Engineering Fracture Mechanics
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Module No. # 01
Lecture No. # 03
Lessons From Spectacular Failures

In the last class, we had started looking at spectacular failures. We saw the Boston molasses disaster, which was followed by Liberty ship failure. In both of those cases, the failure occurred immediately after the few years of its operation. In the case of Boston molasses failure, it wasabout three years later; in Liberty ship, even from the first year onwards, you had started getting reports about fractures, and also the case ofship breaking into two when it was kept at the dock.

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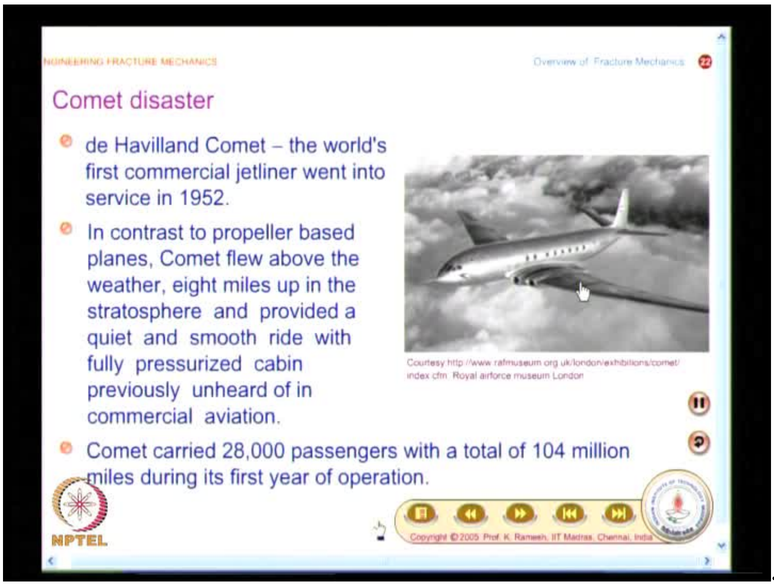

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Now, we look at the third spectacularfailure.This is a comet disaster.De Havilland Comet,the world's first commercial jetliner went into service in 1952.See, what you will haveto look at is – now, jet air planes are very common.So, you have to realize, that was the first jet airliner;so, many technologies have to be tried for the first time.So, from that point of view, the whole design was an engineering challenge.

And what is advantage of a jet airliner? A jet airliner, in contrast to propeller based planes,comet flew above the weather, 8 miles up in the stratosphere, and provided a quiet and smooth ride.So, this is what is important.Inthe ordinary propeller planes, they fly at lower altitudes. It is very noisy and the ride is also generally bumpy. Now, you are able to come out of that problem.The advantage is - it is a quiet and smooth ride, and the cabin is fully pressurized. So, this is the advantage of a jetliner. And if you look at, in the first year of its operation, comet carried 28000 passengers with a total of 104 million miles. So, that is considered as quiet a success.

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This is the overall view of the Comet aircraft, and you can see - the engines are slightly different; it is not like what you have now. And this courtesy of full a figure is from Royal Air Force Museum, London. And what was the problem? Why it failed?

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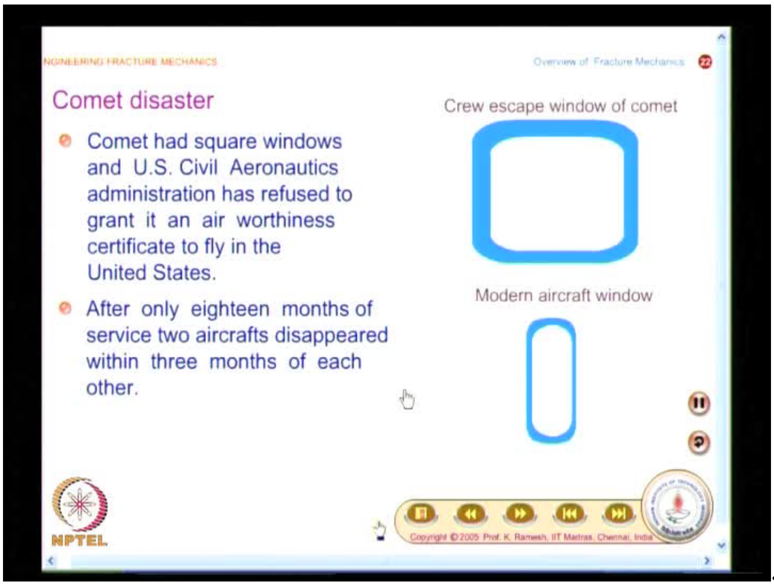

Now, if you had looked at, in the comet, you had a crew escape window which was quite large. I want you to make a sketch of this,whereas the modern aircraft, the window is narrow like this.One can wonder whether, even a small change in the shape of an opening can cause failure.In fact, for some of these, you have a gut feeling whether it will work or not.The U S Civil Aeronautics Administration has refused to grant comet an air worthiness certificate to fly in the United States, purely out of a judgment. They were skeptical about a larger opening because when you have opening,it acts like a stress concentration.So, they were quite not comfortable with it.So, they refused air worthiness certificate in the U S. Comet flew from India; it also flewto rest of the world.

And what happened was, here again, the failure occurred very early in the service.After only 18 months of service,two aircrafts disappeared within three months of each other.

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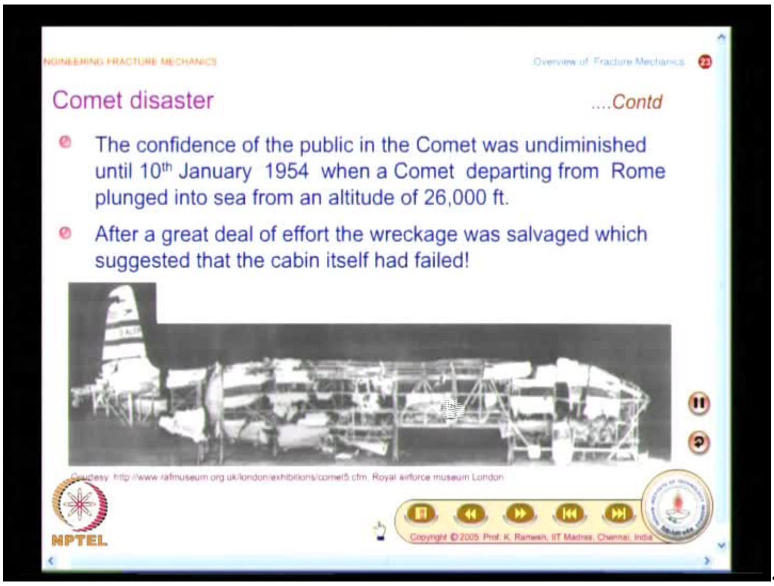

In fact, there was also an accident of Comet flying out of Calcutta.With all thus, the public confidence was intact until 10th January 1954. So, what happened on that day was the Comet departing from Rome plunged into sea from an altitude of 26000 feet. So, people thought, there are some problems in the structural aspect of it; that needs to be looked at because aircrafts missing mysteriously in flight was to be looked at very closely to assess the reason. So, what they did was - they salvagedwreckage from the ocean and they reconstructed the aircraft. And what they found was, to their surprise, the few salvage itself had failed; this was not imagined. Only when they recovered the debri from the sea, when they put all of them together, they found that cabin itself had failed.

