Experimental Stress Analysis

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Lecture No. #02

Optical Methods Work as Optical Computers

In our discussion on the overview of experimental stress analysis, and in the last class, I said that when you say stress analysis, in the complete sense it means determination of 6 stress components, 6 strain components, and 3 displacement components. However I said, determining all these 15 quantities may be a luxury from a design point of view, you may not need a full complete solution. So depending on the problem on hand, you may want to find out only the relevant parameters, and then use it for your design.

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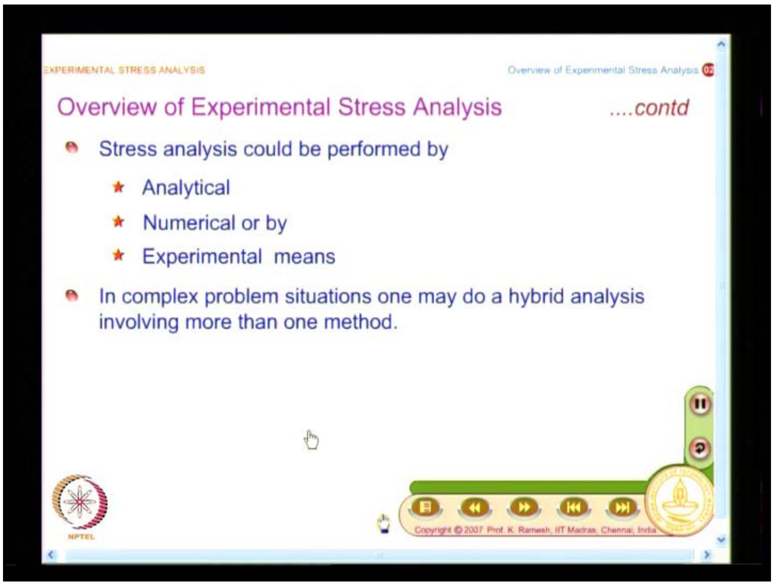

And to do the stress analysis, we have also seen that you could do it by analytical methods, numerical methods or by experimental means. And in complex problem situations, we may want to use more than one technique, so that we get the problem on hand, solved satisfactorily. And if you get into analytical methods, what we find is you get a conceptual understanding on the nature of stress fields; for example, can I have one of the students come here, then show this model. And one other simplest problem that is first taken in course in strength of material says, a slender bar pulled in tension; and in this zone away from the grips, you all know that stress is constant, and that is given by p by a. And what I emphasized yesterday was, you evaluate only a component, and you have to learn that you have to put it in a 3 by 3 matrix, and put the relevant zeros, and understand this as a stress tensor, not just as a stresses component. And a problem of this nature you have readymade solution without solving differential equations from strength of materials.

The moment you take a another problem, for the same plate, if you introduce a hole, it just not possible to solve from strength of materials, because the moment I put a hole, plane section do not remain plane before and after loading; before and after loading plane sections do not remain same. So, your assumption of strength of materials approach will not help you to solve. And if you ask the questions, can this at least be solve by theory of elasticity, which is also not possible, because the size of the hole is comparable to the width of the specimen. However you can still attempt to solve by theory of elasticity, if the hole size is very small like this, for the same width of the member with a hole is very small though physically this is a finite body. From a mathematical sense, this could be considered as at infinite distance away, and you could invoke theory of elasticity solution, and then get a close form expressions. So, the size of the hole is very small compared to this.

Suppose I have a complex object what we do? I have a complex object like spanner and this is the down to earth object, you know you use it at many of your day to day activities; do you get a solution from analytical methods? You do not get this it is such a routinely used specimen a tool if you want to solve it from your course in strength of materials is just not possible to solve. And let it tight in a nut and what you find here I have this spanner, and I have the nut here and when I start tightening the nut obviously you will find stresses are develop. Do you see the stresses here you do not see the stresses here and.

What you what you can say from strength of materials because this is constraint here and you are applying a load here, some sort of the bending takes place in the member. And since you all know something about stress concentration you could there will be stress concentration this zone and this is the load application point for certain general observations, you could make from your knowledge of strength of materials. Because the geometry is complex you cannot solve it by strength of materials even theory of elasticity will not help the only request that what you can do is you have to do it only from a numerical technique or a experimental method.

