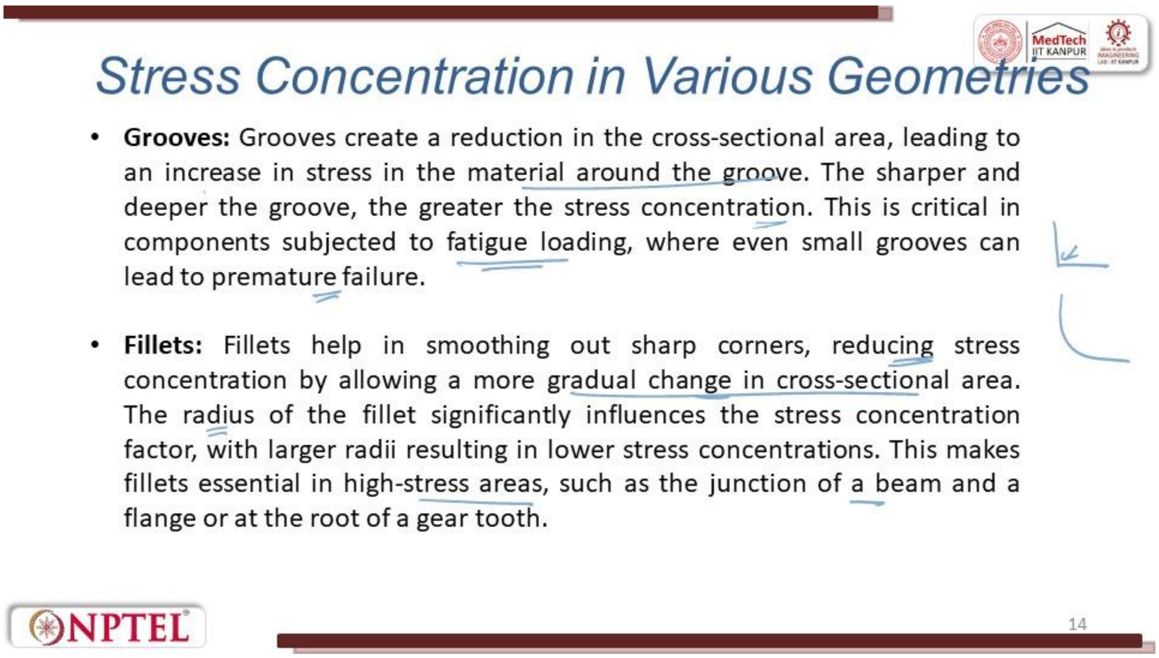
This is a sharp edge. So, here in order to avoid the sharp edge, we always try to give a fillet. Used to reduce the stress concentration at sharp corners in components like crankshaft and connecting rod. External fillet are rounded. They are applied to the outer edge of the component such as the root of the gear teeth and smooth transition and reduce stress concentration to smooth transition and reduce stress concentration.



Effect of on Stress Concentration. V notch and U notch. In V notch and U notch, the stress concentration at notches results from the disruption of the uniform stress flow in a material. The sharp notches cause significant stress concentration due to their angular geometry leading to high local stress at the tip which can cause crack initiation, U notches with their rounded bottom reduce the severity of the stress concentration and distribute the stress more evenly. V versus U. U notch with its rounded bottom reduces the severity of the stress.

So the stress concentration can happen anywhere. Severity of the stress concentration and distribution of the stress more evenly. When we talk about two types of holes, Circular and Ellipse. Holes, the introduction of the hole in a component causes a redistribution of the stress around the hole. For circular holes, the stresses at the edge can be up to three times the nominal stress in the material surface.

For Elliptical hole, the stress concentration is even higher, particularly at the ends of the major axis. So, we will always prefer U knots, we will always prefer circular holes, right.



Grooves, so increase in stress in the material around the groove. The sharper and deeper the groove, the greater is the stress concentration. This is critical in components subjected to fatigue loading when even small grooves can result in a premature failure.

This one. Fillet helps in smoothening. So this one. Fillet of the sharp corners reduce stresses and stress concentration by allowing a gradual change in the cross section. The radius of the fillet plays a very significant role.

This makes fillet essential in high stress areas such as junction of a beam and flange at the root of a gear tooth. We split and we take into next lecture.

So, thank you very much.