Engineering Fracture Mechanics
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Module No. # 01
Lecture No. # 01
EFM Course Outline

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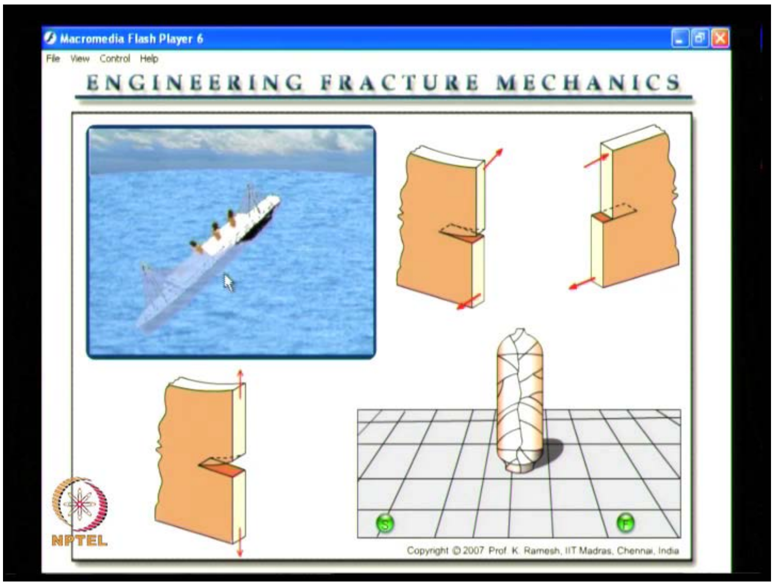

This is the first lecture, in the course on Engineering Fracture Mechanics. The two corner animations give the motivation, why you need to study Fracture Mechanics. There have been spectacular failures of structures, made of ductile material. They fail in a brittle fashion. The other two corner animations focus on the modeling issues in Fracture Mechanics. You have a crack and the crack faces are moving different in each of this. So, you have this as Mode I, this is opening up. This is sliding, this is known as mode II and this is a tearing action, this is called as mode III.

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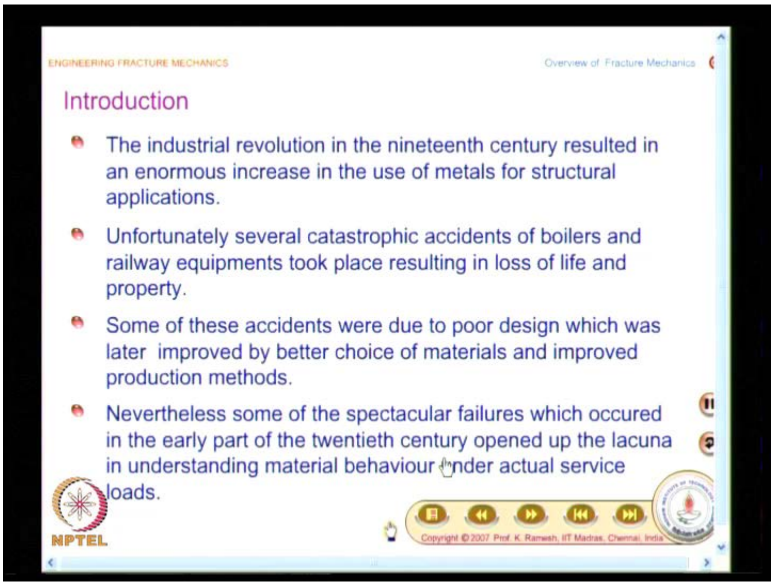

Before, we get into the aspect of Fracture Mechanics; let us, look at the History. See, History is very important. In any subject development, you have to look at, what prompted the people, to arrive at this kind of a methodology. And, if we really look at, it is only in the nineteenth century, when there was industrial revolution; you see an enormous increase in the use of metals for structural applications.

So, earlier, people were not using constructions made of metals, there was an explosive use of metals. So, when you have an explosive use of these metals, you need to understand, what their structural behavior is. So, people have devised a simple test to understand. And, I have also evolved the methodology. And, you will also have a look at you know, a demarcation between what is Art and what is Science. In fact, many of these scientific developments were originally practiced as Art. If you look at the famous sculpture of a horse, standing on two hind legs was designed by Leonardo Da Vinci. Only, he had the idea, how to design it. Others were not knowing what principles behind it are.

So, it was practiced more like an Art to start with; only, a very few individuals, who had an idea, how the structure would behave in reality. Once, more and more people get involved, people conduct tests and try to formulate a mathematical framework and try to capture there understanding as equations. Once, you have it as equations and then you can train many people to practice this. Then, it becomes Science. So, in the initial stages, you find that people used it as Art, later it developed into a Science. And, as I mentioned, when they started using structures made of metals, they had to come up and deal with catastrophic failures. You had accidents. They had design, so that, it functions well. But, there were accidents. So, what you will have to do? You will have to go back and find out, how you can prevent some of the risk. And, if you look at, you know, pressure vessels are very important. You know one of the earliest development in modern Science was, they had developed locomotives and locomotives had boilers and boilers are essentially pressure vessels. And, you come across pressure vessels, in many of our day to day life. You have the Indane gas cylinder, it is a pressure vessel. If you go to kitchen, you have the cooker, that is, a pressure vessel. On the other hand, if you go to aircrafts, they are again pressurized vessels.

So, pressure vessels are very important aspect that needs to be understood well. But, you had catastrophic accidents of boilers. So, that means what? The knowledge at that time was not sufficient to prevent these accidents. So, they decide to look at, what to do. And, they were able to trace out that some of these accidents were due to poor design, which was later improved by better choice of materials and improved production methods. This is very important. See, if you look at any scientific development, there was always a parallel development on material development. And, as people understand the structural behavior, they also felt production methods play an equal goal. You cannot have a design delinking the production method. You have to have an integrated design. That is how, now, modern design looks at any design scenario. You have integrated manufacturing and design. People do not do design say individually.

So, this was also known by earlier engineers and they try to look at, what was the cause of those catastrophic accidents. When they identified that, they were due to poor design; they were able to improve it. When they find that, strength of the material has to be improved, they went in for alloying the materials and new materials is developed and they also improved the production methods.

So, there was scope for improvement for all this. So, you reach a stage, where you find that, you have understood everything. And, no harm will be done. But, that was not the case. So, if you look at, there have been spectacular failures, which occurred in the early part of the twentieth century; because at some point in time, you decide, you have understood, what the structure is, how do they behave in actual service condition. You find that, there is a lacuna in understanding. Your simple remedial solution like improving the design or changing material was not sufficient. So, they had spectacular failures, which opened up the lacuna, in understanding material behavior, under actual service loads. So, once you understand that, you have spectacular failures, you have to deal with it. There is no other go.

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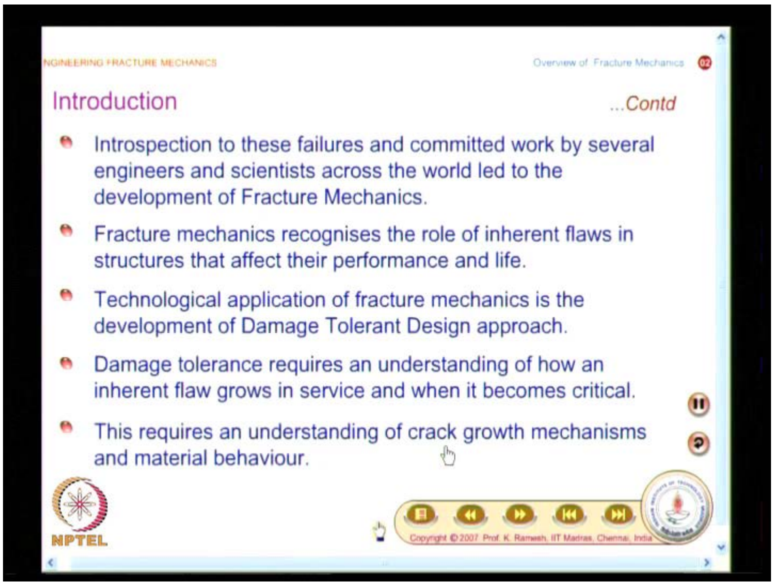

So, introspection to these failures and committed work by several engineers and scientists across the world, led to the development of Fracture Mechanics. In fact, we are going to have a detailed study on these spectacular failures. Learn them, case by case and find out, what aspect of understanding has to be improved. We will look at it, a little while later.

Now, we will have an overall course outline, in a very brief fashion. So, what is the fundamentally different term Fracture Mechanics? See, you have been studying strength of materials or mechanics of solids or advance mechanics of solids, in all those courses you have idealize the material is homogeneous. And, it is also an elastic continuum. You never recognize inherent flaws. Some of the spectacular failures have opened up that, inherent flaws grow in service and they lead to failure.