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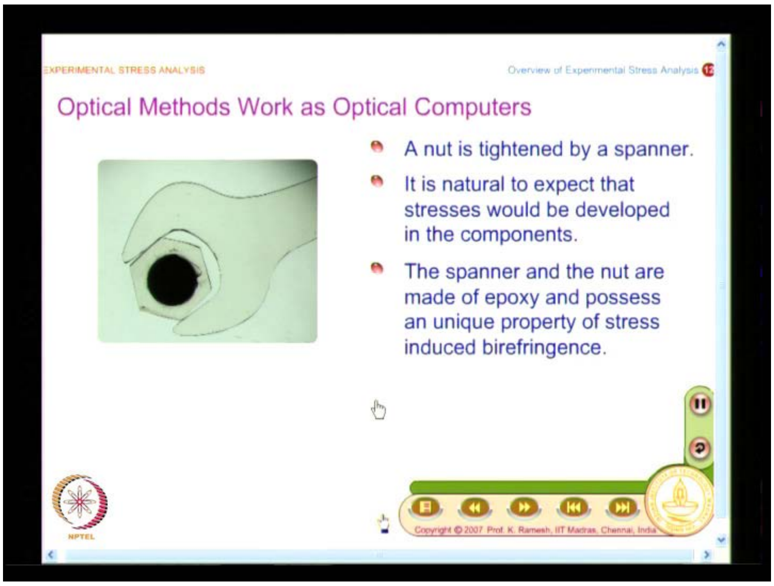

And what we are going to see is, we are going to introducing the new concept that optical methods work as optical computers. And this is what we had seen physically a nut was tightened by a spanner and it is natural to expect that stresses would be developed in the components. And you do not see them you do not see them the difference what I have shown in the previous live exercise and what you see on the screen. Right now the spanner is made of epoxy and nut is also made of epoxy I have a reason for it, because I have an interest show even the stresses as they develop and the nut is tightened by the spanner. So what we find is a very simple problem down to earth problem, you do not have solution from strength of materials after full course on strength of materials. You can only adjust conjuncture what could be the stresses not the actual magnitudes.

And what you have is why I have taken epoxies; the spanner and the nut are made of epoxy. And it possesses and unique property of stress induced birefringence. Really I have told you that each of the experimental technique utilized a particular physical principle which is exploited to reveal a particular kind of information it will not give all the stress components, all the displacement components, all the strain components. And here what we have done is we have taken a spanner and nut which is made of epoxy and it possess it possess a unique property of stress induced birefringence.

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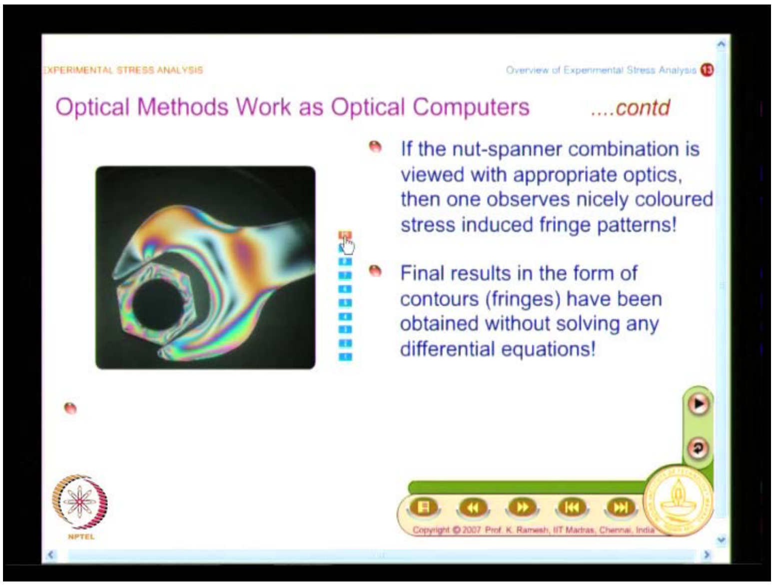

And what I do now is, I introduced appropriate optics and view the same combination with the optics. Optics is not shown here in the screen, but you will see the effect of optics seen on the image. And what you have here is as I change the load, as I change the load as I keep increasing it, you find that more and more colors are emerging and it is seen.