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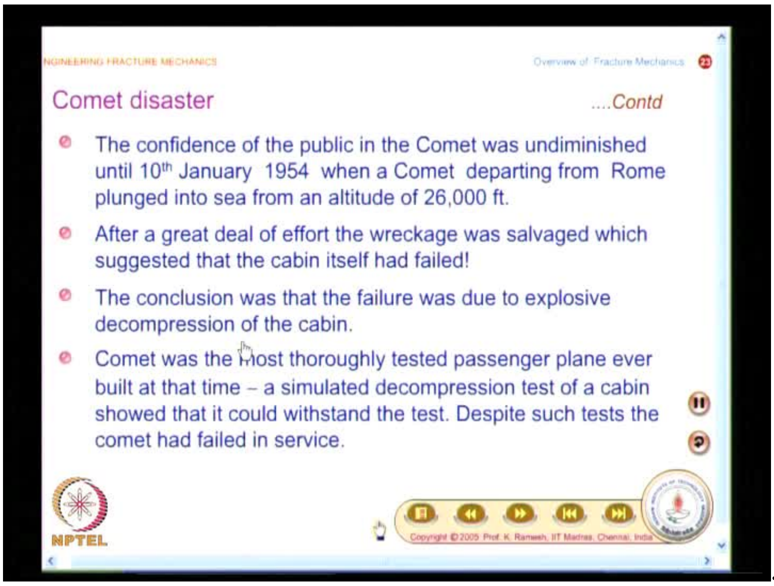

So,the conclusion was that the failure was due to explosive decompression the cabin.Now, what you will have to look at is because it was the first jetliner into service, the engineers have deviced various tests to test the subassemblies, as well as assemblies, and also the full aircraft. So, it is not that without test the aircraft was allowed to fly.In fact, when any new developments take place, it is a celebrity who wants to take a share of it. In fact, I was told that queen Elizabeth has travelled in the comet to southAfrica; fortunately, nothing happened.See you might have heard of Kanishka aircraft which plungedinto sea; that was because of a terrorist attack; it is not because there was a structural failure in the aircraft and because of that it failed; that was not so

Until the accidents happened, people thought that comet was quite okay,and it was the prestige to travel in that aircraft;that isthe way people looked at it. As I mentioned, comet was the most thoroughly tested passenger plane, ever built at that time.See them - the adjective, most thoroughly;it is relative.In those times, they were not doing even that many tests,but the test that they had conducted on comet were quite many.They simulated decompression test of a cabinwhich showed that it could withstand the test.So, they had done the test; with all that, there was failure.So, people have to go back and re-look whether the tests were sufficient.

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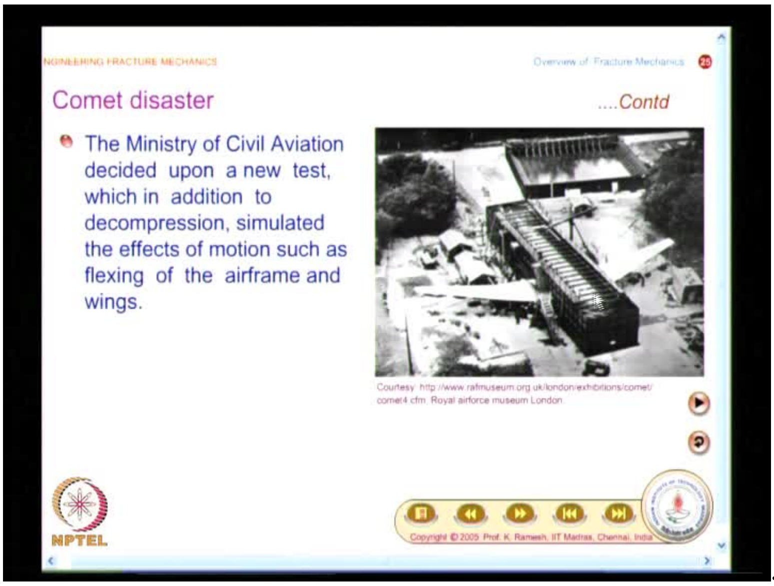

In fact, this is what the committee in UK read this and they suggested a new test to be done.And what was the new test?The Ministry of Civil Aviation decided upon a new test which in addition to decompression simulated the effects of motion such as flexing of the airframe and wings.

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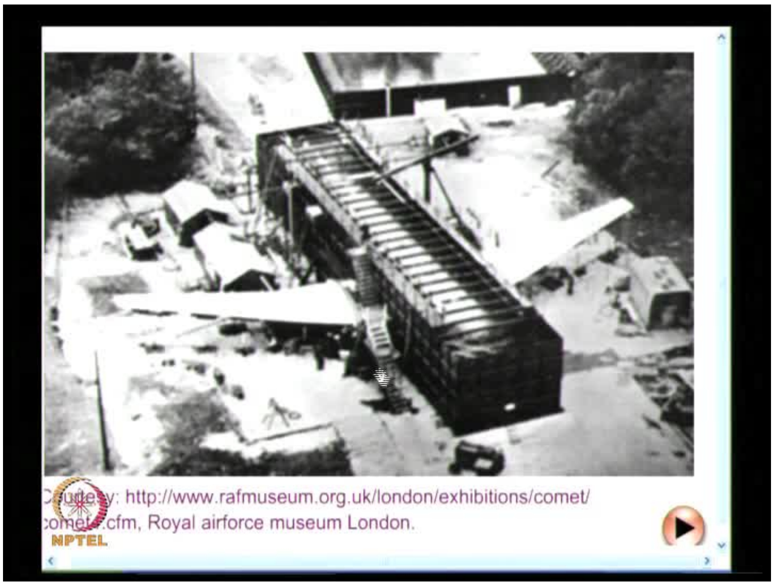

And you can see the test read.Now, it is so huge.They had constructed a water tank; the entire aircraft is submerged, and you had wings protruded out of this, and they were flexed.

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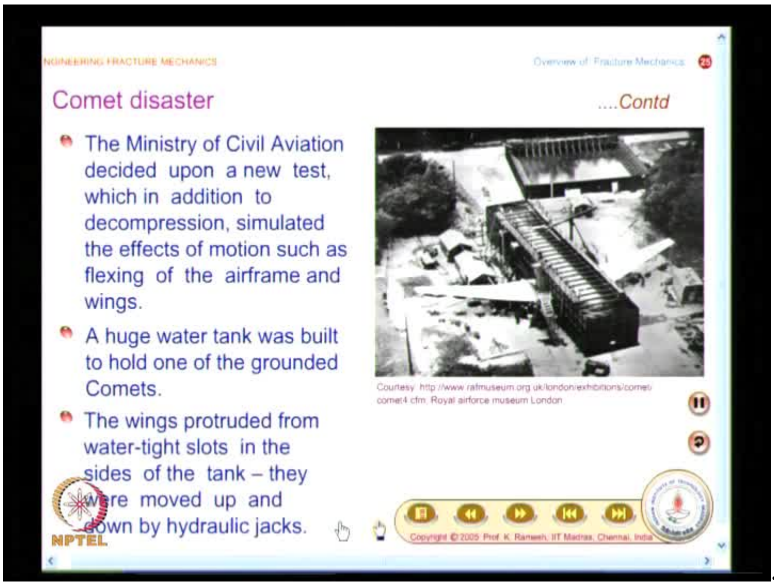

This flexing was not done because in flight, the wings alsocan flex because of the air currents, and it is a very quiet expensive experiment. As I mentioned, the wings protruded from water-tight slots in the sides of the tank. They were moved up and down by hydraulic jacks. So, it is more like a simulated fatigue test and an accelerated one, and they found a real surprise.Let us see what the surprise was.