So, the fundamental aspect of Fracture Mechanics is, it recognizes the role of inherent flaws in structures that affect their performance and life. So, you need to understand this, and, what is the technological application of Fracture Mechanics? Understanding the role of flaws, does not help you to design the structure. You will have to utilize that knowledge in a meaningful fashion.

So, what you have is the concept of Damage Tolerant Design approach. We know that, there are inherent flaws and we need to find out, when there are inherent flaws, how do I tolerate it, how do I make my design methodology; so that, it is damage tolerant. So, when I have to have damage tolerance, if I have to do that, it requires an understanding of how an inherent flaw grows in service and when does it become critical.

So, you need to collect lot more data, you need to have better understanding of, how the crack will grow in service and what periodicity that, you have to go and inspect. You have to collect this kind of data, before you embark on Damage Tolerant Design approach. And obviously, this requires an understanding of crack growth mechanisms and material behaviour.

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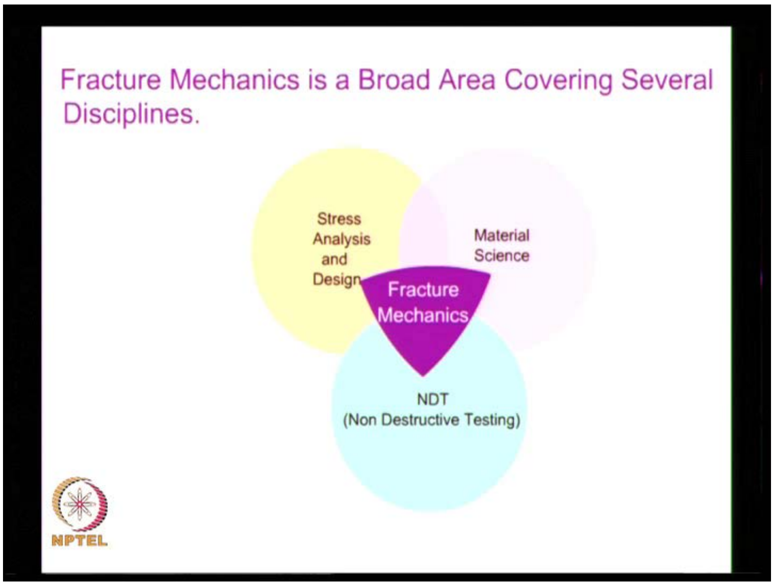

There are many crack growth mechanisms. And, if you really look at, Fracture Mechanics is a broad area covering several disciplines. You need to have Stress Analysis and Design, you need to have knowledge of Material Science and you need to employ Non-Destructive Testing to monitor the crack growth and also, for periodic inspection. So, the confluence of these three fields, give rise to an understanding of, what is Fracture

Mechanics. And, in fact, a little while later, you will look at in detail, what aspects that you will do in Stress Analysis and Design, what aspects you will do in Material Science, and what aspects do we look for in the Non-Destructive Testing. And, I would like you to make a neat sketch of this. And, this gives in a nut shell, what is Fracture Mechanics is all about. So, you need to have combination of Material Science, Non-Destructive Testing, Stress Analysis and Design.

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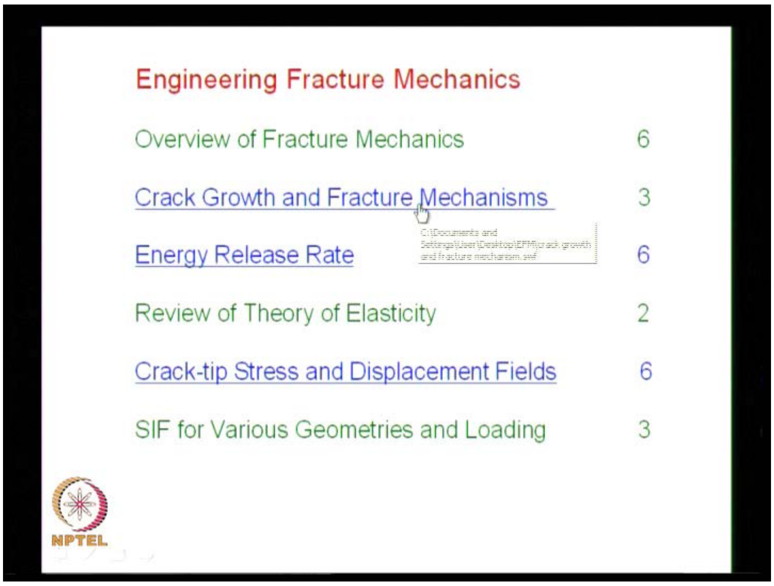

Now, we will have a brief outline of, what is the course will be. So, I will have the first set of six lectures, on Overview of Fracture Mechanics. This would be followed by Crack Growth and Fracture Mechanisms. You know, in this outline, you may not be able to appreciate some of the terminologies. But, you will definitely come across, what is a jargon used in Fracture Mechanics. So, that is what, you will be able to get from this outline. So, this will give you an idea, what will be the course structure. And, for these lectures hours are approximate. We may have a lecture more or lecture less. So, this will be followed by Energy Release Rate. And, that will be for about six lectures. Then, you will have Review of Theory of Elasticity. That will be for two lectures because you need to have this background, for developing Crack-tip stress and Displacement field equations. So, that will be for about six lectures. And then, you will have in Fracture Mechanics, you have a parameter called Stress Intensity Factor; abbreviated as S I F. This, we will look at, for Various Geometries and Loading. This is simply for three lectures. And, if you really look at, for all of these chapters, you will have support of animated slides. That will help you, to understand the concepts in a very convenient fashion.

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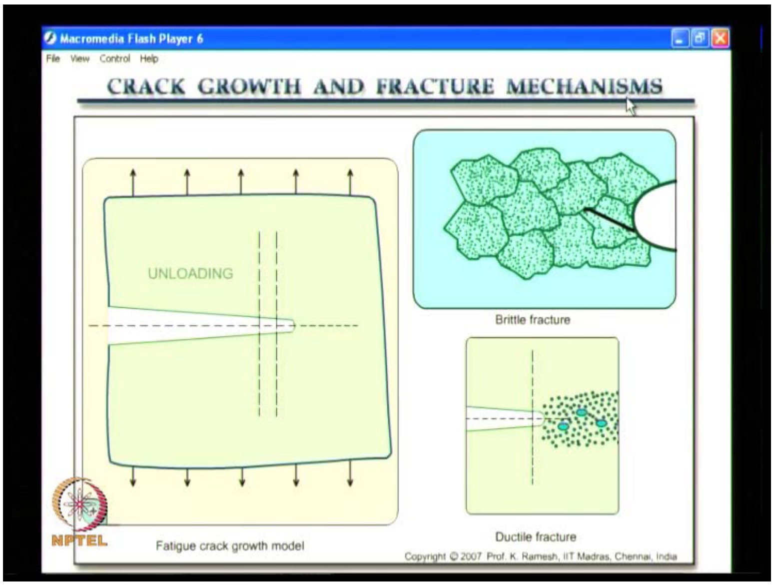

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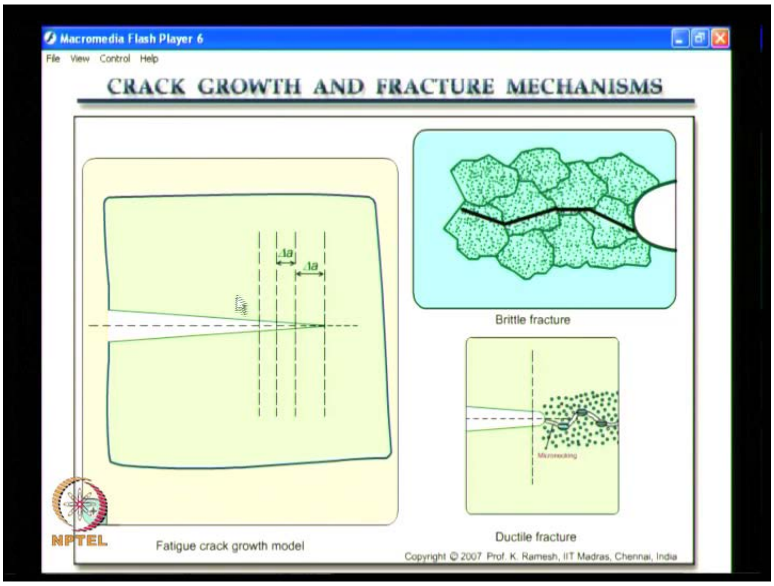

For example, in Crack Growth and Fracture Mechanisms, we will talk about brittle fracture, we will also talk about ductile fracture and we will also look at several crack growth mechanisms. And, this animation shows, in a nutshell, what happens, when crack grows by the process of fatigue.