So, what it shows is whatever the colors that you see or a function of the load applied, and I would like you to make a sketch of this in a reasonable manner at least for the spanner forget about the nut, at least for the spanner you make a reasonable sketch of this spanner. And you should thank the nature, these are not artificial colors it reveals the stress information in the form of such rich colors. The colors are very nice and normally when you go for a computer plot, you usually plot to indicate what is of a high value as red and low value as blue and you have a gray scale suitable for different application, but here the colors are see naturally, and nature wants to reveal the stresses in colors to ensures the experimental mechanics person to conduct the experiment.

And I would like a reasonable sketch of it capturing the salient features, and what you have here is you have stress concentration, this is the load contact point and you have stress concentration here, and you have the fringes develop on the edges. And you have seen very clearly you have seen very clearly that all these colors have emerged as a function of what you have applied as load and for your benefit I will repeat it again.

So when I have the least load it is like this, as the load is increased stages you find the fringes are formed and we call these as fringes. And what you get here I get first information I get is, I get this over the entire spanner I get information. So I get a whole field information from an experiment, a whole field information from an experiment and what I have here is there results in the form of contours have been obtained and I have got it without solving the differential equations goes what is the effect I have done is, I have to make the model or this spanner as well as the nut.

And then put it in appropriate optics, and reveal the pattern I have to do a similar exercise as a numerical approach what I will have to do is? I will have to formulate the problem as set out differential equations. Solve it either the in closed form or at least in the form of approximate approach, then re-plot go to computer use plotting software and re-plot the values then I will get these contours.

So, in that sense what I could say is that optics has done the job for you. So, I could call this as optical methods working as optical computers. The effort that will have to do is you have to make the model there is some prize you have to pay for it. In a case of numerical method you have to pay a prize in formulating the problem, in the experimental method you have to pay a prize in fabricating the model. Now what is important is I have I have seen this rich contours and what this contours how do I know what this contour represent, to here only you have to look at what is the physics behind the problem.

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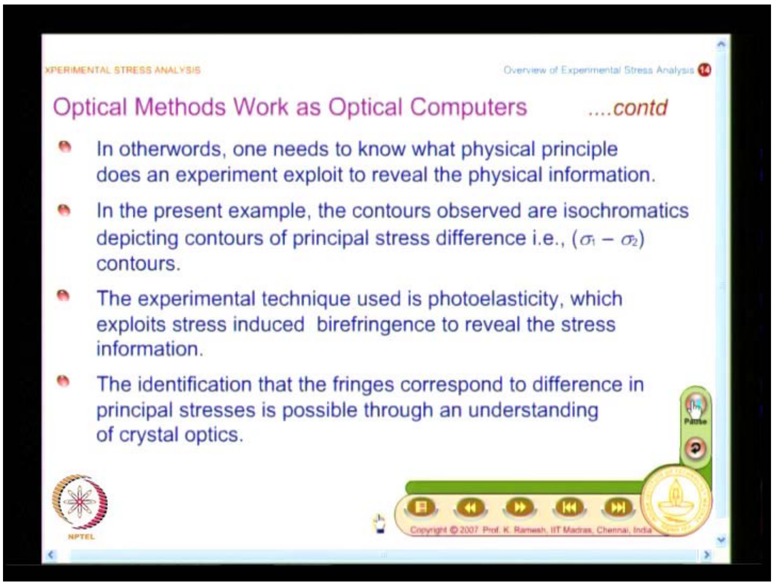

So, physics is very important in understanding and interpreting the results given by an experimental technique, if you do not know the physics you will not be able to interpret fringe patterns. And that what is summarized here, and what you have is one needs to know, what physical principle does an experiment exploits to reveal the physical information.