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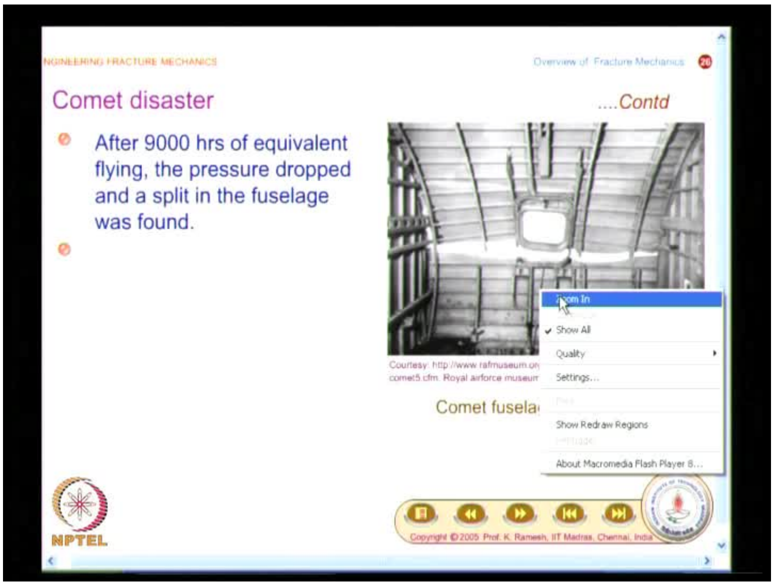

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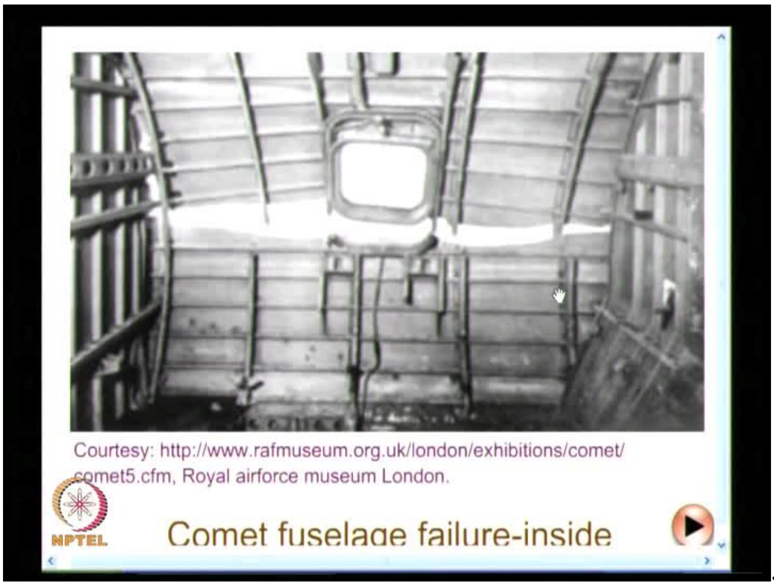

So, what happened was - after 9000 hours of equivalent flying, the pressure dropped, and a split in the fuselage was found.And where this happened?It happened near the escape window that US administration was not allowing it to fly because the size was larger than what it could be, and you had the crack propagated from this.So, onceyou have an opening in the fuselage, you have decompression taking place.It was only a small crack; a small crack in the corner of an escape latch window has caused the failure.So, when I have a small crack, from an actual point of view, it will behave like a crack plus link of the window.

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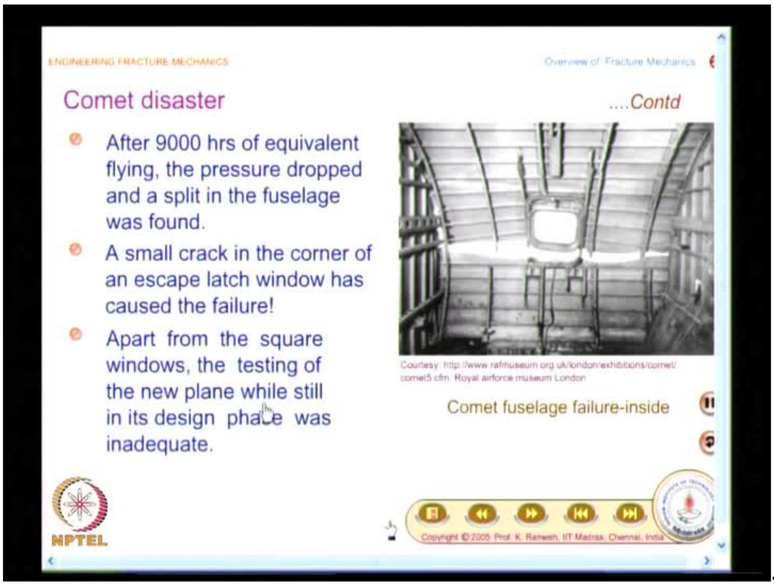

If I have this on one of the corners, the crack may be a few millimeters, but that totalcrack, the way it will behave structurally would be few millimeters plus length of this diagonal.So, this is what you will have to keep in mind.You will have surprises when you are really going in for new design.In fact, the company went bankrupt because of this failure, and the beneficiary was Boeing.Boeingwere also designing their planes.So, they took all the lessons from the Comet disaster; made suitable modifications in the Boeing; then Boeingbecome a successful airliner.So, what you will have to look at is - apart from the square windows, the testing of the new plane while still in it is design phase was inadequate.

So, that could be one of the possible conclusions because they had thought that they had done enough number of test, but the test were not sufficient.AndI had also mentioned earlier, simulatingactual service condition loads is not a simple task because you will have to assess what are the service loads. They had ignored the flexing of the wings, to start with; then they found, when you incorporate that, that provided an explanation that the structure what they had made as Comet was not fully design proof; there was a design fault, and comet had structural problems.

In fact, if you look at some of the early history on fatigue development,that is the time where they were finding out after so many cycles, the structures will fail; crossing the

Atlantic Ocean was a big task; it is not a simple task.Now, every other person travels across the globe; people do not even think that it is a difficult task.

So, in the early days of aviation, crossing the Atlantic was one of the biggest challenges,and there were also engineers who were working.They were calculating.By the time you cross once the Atlantic, the plane will fail because a fatigue life of that structure was such, it could with stand only so many cycles as it passes through Atlantic.In fact, such accidents have happened.It is only through accidents, you find improvements have to be incorporated on the design.

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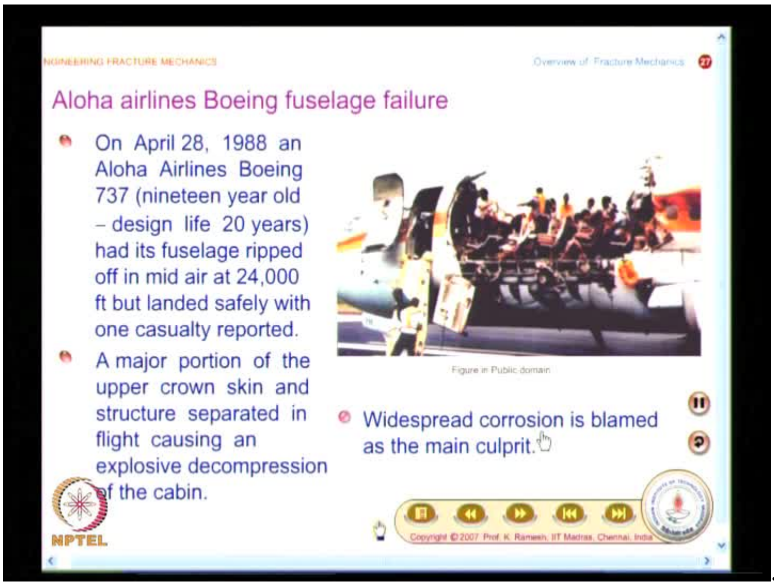

Now, we move on to another very famous accident.This is Aloha airlines Boeing fuselage failure, and this accident is slightly different. You know,in all the three other cases, we saw that the accidents took place very early in the surface, or within few years after the structure is built and put into surface.Here, it has happened after 19 years.The actual design life was 20 years.