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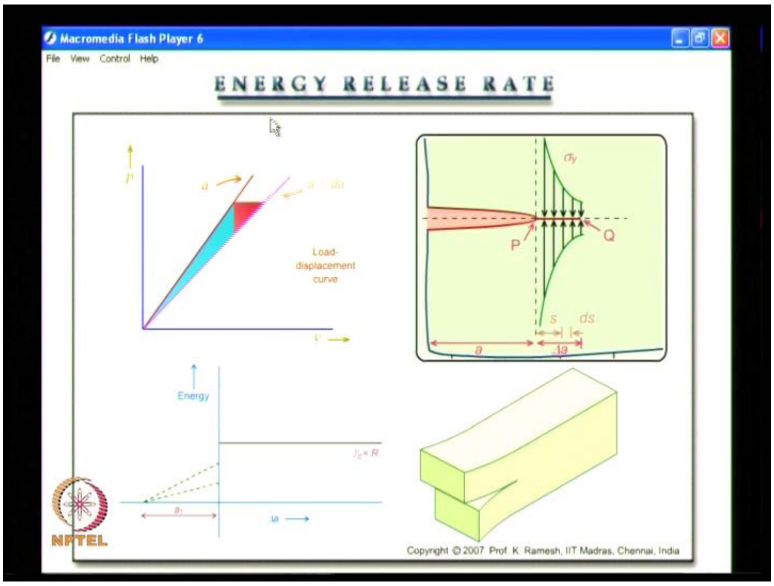

You know, I planned to show for a few chapters, the type of animations, that would give you a motivation for you to look for the kind of information, you will learn in this course. And, one of the very important topics in Fracture Mechanics is Energy Release Rate. You would essentially, want to find out, what is the energy required for crack to propagate. But, what we will do is, we will find out the energy require to close. We will develop the Mathematics behind it. And, we will idealize the situation. From, then on, we will find out, what is energy for require for the crack to grow.

And, in the context, we will also see, what the energy availability is in constant load, as well as constant displacement. And, we will also talk about Energy Release Rate, as well as the resistance. These concepts will come under the topic on Energy Release Rate.

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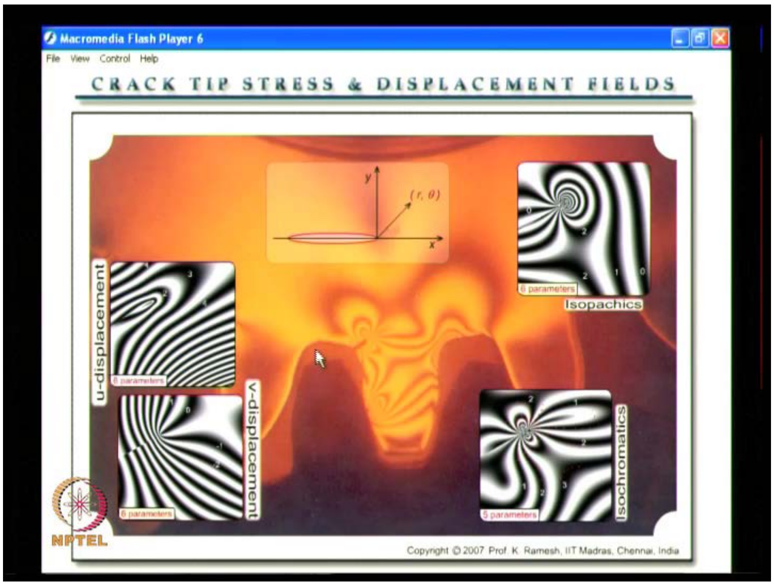

Then, we move on to Crack Tip Stress and Displacement Fields. And, if you watch it carefully, you know, you have a gear teeth and you have a crack in the tensile root fillet. And, if you watch it closely, I have this changing and if you look at, this is the function of number of parameters. And, this is for six parameters. It now, varies from parameter 2, 3, 4, 5 and 6. You will find the geometric features of these fringe pattern, is well captured, when I have more number of terms in the series. See, this is very important. The moment, you come to Fracture Mechanics, it is only experimentalist, who really focus on higher order terms and that, utility in experimental evaluation of fracture parameters.

And, what this slide show is, you have the Isochromatics from Photoelasticity, you have Isopachics from Holography, which are essentially contours of sigma 1 plus sigma 2. And, you have u-displacement isothetics; it is from Moire and v-displacement isothetics. And, you also have another important concept that, in the whole of these developments, we will take the crack tip as the origin. And, the x axis is along the crack axis and y axis is perpendicular to that. And, we would identify a point by r and theta. That is how; you will get the stress field equations. As an experimentalist, I would give you the infinite series solution, as part of this chapter.

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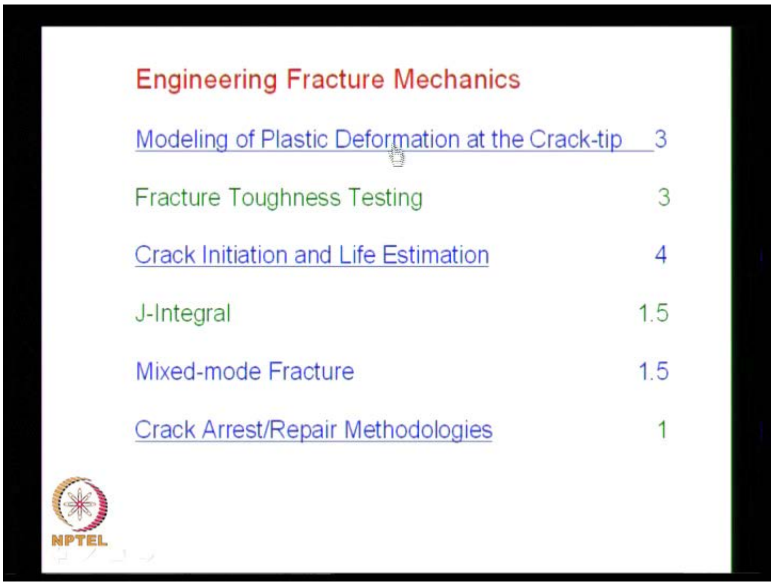

The next chapter would be on Modeling of Plastic Deformation at the Crack-tip. It is very important. Then, you have a new test to apply in Fracture Mechanics; you learn that in Fracture Toughness Testing. This is followed by Crack Initiation and Life Estimation. This really brings out the utility of Fracture Mechanics in monitoring crack growth. Next you will have a discussion on J-Integral. When you want to go from Linear Elastic Fracture Mechanics to Elastoplastic Fracture Mechanics or Non-linear Elastic Fracture Mechanics, J-Integral is a useful concept. This will be followed by Mixed-mode Fracture. And, finally we will also have a brief discussion on Crack Arrest and Repair Methodologies.

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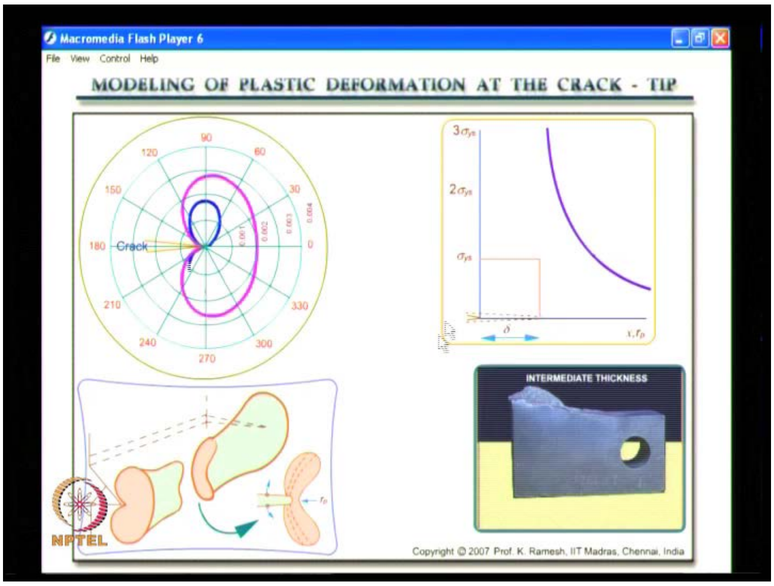

It is like, what I mentioned earlier for selected chapters, we will also have a look at, what kind of concepts that, we would learn. The shape of the plastic zone, at the crack-tip has attractor repulsion. There are different models for it. And, you also want to know, how the plastic zone does vary, over the thickness of the specimen. How does it look at the surface, how does it look at the interior and you will also like to know, how does it affect the propagation of crack, how does it propagate at initial stages, how does it propagate at the later stages.

Suppose, I have a crack and I have a plastic zone, how do I mathematically model it. There are certain simplified approaches, to take into account this plastic zone, in a convenient fashion.