So, you could have brushed aside.Fine, it has come for 19 years;why do I worry about the failure?The failure was spectacular for various reasons.Imagine that you are flying at a high altitude; suddenly a portion of the roof flies off; you are without a roof; this happened, and fortunately because the pilot was experienced, he landed the aircraft safely, and only one casualty was reported. There were not many people who are used to flying.There would be announcements the flight belt sign is switched off, but it is recommended that you keep the belt on you for emergencies.Many times the frequent flyers they will not put the belt thinking that everything is safe.

In fact, the Aloha airline failure, if you really go back and look at what they had done, just because the people were tied to the seats, they were all saved.Because once there is an explosive decompression, people will be sucked out.It is only the steward who was standing, was sucked out; there was only one casualty. So,it is always prudent to put your flight belts on, even when there is no announcement regarding that.

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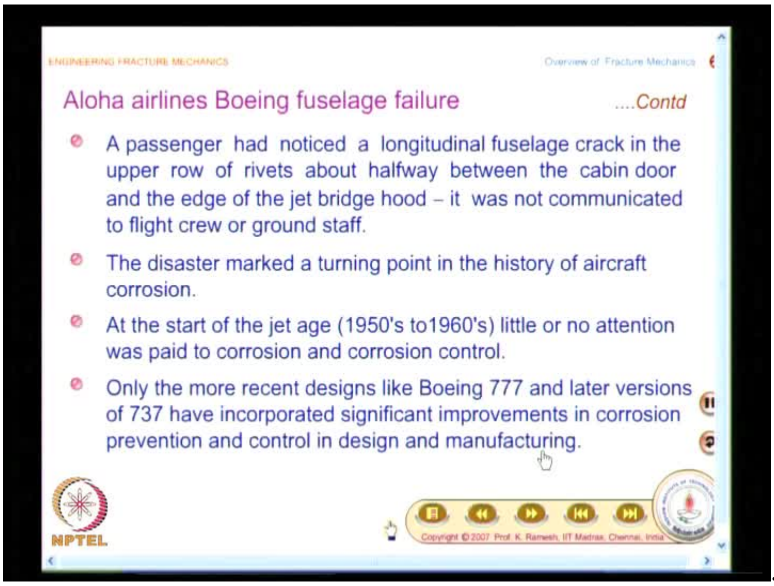

So, why this has happened?See this is how engineering proceeds;people do not take it.WhenI had designed it for 20 years, why it failed in 19 years?So, when they did the postmortem, they found that widespread corrosion was the main culprit.And in fact, even before for that flight, it appearsthat a passenger had noticed there a longitudinal fuselage crack in some portion of the roof; however, it was not communicated to flight crew or ground staff.So, people had found some evidence why the whole thing failed in a particular portion.

So, the passenger had noticed a crack, but he has not reported it.So, you will be afraid; you would not know; the passenger may not be an engineer;he would have been a common passenger whohave observed; would not have understood what is the role of a crack, but this accident had changed the aviation history.It was the turning point in the early start of the jet age.There was little or no attention paid to corrosion and corrosion control.So, people realizedcorrosion control is equally important at the design phase.

So, if you look at an aircraft, it flies though sea, and also in western countries, you will have deposition of snow; all that induces corrosive environment.So, unless you allow all these water to drain off and carefully look at whether there is a possibility of entrapment of water.If you do not take such modifications in the design, corrosion is going to be a problem.So, aviation people understood this.And in the case of Boeing777 and later versions of 737 have incorporated significant improvements in corrosion prevention, and control in design and manufacturing.

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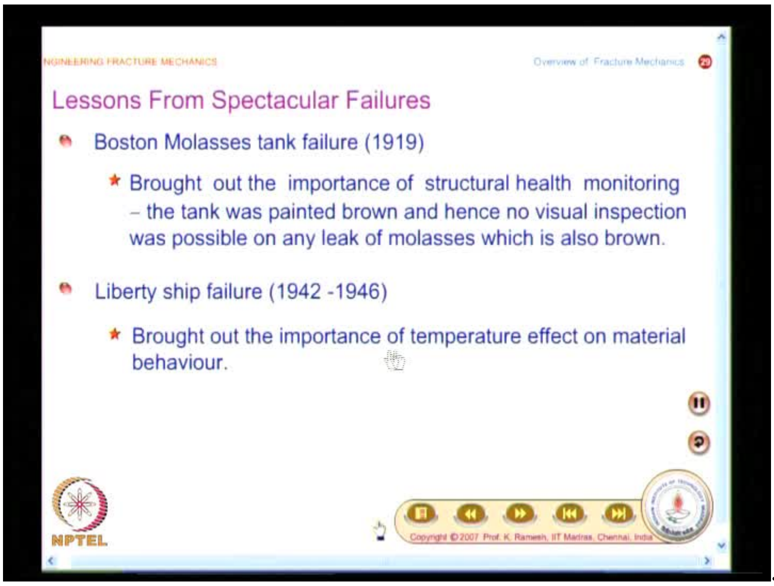

So, we had seen failures for the last70 years or so, in a span of 70 years, and what werethe main lessons from each one of these failure?Each one of these failure was selected to identify a particular improvement or cause that needs to be looked at in engineering practice.In the case of Boston molasses tank failure, it has brought out the importance of structural health monitory.You know, this is a very important aspect to see.

Many of you will be using a cycle. I do not know you have a habit of preventive maintenance; just put the drop of oil; you never do that; people have become so lazy.You allow it to rust and buy a new cycle rather than maintain it.Structural health monitoring,the first principle is - you will have to do preventive maintenance.You will have to monitor what happens; whether the structure is alright or not?Why it has broughtout the importance of structural health monitoring?Even if you want to inspect it, there was no provision.What happened was the owner of the tank has painted it brown; molasses is also brown in color; so, even if there had been a leak, it was not possible to quickly see it through visual inspection.

And Liberty ship failure brought out the importance of temperature effect on material behavior.It is very important.In fact,in Boston molasses tank failure, there was only one tank that failed.In the case of Liberty ship failure, you had thousands of ships had major fractures, and some of them broke into two.So, definitely, the engineers whodesigned and fabricated would be questioned - why there had been suchastronomical number of failures?It brought out a very important aspect that low temperature can cause a material to behave in a brittle fashion.And Comet disaster highlighted that, cracks could develop in stress concentration zones and grow in service due to fatigue loading causing failure

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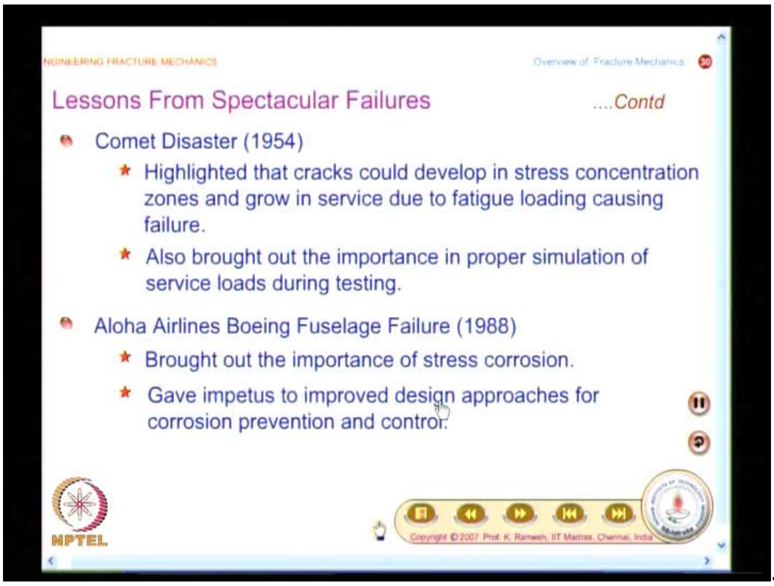

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And we also saw that the number of test that they had done was not sufficient, though they had concluded they were sufficient and allowed into fly.So, you will always have to look at proper simulation of service loads during testing.It is very important in any challenging designs.Earlier, in the case of Aloha Airline Boeing fuselage Failure, it brought out the importance of stress corrosion.So, once you have understood thestress corrosion could be a cause, aviation industry improved the design for corrosion prevention and control.It is very important and let us summarize.

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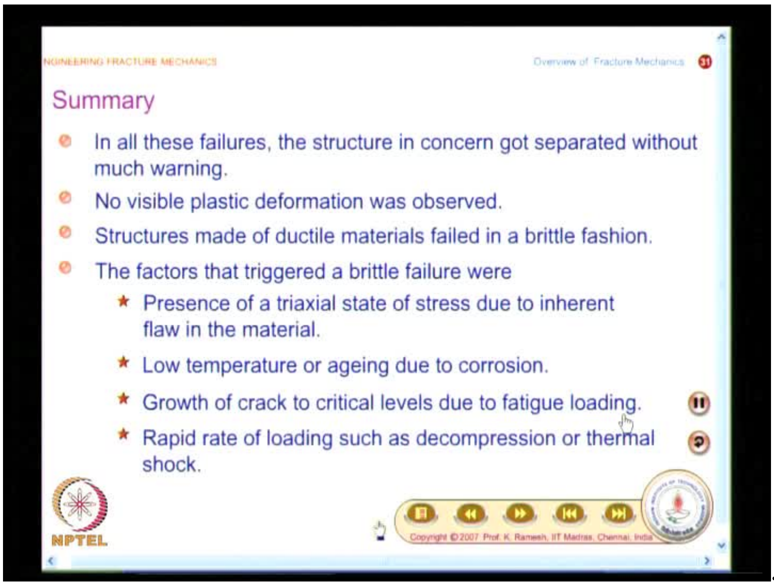

What is the kind oflearning that you could get from all these failures?There are certain commonalities:

In all these failures,the structure, in concern got separated without much warning.See there had been a warning like plastic deformation or large deflection; people would have at least attempted to diffuse a situation by reducing the load, or do some such thing; it was no warning.

So, that means the understanding of material behavior until then was limited; they had some understanding, but when they had stretched the design to its limits,it was failure.The other significant observation is - no visible plastic deformation was observed.Althoughwe would see later, there would be localized plastic deformation, the structure as a whole had no visible plastic deformation.You never made the Liberty ship out of glass; they were all made of ductile materials.And what you find is - structures made of ductile materials failed in a brittle fashion;it is only brittle material that will fail without warning.A similar situation has happened for structures made of ductile materials.

And if you look at the factors that triggered a brittle failure,we will see one by one; some of them we willbe able to understand; some of them we will develop the understanding, as we go by.

So, the firstpoint is presence of a triaxial state of stress due to inherent flaw in the material.See, you all have looked at problem of stress concentration.You have been told in a first level course in strength of materials, when there is a geometric discontinuity, in the vicinity of that, stresses would be high.This is what people talk about it.Suppose you take the case of a plate with a hole, you have stress concentration near the hole boundary.

Suppose you take two situations: one plate without a hole, and another plate with the hole; when I apply uniaxial tension in the case of a plate without a hole,I would have only uniaxial stress field; the moment I put a hole, I have stress concentration, and in the vicinity of the hole,the stress filed becomes bi axial. So, you have a uniaxial externally applied load, but in the vicinity of a stress concentration, the stress field is y axial.Suppose I have a crack, that thickness of the specimen also come into the effect, and you will also have triaxial state of stress which we would see in course of fracture mechanics developments.So, the observation is - there was presence of a triaxial state of stress.

And in the case of Liberty failure, you found that there was low temperature.And in the case of Aloha, there was ageing due to corrosion, and what happened was - you had inherent flaws, and these cracks grew into critical levels due to fatigue loading.And another aspect isthe rapid rate of loading such as decompression or thermal shock.Because if you want to go and learn from some of the spectacular failures, you will have to look at the kind of features that was very obvious, and more or less common between these failures.

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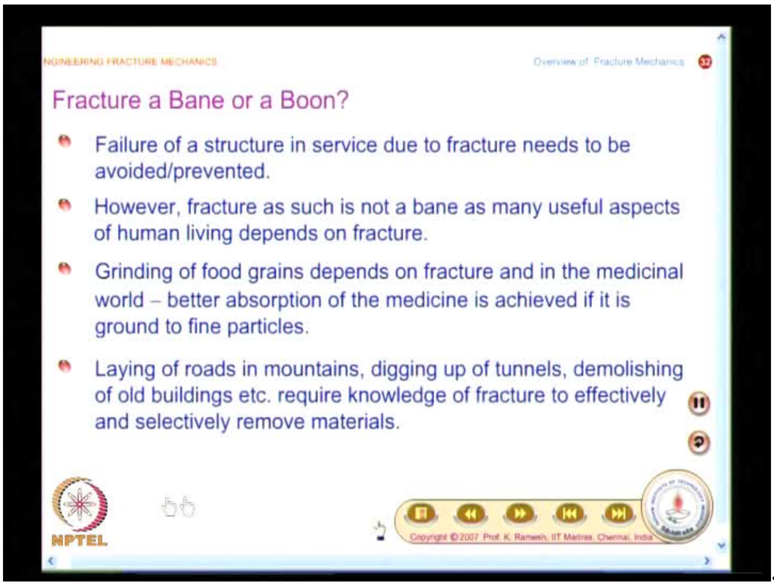

Now the question is - we have been talking about fracture of a structure in service needs to be avoided or prevented. You get an impression - by all means fracture should be avoided.It is never the case. So, when you had learned friction, friction was necessary when you want to have breaks; friction is not necessary when you want to improve the efficiency of the engine; so, the friction is needed as well as not needed. On similar vein,fracture is needed in some cases; fracture is not needed in many of the structures.

So,it isit is always comes in duality.You will have to find out and assess depending on the context. That is what is mentioned here.Fracture, as such is not a bane as many useful aspects of human living depend on fracture.Can you think of very simple day to day living depends on fracture?Because we do not apply, we take many things for granted.If you are a scientist, you will have to investigate and find out a reason for everything.Simple thing like grinding of grains; if you want to go and have chapattis you need to have wheat flour.How do you get the wheat flour?If the grain is not ground and you make it as a powder,you are not going to get your daily dose of your chapattis.

So, such a simple day to day importantactivity requires fractures; not only this, see if you look at the medicinal world, they have found out there is better absorption of the medicine, if it is ground to find particles.I do not know how many of you are aware.You all take a capsule, and capsule - if it touches your tongue, it is sweet; it serves one such purpose.

If you open up the capsule, you will find a very fine powder inside; thepowder,is in general, may be bitter; you will not be able to swallow it if it is not put in a capsule, but with in a capsule, you have powder. So, for all these powders,you need efficient fracture.So, fracture is important.

Not only this,suppose, you have to lay the roads in mountains we have, or digging up tunnels, and demolishing old buildings require knowledge of fracture to effectively and selectively remove materials.In fact, in the discovery channel, they show how they use detonators in a calculated fashion to demolish old buildings without the product of demolition, go out of that building range because it is all in a public locality where several other buildings are nearby.And if you want to demolish a building, you should know how much detonator, in which sequence you have to fire,what should be the strength of it - all these require understanding a fracture.