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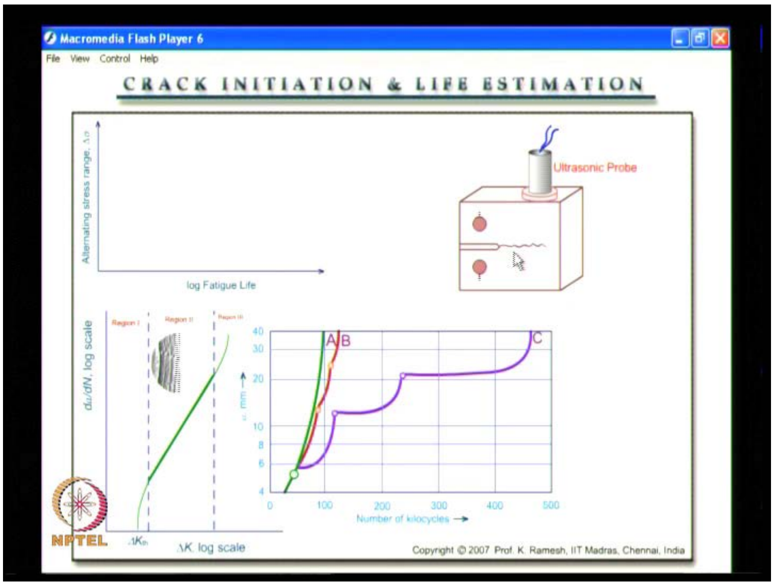

The chapter on Crack Initiation and Life Estimation is the real utility of Fracture Mechanics. And, you have to perform detailed tests, where in you develop crack growth curves, by monitoring a growth of the crack, as a cyclical loading is applied. And, from this, you try to get a sigmoidal curve, which shows from crack initiation to fracture. There is a particular phase, where this is linear; this zone is dominated by the formation of striations. We will look at, what those striations are. These are shown here. And, this is known as a famous Paris law, which controls the segment. And, this brings out, what is the role of crack initiation, how long does it take for the crack to initiate and how long it does it take for growth. And, this graph shows, what happens, when I have over load.

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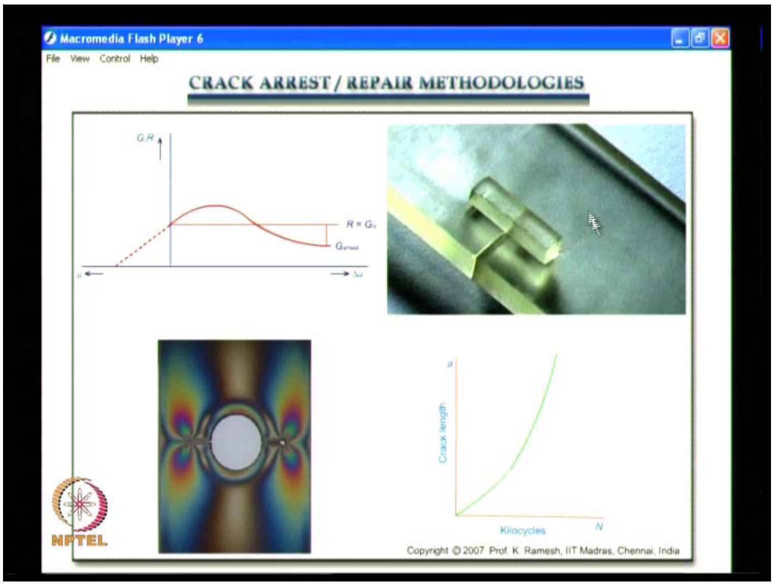

Finally, you know, you need to have methodologies for a crack arrest, as well as how to repair. And, this shows a patch and you find, I have a crack and the patch is put perpendicular to that. There is a reason for it. And, this shows another concept, by suitable methodologies, you are in a position to delay the crack re-initiation. This is what, you want to do. Here, because of a hole, the re-initiation of the crack is delayed. And, I would use extensively, the use of photoelasticity in bringing out various concepts of Fracture Mechanics in this course.

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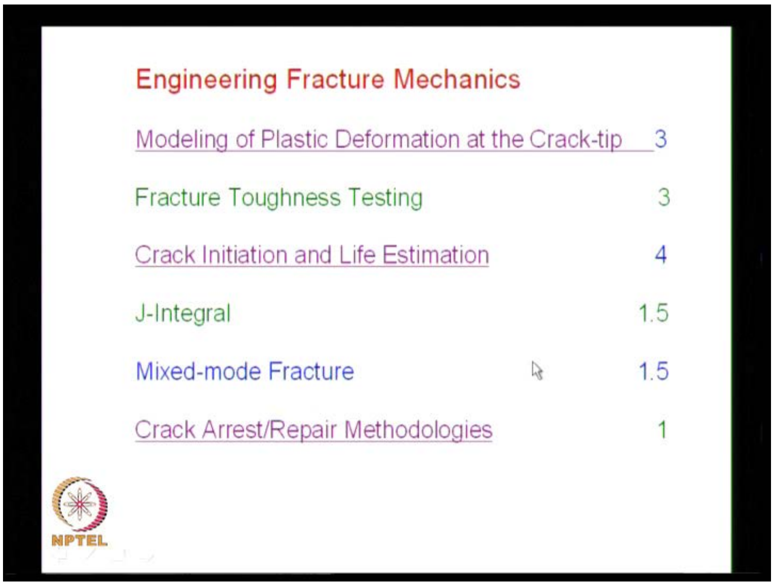

So, total lectures would be around forty. There would be some small variations, as we go by. It depends on the class. And now, what we will have to look at is, we have seen a brief outline of what is Fracture Mechanics. As a full course, before we get on to the full course, let us, review what we have learnt. And also, find out, what is it that, we have been able to use from that knowledge and what is the lacuna in our understanding earlier. And, what you will have to find out is, you have done a course in strength of materials, which is called as Mechanics of Solids in recent days.

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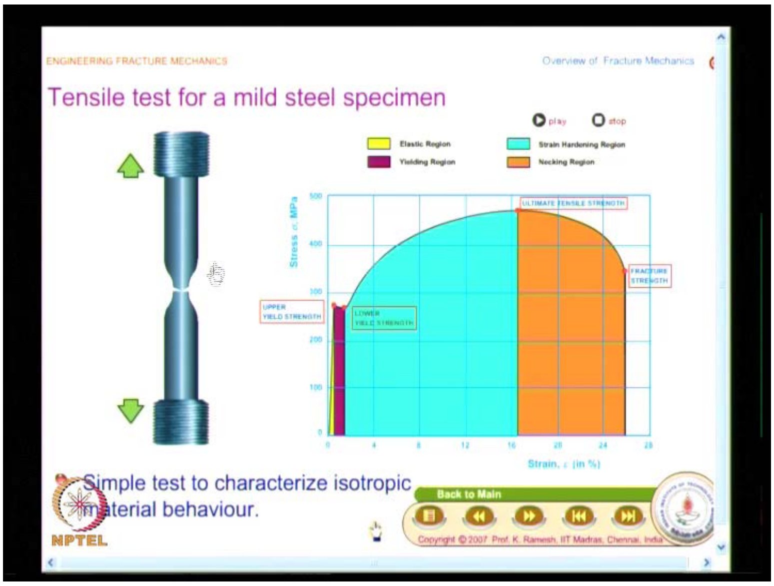

You have gained knowledge, the knowledge is useful, but it is limited. And, what you do in this, you have a famous tension test. And, you just watch this animation; there is synchronization between the rod being pulled and the graph here.

So, what you find here is, initially there is a linear region, then there is a yield region, then you have a work hardening and you reach the ultimate tensile strength, then you have necking takes place and finally, there is material separation. And, this is a ductile material. And, if you really go, you have codes exist on, what should be the type of the specimen that, you will have to use and how it should be graved, what should be the surface ridge that detailed codes exist.

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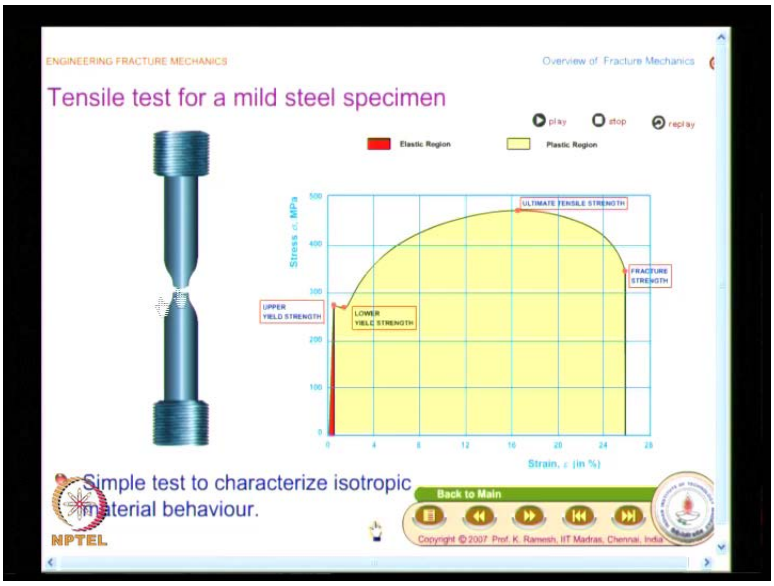

So, what you are going to do is, you are going to follow the code and perform this test. At the end of the test, what you get? You get this stress strain curve. And, what you find here is, you have the red shaded portion, this is the elastic region and what you have here is the plastic region. A plastic region is, very large in comparison to elastic region. And, as Mechanical and Aerospace Engineers, you all know, we design our structures, such that, the components remain within the elastic region.