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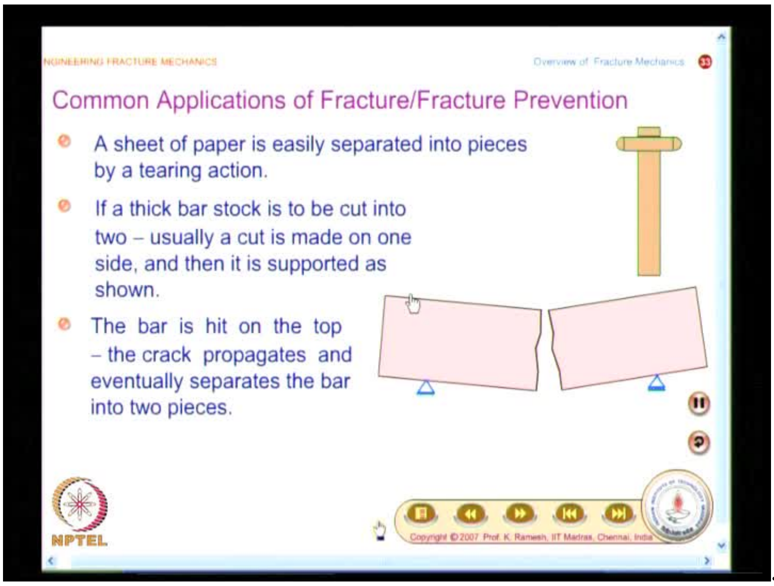

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So, fracture is as such not a bane.It is needed in some cases; it is to be prevented in some cases.And if you look at and investigate many of our day to day living, we have applied the knowledge of understanding of fracture in some way or the other.You would see some of them:See, suppose, somebody gives you a sheet of paper.How do you do it?You will not go and take the paper, and pull it like this.If you pull it like this, you will have absolutely no control on the way separation of the paper will happen.You will take it and put a fold, and then tear it.

What you have understood is paper separates itself very well by a tearing action.You have got it by experience. You have not attached the fraction mechanics theory to it.Now, after learning fraction mechanics, you can go and say, that is in mode three; tearing action, you will see.And if you go to the workshop, if they have a very thick bar, if they have to separate into two, what they will normally do is - they will put a crack on one side and put it as a beam under simply supported conditions, and they go and hit it; they do not go and cut this from top to bottom; that will take longer time. Whereas, you put a crack and then hit it from other side; it will separate very well.So, this is how people do it. You may not be aware because people do not want to come near anywhere near experiments; people always want to sit before the computers, do simulation, see nice colors, and be happy with it.You have to walk along the work shop andsee what kind of practice is that they are doing.

So, what do you find here is - the bar is hit on the top, the crack propagates, and eventually, separates the bar into pieces. So, this is about how we efficiently use without knowing the knowledge of fracture; by purely experience, you employ the utility of fracture knowledge.

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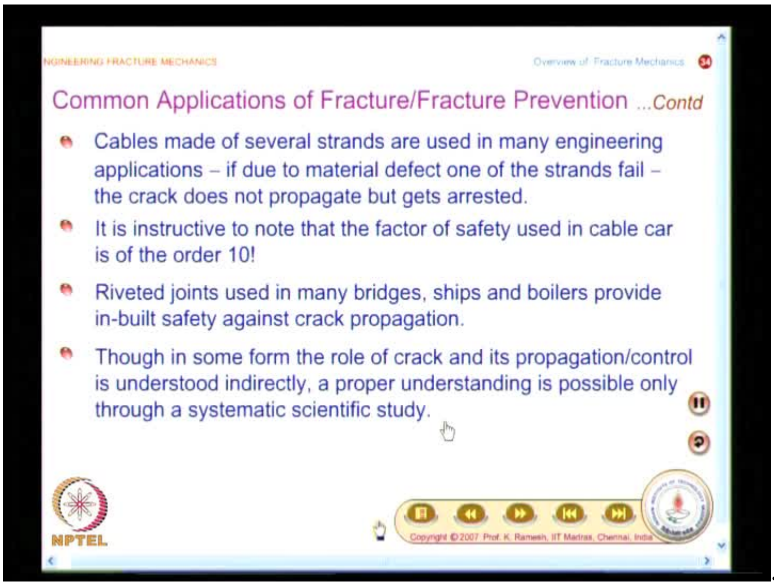

And if you look at, cables made of several strands are used in many engineering applications.Why you have cables made of several strands?It is for fracture prevention; if due to material defects one of the strands fails, that crack does not propagate, but gets arrested.See, one aspect is - when you have multiple strands, you want the cable to be flexible;it serves one such purpose; the other such purpose is - even if by mistake one strand fails, there would be some time lag before another crack initiates.So, this was the problem with Liberty failure.When the complete ship was made up welding when a crack in got initiated; it propagated without anyresistance; this, they understood; they provided crack arresters and they salvaged some of the ships.

And also, you have to look at for all the cable car operations because the uncertainties are they are very many, and the consequences will be very bad, if there is a failure, they use of factor of safety at the order of ten.I had already mentioned that when you use the factor of safety closer to unity, then you need to have better analysis.See, if you look at some of the ancient temples, they wereall made of granite structures; nothing will happen to it; you cannot have that kind of structure everywhere.

So, you need to definitely bring out factor of safety down.So, having a higher order safety does not add togood engineering practice; it only shows you are not completely confident about your own design.

And if you look at many of the bridges, they have riveted joints.You also find them in ships as well as boilers, and they provide in-built safety against crack propagation.See, if you look at, riveted joints are very precise; machining is required; it is not so simple. Welding is lot more simpler, but if you have riveted joints, it serves as in built safety against crack propagation.So, though in some form, the role of crack and its propagation or control is understood indirectly, a proper understanding is possible only through a systematic scientific study; that is what we have embarked up on in this course.

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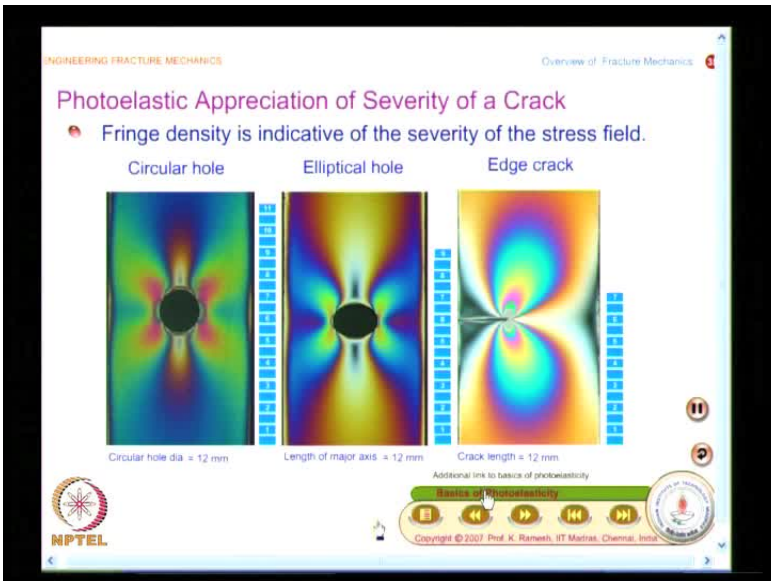

And for this course, I had mentioned earlier that I am going to use extensively, the technique of photoelasticity, and what I will do is, before I come back to this slide, we will go and see what is photoelastcity.

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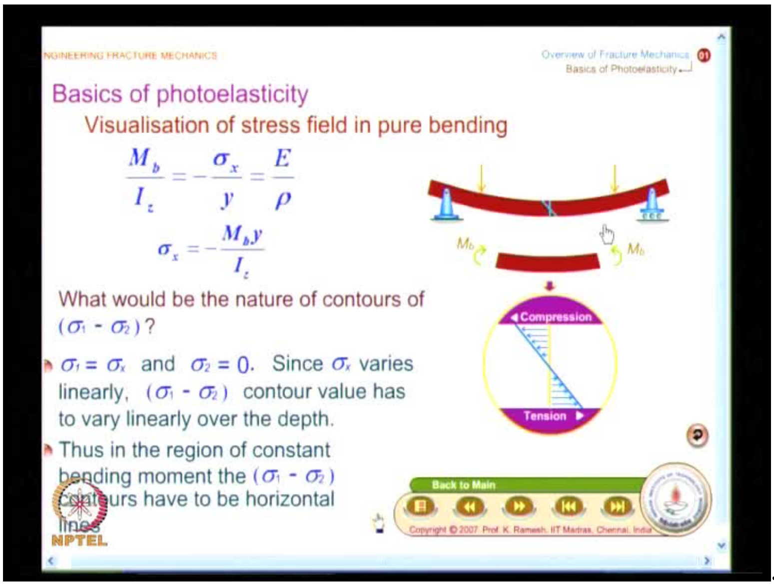

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And I will take up a very simple problem of beam and bending.I know in this class, some of you have already done a course on experimental analysis. You know what is photoelasticity and what those contours represent, but for a general audience, they may not have an exposure to photoelasticity.And particularly, in a course instrength of materials, while you develop the concept of stress, the focus was mainly on what happens at a point of interest?You graduate from p by a as definition of stress, to state of stress at a point, and you say, state of stress at the point; you find out what is the value of stress vector on all the possible planes that passes through the point of interest.So, you represent that as stress strengths,or mathematically, or you look at more circle; each point on the more circle represents a particular plane. So, the focus was more on developing the concept of state of stress at a point.

So, you look at what happens on all the planes that passes through the point of interest.You very rarely look at what is the variation of stress feel over the structure; that is also very importantbecause when you are looking at a stress concentration problem, you will get a knowledge only when you look at how there is distribution.And when you want to look at that kind of an information,I need do go for plotting a contour, and what is the contour?By definition, along the contour, the value of the variable remains same.

So, you find out points in this domain which has a constant value and join them together by a line.Now, let us take the problem of a beam under bending.I have a beam under 4 point bending, and in this central zone, your flexure formula is applicable.You would be able to find out the bending stress sigma x from this, and this varies linear (Refer Slide Time: 36:55).So,that is what you get here.Because I want to introduce photoelasticity,I would like you to plot what would be the nature of sigma 1 minus sigma 2 for this problem.Because the problem is so simple, completely the stress field you also know what is the definition of a principle stress.

Now, you try to look at what would be the nature of sigma 1 minus sigma 2 in the domain of the beam.I would like you to try it out; take 2 minutes and try to look at because you have the knowledge.I have this stress varies linearly over the depth and I have already mentioned, a contour is nothing but you pick out points in this structure which has the same value of sigma 1 minus sigma 2, and you have all that information available from your flexure formula.Suppose you anticipate from your analytical understanding, what is the nature, and predict this is how the contour could be, and if your thinking is correct, we can proceed to the next step, perform an experiment by photoelasticity, and find out what those contours represent.If they match, then we can come to certain kind of an understanding what photoelasticity gives because I take this kind of an approach for introducing photoelasticity; mainly because it comes from the stress route.

The other way to look at is go to crystal optics; find out what happens to a polarized beam that passes through a crystal from that point; look what happens to the refractive index; from then on, relate it to sigma 1 minus sigma 2; that would take at least 10 to 15lectures.We will not take that kind of a route.We would take a very simple route of looking at problem and plot a contour, and then find out from an experiment how the contours look like; by comparison, we will arrive at certain conclusions.Because the problem is very simple, you can say, sigma 1 is sigma x and you have a tension side as well as compression side.In the tension side, sigma 1 is sigma x and sigma 2 is 0, and since sigma x varies linearly, sigma 1 minus sigma 2 contour value has to vary linearly over the depth.

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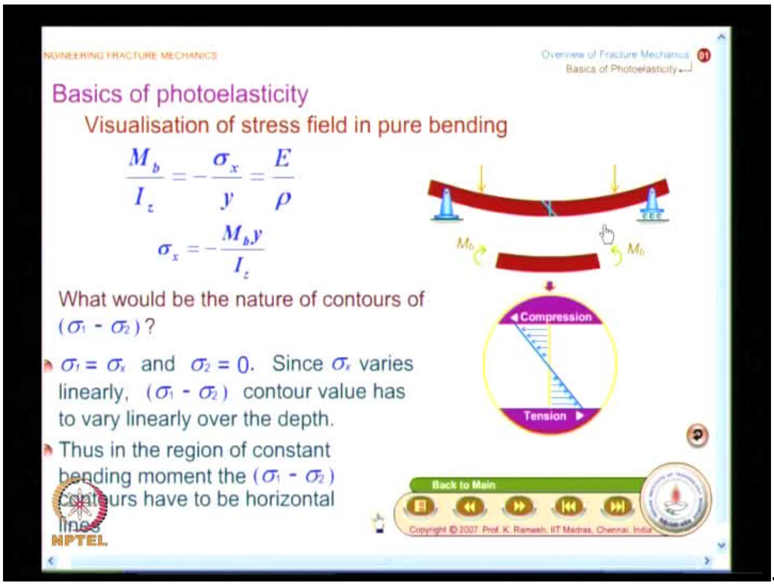

So, this changes.What is sigma 1 and what is sigma 2 will change in the tension side and compression side, but eventually, the value of sigma 1 minus sigma 2 will be dictated by the value of sigma x.So, if you are understanding the meaning of contour and translate it in the region of constant bending moment, the sigma 1 minus sigma 2 contours have to be horizontal because this is one of the simplest problem you learnt in strength of materials and you have the solution for every point in the domain; away from the points of loading.That is why I have shown a beam with 4 point supports, butI have taken only a region.We can have a look at this. This is away from the point of loading.Ihave not extended it till the end.

So, when you go closer to the supporting points, you will find, there would be deviations. So, a simple calculation, an extrapolation of your understanding, shows the contours are sigma 1 minus sigma 2 have to be horizontal lines.

So, what I am going to do is - I will now make a beam out of Epoxy which is a photoelastic material, and then put it in an equipment called the polar scope, and bend it.This is what I am going to do and I am going to see what that optical technique gives.We have already set that the contours have to be horizontal.Let us see what you have as the result.

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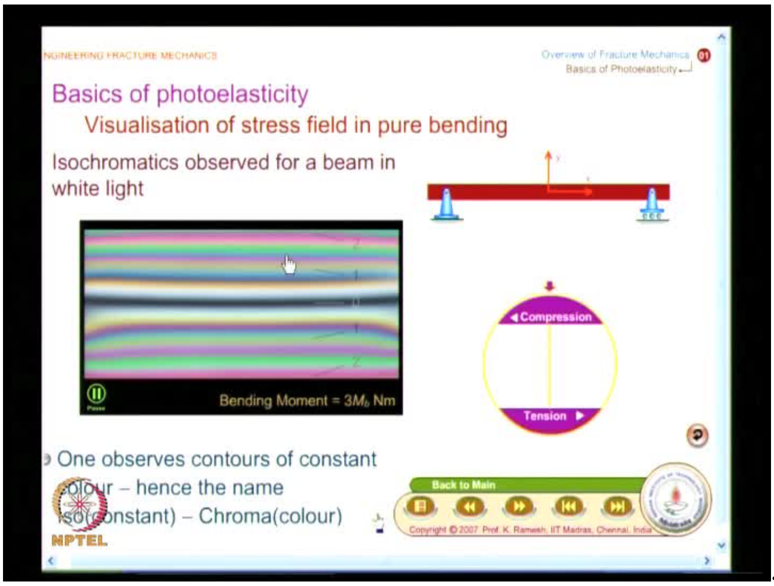

So, here, you have here, this is the beam.And what you find here is the value of the bending moment is progressively increased from 1M b to twice of that, and then thrice of that, and we will look at for this case.