And, what do you learn from this graph? Before material separation, you have a very long safe zone, where in, the material deforms plastically and gives you a warning. Before it separates, this is what, you anticipate, when I use the ductile material for structural application. But, this is not happen. In the case of spectacular failures, which I had shown earlier, you found that, structures made of ductile materials, suddenly, break like glass. Why this was happen? What aspect was it, not model in the conventional analysis? And, you can also look at one more aspect in this animation. This is a controlled animation, which we have done and you find this fracture is happening at the center of the specimen.

Just, go back and think, is that the way, when you recall the tension experiment that, you have done in your undergraduate course? Just, go back and think was it happening, at the center. I had shown that, as a center, it is a point to ponder, think about it. This is a very simple test and useful to characterize an isotropic material behavior. And, we will see, what it is, a little while later.

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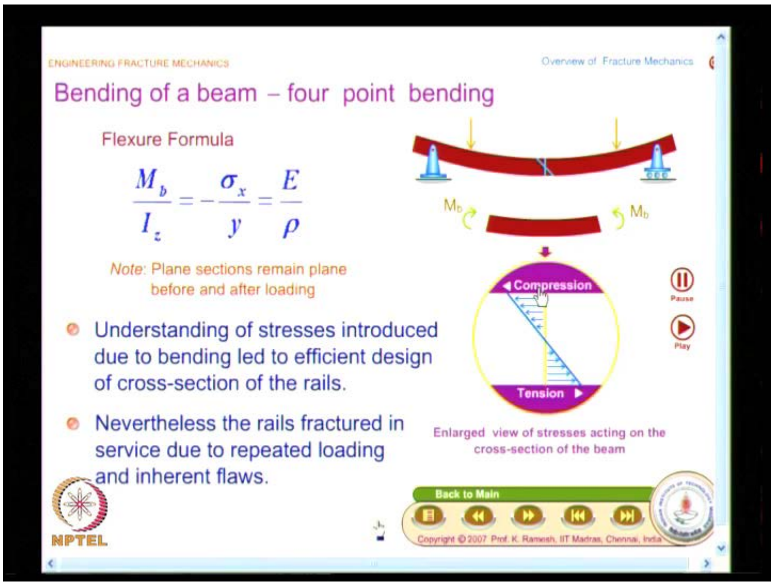

Then, we move on to bending. And, this is what, you learn in the first level course. So, you go to Bending of a beam and we take up four point bending. And, you develop the Flexure formula and you learn whatever the stresses due to bending are linear over the cross section. Over the depth of the cross section, it is linear, you have compression on the top fiber and tension in the bottom fiber and the inner core, does not contribute to load sharing.

So, this is very useful. You know, you have learnt a very useful knowledge. The strength of material course, what you have done is not a waste. What is attempted to be shown here is the knowledge, you gained is limited. With that knowledge, you could do certain kind of problems, but that knowledge alone is not sufficient, to address the kind of failures that, you come across in actual service condition. And, what you gain? Because of the understanding of bending, you are able to do efficient design of cross section of the rails.

If you had no understanding of bending, you would have taken a square section as a rail. You would not have taken, the "I section" for rails. This is the" I section". This is the photoelastic model. You would not have taken a section like this for rails. So, the knowledge of bending definitely helped. And, you have several thousand kilometers of railway line, so, you have enormously saved the material. So, the knowledge, what you have gained in strength of materials was useful. But, what happen? The rails fractured in service, due to repeated loading and inherent flaws. So, you need to do something more.

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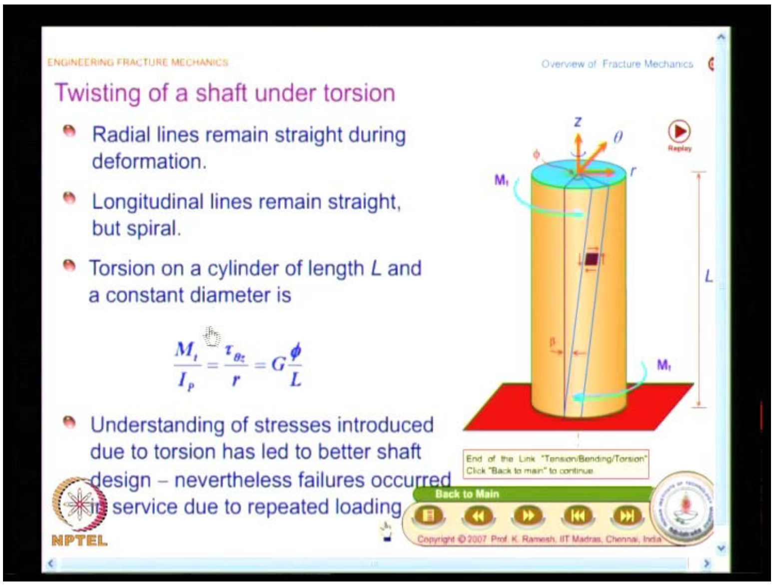

The next one, you learnt in a first level course is what happens in the case of torsion. So, you go for Twisting of a shaft under torsion. You take a circular cross section because you want to avoid solving differential equations. You want to invoke plane section, remain plane before and after loading. And, similar to the Flexure formula, you develop the torsion formula. And, this again, shows the shear stress varies linearly over the cross section. It is, maximum at the boundary and 0 at the center.

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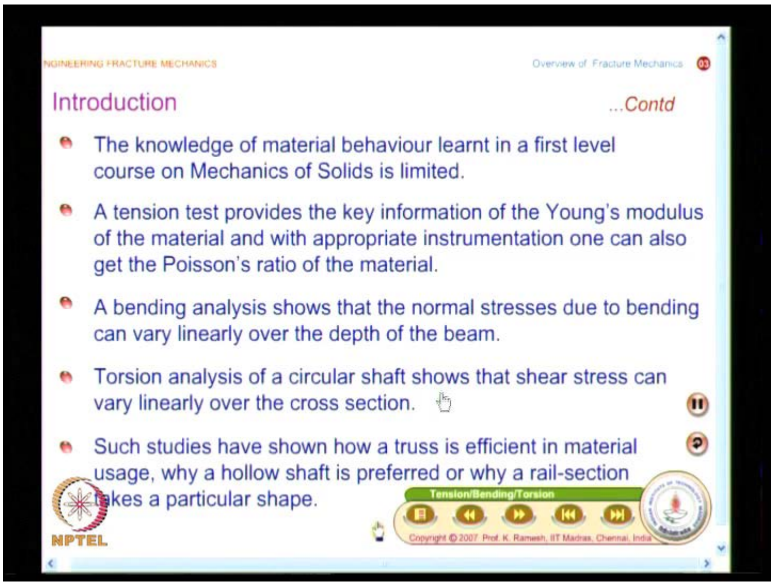

So, what have we got from the tension test? I said that, you can find out the parameters to characterize an isotropic material. And, if you really recall your understanding of Solid Mechanics, you need two elastic constants to characterize the isotropic material. I can get both of this, from a tension test. I can get the Young's modulus and if I have an appropriate instrumentation, I can also get the Poisson's ratio. So, what we have achieved was, by just performing one material test very carefully, you have been able to characterize the metal for doing simple designs; absolutely, no problem.

And, your knowledge of bending, as shown that, normal stresses due to bending, can vary linearly over the depth of the beam. Otherwise, you would not have understood this. And, in torsion analysis, the shear stress varies linearly over the cross section. And, what is the ultimate advantage of this? Because of a first study in strength of materials, you have been able to understand, how a truss is efficient in material usage; because the entire cross section participates, it is supporting only axial load. Why a hollow shaft is preferred and why a rail section takes a particular shape? So, definitely the first level of the course has given you certain level of understanding. But, the knowledge is limited. And, you have banked on one simple tension test, for application of this knowledge to designing structures.

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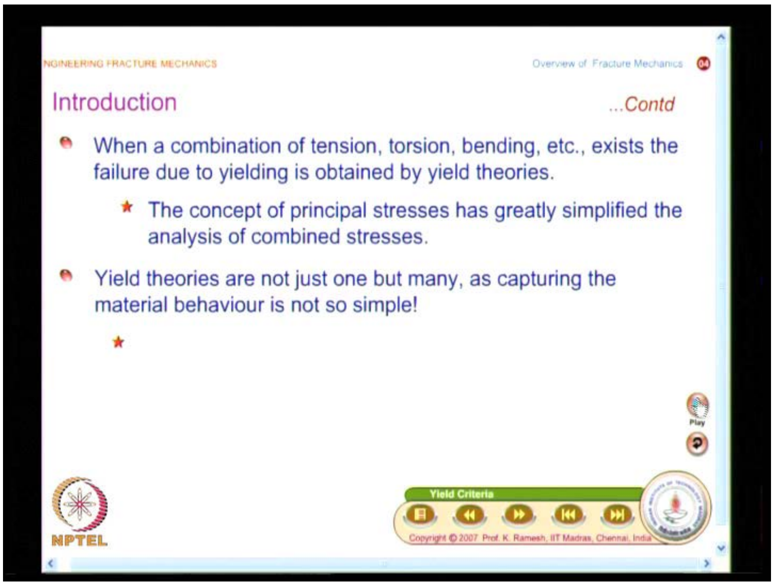

In a real life situation, what happens? You have tension, you have torsion, bending, all exists together with various proportions. Suppose, I have a combination of this, how do you handle this? This is done by yield theories. And, what you do in yield theories? You have the concept of principal stresses develop, which has greatly simplified the analysis of combined stresses. If I do not have to worry, I learn tension, torsion, bending separately, but if I find all of them exist with various proportions in an actual structure, I can always find out the principal stresses and invoke the yield theories. And, when you look at the yield theories, are they just one? You did not have. You had idealize the material is homogeneous, you would also idealize it is an elastic continuum, you did not consider inherent flaws, with all such simplification, when you want to go and analyze a structure with combined loading, you invented the concept of principal stresses which simplified drastically. But, you could not have just one yield theory to analyze and predict, what would happen to a ductile material.

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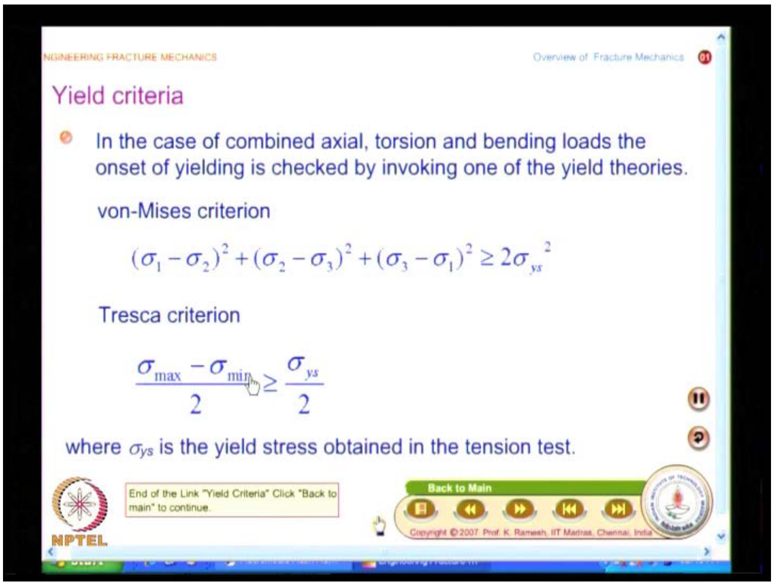

So, you have different yield criteria. This is more like, review of your strength of materials, it is good, it is better that your notes has these equations. So, you have the famous von-Mises criterion, which uses all the three principal stresses. So, I get this as sigma 1 minus sigma 2 whole square, plus sigma 2 minus sigma 3 whole square, plus sigma 3 minus sigma one whole square, should be less than or equal to 2 sigma y s squared, for yielding not to take place. If it is more than this, yielding will take place. And, this yield strength was obtained from a simple tension test. What is the advantage of yield criteria is it has greatly simplified the investigation of what happens, what causes yielding; because yielding was considered as a failure in the initial stages of structural application of, whatever the knowledge you gain in strength of materials. People did not want to have the structure, any part of the structure, to become plastically deformed. Because when you make a structure out of ductile material, we have seen from a tension test, after lot of plastic deformation only the material separation occurs; because from a design point of view, we do not want fracture.

So, even, when the material yields, if you are able to take corrective measures, the structure is safe. If the structure behaves like that, there would not have been any Fracture Mechanics. But, structure did not behave like that in actual service condition. And, you had von-Mises criteria and you also had Tresca yield criterion. The moment, you come to Tresca, it is done slightly, differently and the mathematical calculation is very simple. But its utility you have to be very careful. It says only sigma max minus sigma minimum, is greater than equal to sigma y s.

So, I essentially, find out the maximum shear stress and I compare it, in a tension test and if it is within that, yielding will not occur. If it is greater than that, then yielding will occur. And, when I apply this, I have to be careful in identifying, what sigma max is and what sigma minimum is. See, this is where, many students make a mistake.

Suppose, I have both the principal stresses are positive, when both the principal stresses are positive or negative, you have the third principal stress as 0. And, this is very important. So, the sigma minimum will become differently; when it is positive, when it is negative. When both the principal stresses are positive, sigma minimum will be 0; when both the principal stresses are negative, then sigma minimum will be something else. So, you have to be careful about the role of the zero stress.

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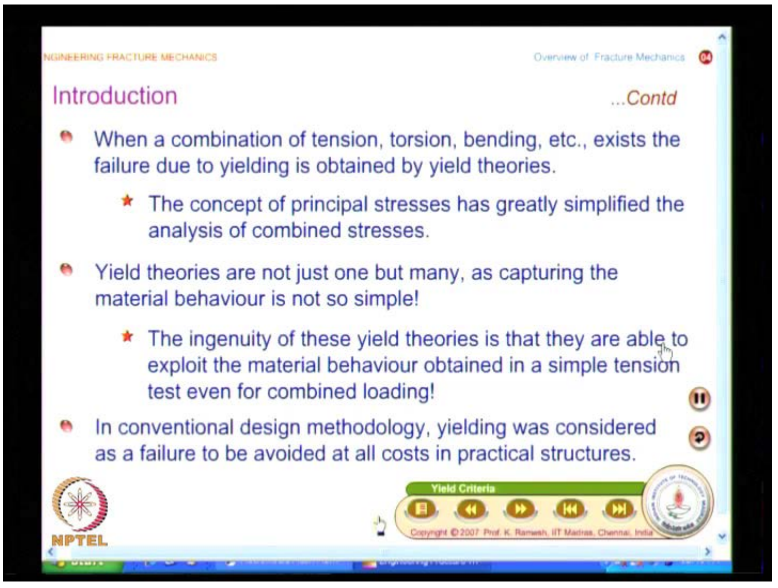

So, what we have just now, saw was that, yield theories are not just one, but many. Why it is so? Because capturing the material behavior is not so simple. Suppose, I graduate from simple strength of materials to Fracture Mechanics, in simple strength of material itself, I had many theories. You cannot simply say I am doing an Advanced Fracture Mechanics.

So, I should have only one theory for fracture to be defined. It is just not possible. You will find one of the important aspects in Fracture Mechanics is, in which way the crack will propagate. There are many theories to say, to find out, which way the crack will propagate. You do not have one theory. Whatever, we have learned in strength of materials or whatever, the kind of procedures we adopted, similar procedures exist in the Fracture Mechanics also.

That is how, we learned the subject. You had one simple tension test; you are able to answer certain questions. Then, you realize that tension test is not sufficient. So, you need to go for little more tests. And, what people have done in those days, we will look at it. Though, you had many yield theories, what is the advantage of these yield theories? The ingenuity is that, they are able to exploit the material behavior obtained in a simple tension test, even for combined loading. See, if you are not learned this course, and learn the yield theories, suppose, you want to find out, whether a structure will remain safe in the actual operating, then you have to take the structure and apply the actual service loads and then, will may find out, how the failure will occur. In fact, this is done for aircraft and locomotives, as well as the passenger cars. But, you do not do it for day to day small components. So, routine components are designed based on design methodology. Otherwise, the cost will enormously increase; because one of the greatest difficulties in design is, how to identify the service loads. You may not have modeled all aspect of service load, in your design calculation. So, that is the reason people go for finding out test on actual structures. And, if you finally look at, in conventional design methodology, yielding was considered as a failure to be avoided at all costs, in practical structures.

So, this they have realized. Yielding should be avoided at all cost. And, you had several yield theories. So, this was one of the failure modes; see, when you say failure, you should quantify, what you mean by failure. One definition of failure, in conventional design methodology, was yielding should not take place at any portion of the structure.

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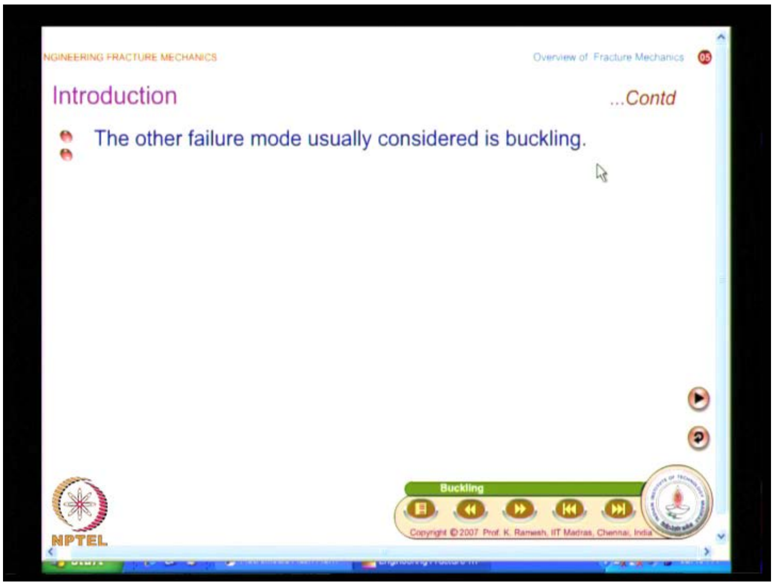

What are the other criteria? The other criterion is people considered buckling as a failure mode. And, what is it that you have learnt in buckling?