So, what you have here is -I have horizontal contours.So, you can infer that these should be contours of sigma 1 minus sigma 2 because that is what our analytical calculation showed that they have to behorizontal; they are horizontal and I had already warned - near the points of loading, there would be small deviation; here it is not strictly straight in this zone; you are able to see that as horizontal lines.And another interesting point is these are colors actually seen in an experiment, and it is purely an optical phenomenon.When a white light is used, the nature reveals it in such rich colors;so nice.So, you get an enthusiasm to do stress analysis because you can see nice colored fringes, and with some training, it is possible for you to label the fringes as 0, 1, 2, and when the load istripled, you have higher number of fringes.

So, in linear elasticity, when the load is double and when the load is triple,the stresses also progressively increase;so, all that you see. So, you can infer from this that whatever the contours that I get in photoelastic fringe pattern can be considered as contours of sigma 1 minus sigma 2.

So, this is what you will have to keep in mind, but the problem that we have taken is a very special one; even if you had plotted just contours of sigma x, they would have remained horizontal, but that is only a special case.In a generic environment, it is only sigma 1 minus sigma 2 is sensitive to photoelastic effect and that is what you get in a photoelastic test, and these contours also have a special name.These contours are known as Isochromatic; the meaning isiso means constant; chroma means color. So, it mentions that these are contours of constant color.So,that is what you find here.We have contours of constant color appearing in a simple photoelastic test.

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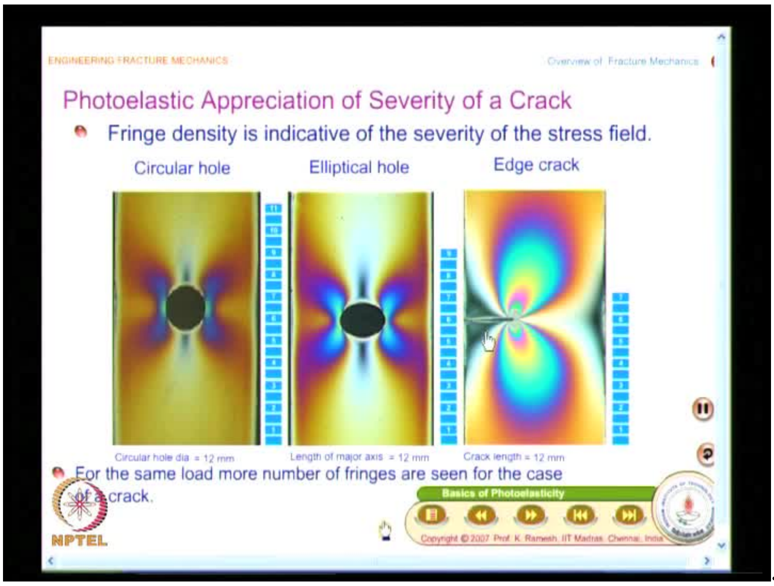

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Now, we go back and see nice set of comparisons.Here,I have a plate with the hole which is a circular hole; this is different from what you had learned from theory of elasticity.In theory of elasticity course, what you learned?You take an infinite plate with a very small hole.In fact, if you look at the evolution of understanding of stress concentration, there were very many debates between scientist of all order, and mathematicians were arguing an infinite platewith a small hole is equivalent to a plate without a hole. There, in fact, people had acrimonious discussions in trying to accept that there could be stress concentration.

Only in those days, photoelasticity got developed and the results from photoelasticity were very useful to establish the concept of stress concentration.So, when you are doing an analytical approach, you take an infinite plate with a small hole.If you want to go for a finite plate, analytical approach will not do.You will have to either do an experiment, or you will have to do a numerical analysis

So, here, what we have is the finite plate with a hole.You have taken a circular hole, and the circular hole diameter is 12 millimeter, and this is another case where it is an elliptical hole.Again, the major access is 12 millimeter, and here you havea crack coming from one of the edges which is also having a length of 12 millimeter.Ideally,I should have taken example where I have a crack, which is at the center; center of the crack is difficult to make in an experiment. So,an edge crack is used

And what you find here?whenIWhen I do the animation, again you will find, as the load is increased, you see more and more fringes are developed, and here you have the bar; this goes up to 7.

Now, let me see what is the kind of fringe pattern in the case of a circular hole when I have the loading is 7?And when I have the loading is 7 for the case of an elliptical hole and what you see in the case of a crack? I want you to make a sketch of it.These features are very important.So, what you find here is - you seecontours of sigma 1 minus sigma 2 for different problems of stress concentration, and you have a striking feature.When I have a crack,I have fringes symmetrical about the crack access, and they are also forward tilted, which is also happening in the case of an elliptical hole.You have this forward tilted like this and this also forward tilted like this, and one of the striking feature that you come across here is for the load 7.

The least number of fringes are present in the case of a plate with a circular hole; in the case of an elliptical hole, the fringe has become larger and you also find an appearance of another fringe coming out at the edge of the hole, whereas in the case of a crack, you see a large number of fringes which is definitely indicative of something more important in the case of a crack.

So, before we get into a mathematical analysis, when you compare the role of a circular hole, elliptical hole, and crack, you find - the crack has the large number of fringes, and you can immediately get an understanding that crack is lot more dangerous.Crack is lot more dangerous is what you get as the message, and we would develop the mathematics to substantiate that, and that is what we are going to do in the caseon fraction mechanics.To summarize, in this class, we had looked at the other 2 spectacular failures. Then we identified what is the commonality in those failures.We found that there was a higher rate of loading; the failure was brittle in nature, although there was no major plastic deformation on the structure as a whole.Then, we also looked at whether fracture is a bane or a boon.We found fracture is needed in day to day living; it cannot be avoided; you need fracture in certain applications; you need to prevent fracture in certain other applications.

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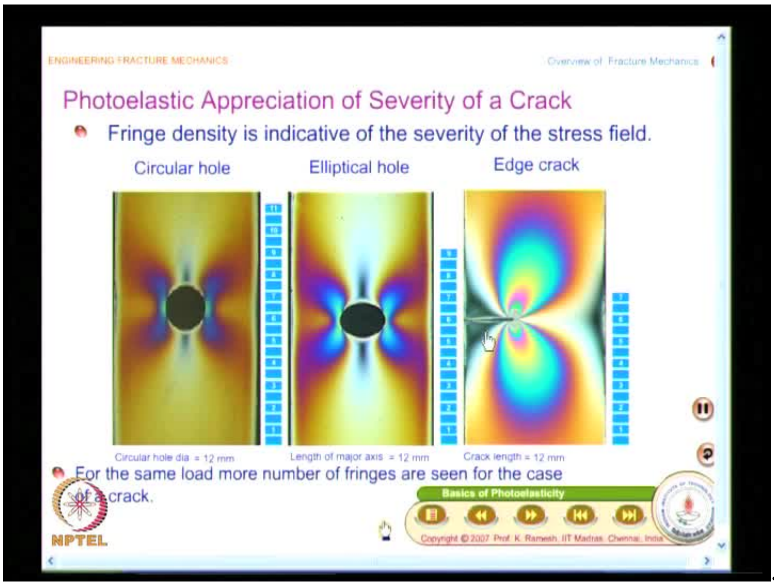

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Then, we moved on to look at what is the basics of photoelasticity; it is very simple fashion. It has been introduced.You can, from now on find out whatever the fringes you get, representcontours of sigma 1 minus sigma 2.