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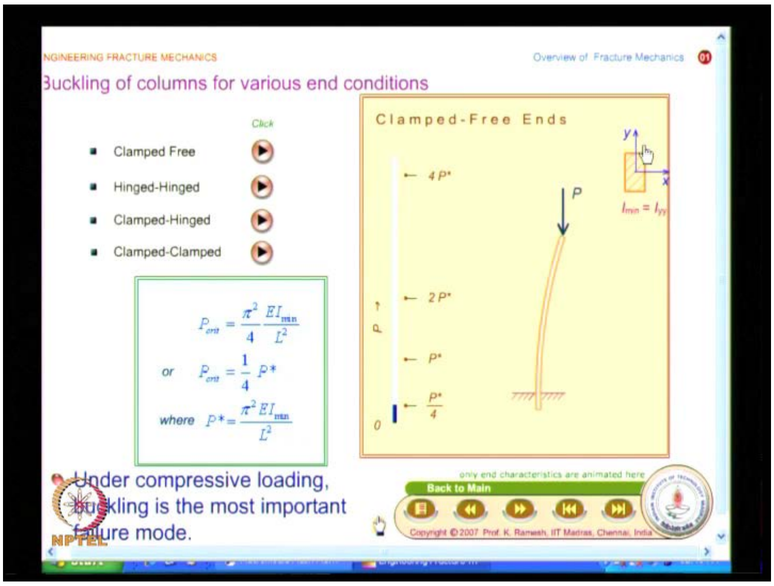

In the first level course, you simply do column buckling. And, you look at it, for various clamped end condition. And, we will see for a clamped free type of column, how the buckling occurs. And, you see that a column, which was straight, when the load is sufficiently increased, it has taken a buckled shape. And, it is shown that, it is buckled in the plane of the screen. Why it has happened in the plane of the screen? If you look at, I have a cross section, which is rectangular like this and we also have the concept of moment of inertia and you find that, I minimum is I y y. I have shown that buckling has happened in one way.

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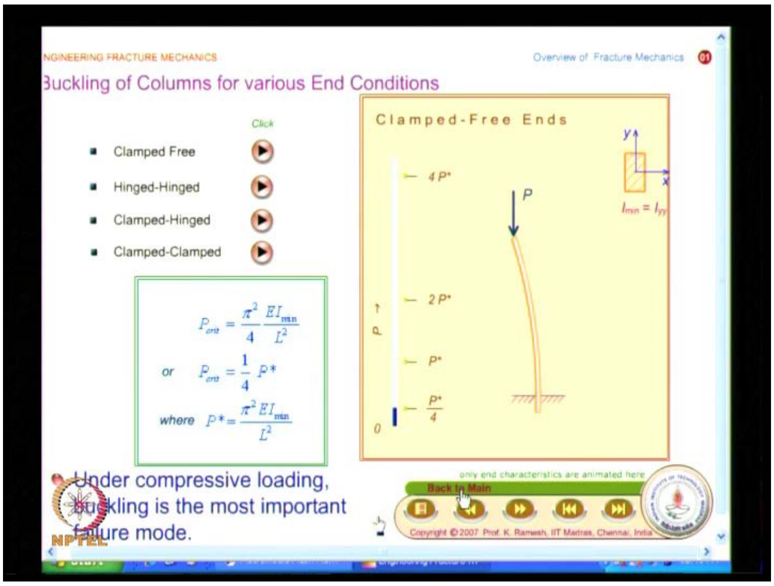

Suppose, I apply the load again, will it happen in the same fashion? Or, if I repeat the experiment, after a few days, will it happen in the same fashion? This is not so. We will see what happens. And, you find it has buckle in other way. Buckling can happen in this plane, either way. It is dictated by what? It is dictated by the kind of initial conditions. What are the kinds of imperfection that is, represented in the structure? These imperfections are never model, very difficult to model.

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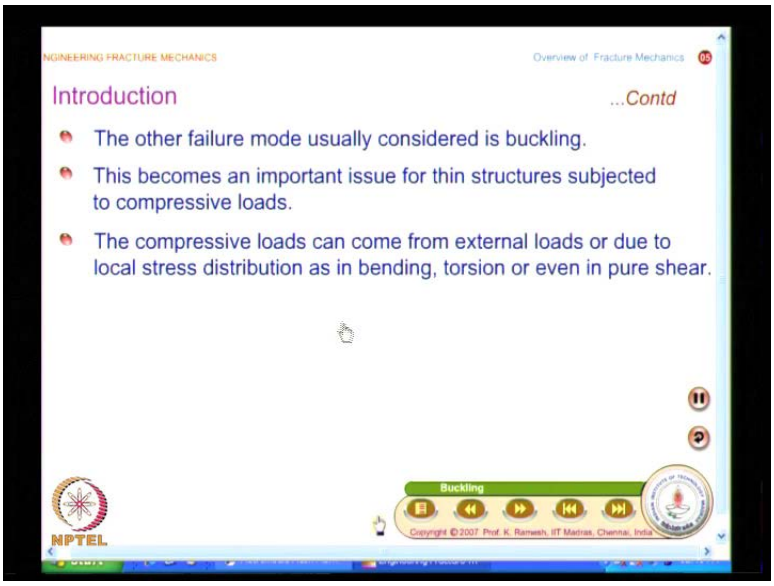

See, all along, you have been concentrating only on column buckling, but you have to enlarge this scope. Buckling becomes an important issue for thin structures, subjected to compressive loads.

So, you should not carry the impression, only columns will be buckled; because that is the danger. In the first level course, you have Mathematics developed, only to analyze columns. And, the time is sufficient, only to introduce this. By the time, the course ends.

So, you should not go with the mental picture that, only columns will be buckled. And, we have generalized it. Any thin structure, subjected to compressive loads can be buckled. Where do the compressive loads come? The compressive loads can come from external loads that is, obviously, seen in the case of a column buckling or due to local stress distribution as in bending, torsion or even in, pure shear. And, let us see an example, for each of these cases.

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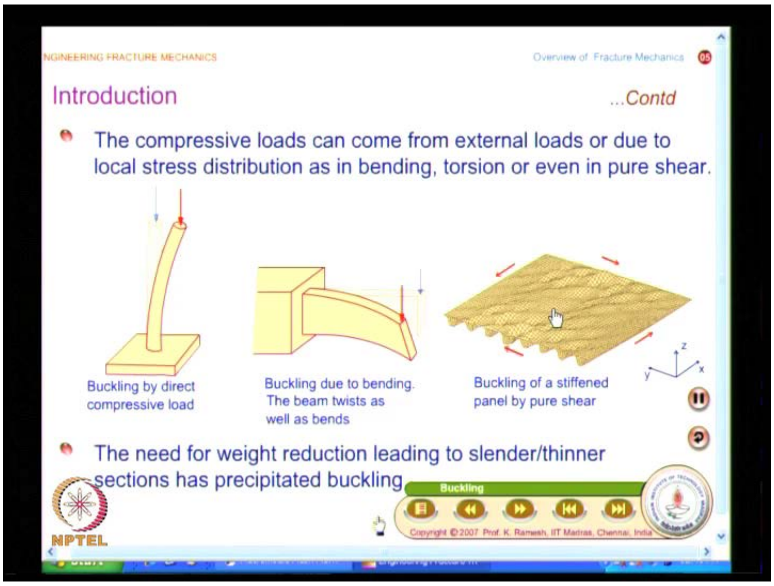

If we start with the column buckling, it is everybody knows and you have a buckling, due to bending the beam buckles and you have a panel, which is reinforced by stiffeners. And, as the shear is increased, you find that the surface as buckling. And, in the case of a beam buckling, what do you find here is, the beam bends, as well as twists.

And, you all know in the case of a bending, you have a tension side and you have a compression side. If you have a thin web, it can buckle also. So, buckling can be precipitated by bending. And, the third example shows, buckling is precipitated by shear and from your strength of materials, you all know, a pure shear state can be thought of as combination of tension and compression. So, what you will have to look at is, any thin structure, subjected to compressive load can buckle. And, why we go for thin structures?

See, now, we are living in a space age and we want to have structures that, are pumped into space, even if you reduce 1 kilogram of weight, you save enormous amount of fuel. And, when we talk about optimization, we want to remove extra material, wherever it is placed, which are unwanted. You would like to scoop out material. So, by all this processes, you are going in for thinner structures. So, one of the greatest problem in Space Technology is actually buckling.

So, the need for weight reduction, leading to slender or thinner section has precipitated buckling. So, when you are really looking at structure, in the larger perspective, you will have to define, what the failure is and that failure, should be addressed. So, do not think, always, there is material separation. Material separation is one of the aspects. Buckling could be equally a challenging problem that, you may have to deal with for the kind of design scenario, you are involved with.

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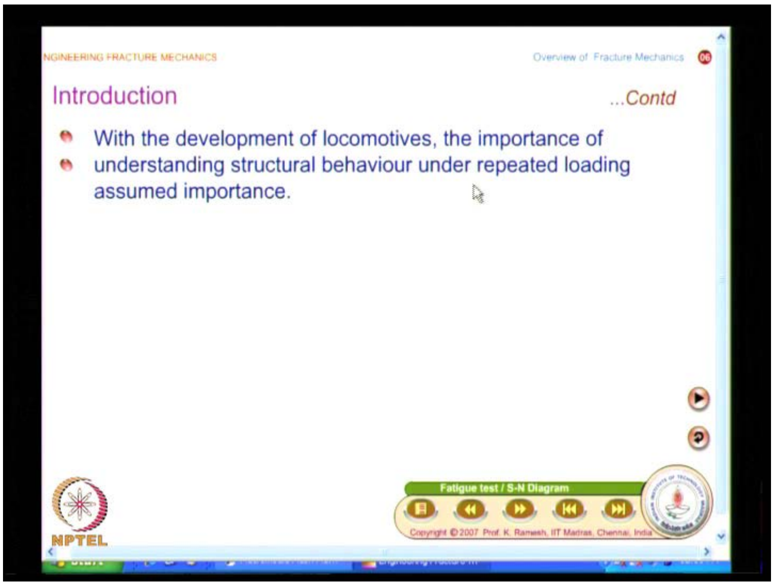

So, you have to define, what the failure is. And, this is what, you learn in the first level course. You will learn yielding should be avoided and also, you will learn that buckling should be avoided. And, you know, with the development of locomotives, the importance of understanding structural behavior, under repeated loading, assumed importance.

You know, you will be surprised. When, trains were introduced in the later part of nineteenth century, they were traveling at a speed of 15 miles per hour. And, the newspaper "New York" reported, it is traveling at such a terrific speed. Women and children will be annoyed. And now, you have trains traveling at the speed of 350 miles per hour. So, we have come a long way. We have been able to do that, mainly because you have better understanding of material. And, we will have to look at the need for understanding repeated loading; because in a tension test, what you do? You take a specimen and then, just pull. This is what, you do it. You have a tension test and then, you simply pull it, you are only applying a monotonic increase. You are not applying a repeated loading.

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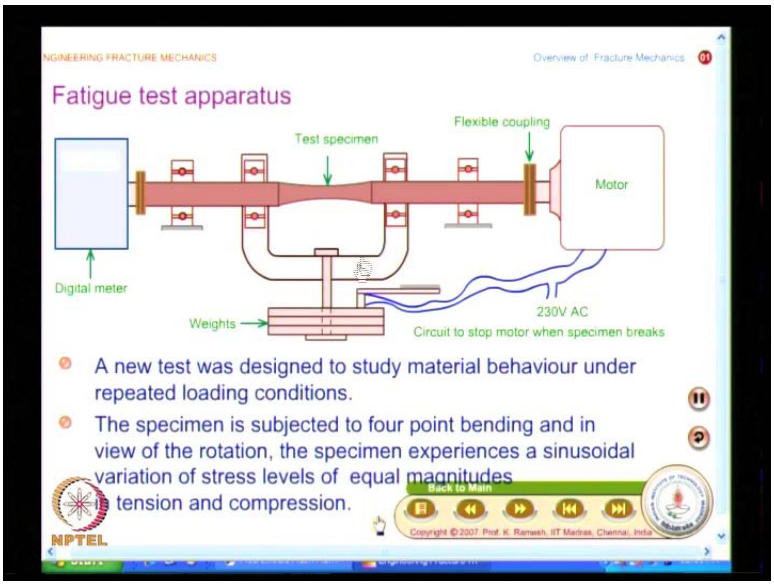

Now, let us look at, what you do in a fatigue test. I would like you to draw a neat sketch of this test apparatus. Because you need to know, what way the fatigue test is conducted and what kind of data is recorded.

You know, this is the test section and this is supported by four points; one, two, three and four. And, you have a motor, which is rotating the specimen. And, you have a load apply to this. So, if you look at, from the bending moment diagram, this portion is under constant bending movement. And, you have a digital meter, which records the number of cycles. And, what you do is, when the specimen fails, the weights drop of and the contact is broken and this, switches of the motor. So, what you do? You have recognized by looking at, actual service failures of locomotives, repeated loading is important.

The moment, you understood repeated loading is important; it has to be simulated in a laboratory condition. So, in a laboratory condition, you have to design a new test. And, this test records, only one information. For a given loading, after how many cycles, the specimen fails; you do not record anything beyond this. That is what, is very important. The specimen is subjected to four-point bending. And, in view of the rotation, the specimen experiences a sinusoidal variation of stress levels of equal magnitudes, in tension and compression.

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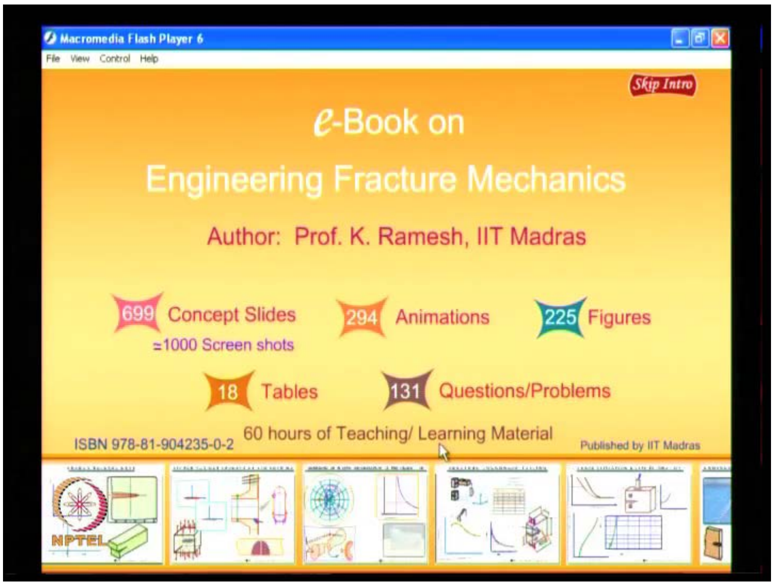

So, you have a sinusoidal variation and what do you record? You record, as the specimen breaks, how many cycles that has taken. You do not record any other information. And, you know, for this course, I will be using my book on, e-book on Engineering Fracture Mechanics. This was published by IIT Madras. And, this comes for about 60 hours of teaching and learning. And, this is dedicated to my father, who was a learner all through his life. And, what you will have to know is, you know if you have to be a teacher, you have to be a learner all through your life. And, that is very important. And, what we have seen in today's class of us, a brief outline of, what is the course on Fracture Mechanics.

So, we had looked at the kind of chapters that, we will look at. And, we also learned some jargons. You know those jargons; you will not be able to appreciate it right now. But, we will develop the Mathematics, as well as the Physics behind the development of those ideas, later part in that course. Then, we moved on to a review, what we have learnt in a simple course on strength of materials.

The knowledge, what you gained is very important. But, what is emphasized is, the knowledge you gain is limited. That humility is needed. You know knowledge, what you have gained in a course, in strength of materials is very useful. Without that, you cannot appreciate, why a beam behaves in a particular fashion, why a torsion member behaves in a particular fashion and how, we optimize some of the structures, why do we go for hollow shafts and if you really look at, nature has understood all of this. Even before, as scientists, we have understood.

You find birds have hollow bones. We also have hollow bones, the center portion, you have this hemoglobin is generated. It is very soft. Actually, if you walk in stairs, your thigh bone is the longest bone in the body; femur bone is subjected to bending, as well as torsion and, is a hollow structure. So, the nature has understood, so beautifully, some of these concepts. And, as we go by, with understanding of little more Science, you know, whatever you come across as truth, we classified initially as brittle material.

But, more and more, research people have done, it is found to be a functionally greater material. In fact, if you look at the development of composites in structural application, people decided, under certain directions you need more strength. So, why not, I develop an esoteric material, which displays higher strength in a particular direction.

After the graduation from this, people went in for developing functionally greater material, which is little more mathematically challenging, from the point of view of analysis. After understanding, always, you come back and see, what happens in nature. Nature has already understood this. And, we will see in this course, whether fracture also we have been using it, indirectly without learning the Mathematics; we would see some of those examples.

We will see in the next class.