In fact, the purpose of this course is get into the physics of the problem and understand for yourself completely that this physics is exploited and what I see is this is the contour but what I will do now is you take my word for granted at this stage of the course. And in the given example the contours observed are isochromatics, depicting contours of principle stress difference. And for you to understand this, we have to develop crystal optics nevertheless if time permits towards the end of this lecture itself, you will be able to appreciate from solid mechanics point of view, how one can say that this contours are sigma 1 minus sigma 2 contours.

And the technique that is used this photo elasticity and I say said which exploits stress induced birefringence to reveal the stress information that is why I have taken a specimen which behaves like a crystal when this loaded that is what the epoxy that has a phenomenon of stress induced by the fringes. And because stress as induced the changes in the optics, so by analyzing the optics information it is possible for you to relate the effect of optics in terms of stress patterns. So that is what we have done in this simple exercise, and if you want to have a complete understanding, you have to have a basic understanding of what is crystal optics that also we will develop later I n the part of the course.

Currently the industries to focus when you look at an any experimental technique you need to understand the physics behind it and physics could be different for different techniques, only if you know the physics you would be able to interpret. Getting color contours that to color contours very nice but experiment does not stop there. After getting the color contours you should know how to interpret, the interpretation is possible only when you have understanding of physics. And many instances interpretation itself will be very challenging and this is where people would like to take the assistance of automated data acquisitions and processing methodologies where they would like to minimize the interaction of the person conducting the experiment. And you have to understand you will be surprised, many of your done in your physics course you would have done in experiment and finding out the refractive index of the glass.

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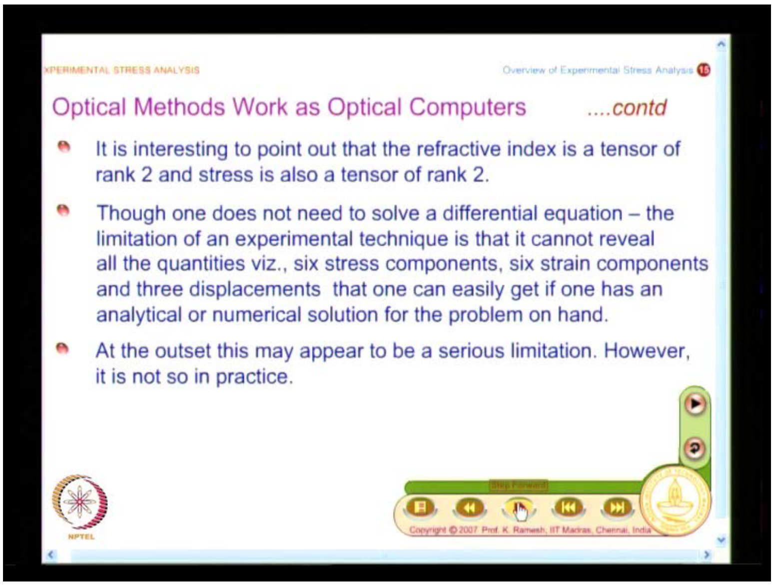

And you would have just got a member and you would have thought like in the case of introducing strength of materials, you take a slender member and then pull it and then you find out stress introduce is p by a you thing that it is a scalar. Because you are only looking at the component where you are looking at the value you, are not looking at totality of the stress at a point of interest. Similarly, you tend to think the refractive index is also a scalar, in fact it is not so refractive index is also has direction dependence. And it is a tensor of rank 2; stress is also a tensor of rank 2. So whatever modification on the refractive index if you are able to capture it by optics you could relate that to stresses. And if you look at this was develop way back in 1816 also that it first set of experiments he was able to do that all those details you will see later part of the course. So this is what I would like an emphasize again, we do not solve a differential equation from that point of view its advantage is, but the limitation of experimental technique it cannot reveal all the six stress components, it cannot reveal all the six strain components it cannot reveal, all the three displacement components. In this particular experiment we have been able to get only sigma 1 minus sigma 2 that to you are taking my word at the end of the course I would like every one of you to say, convincingly that this is so because you know the physics behind experiment.

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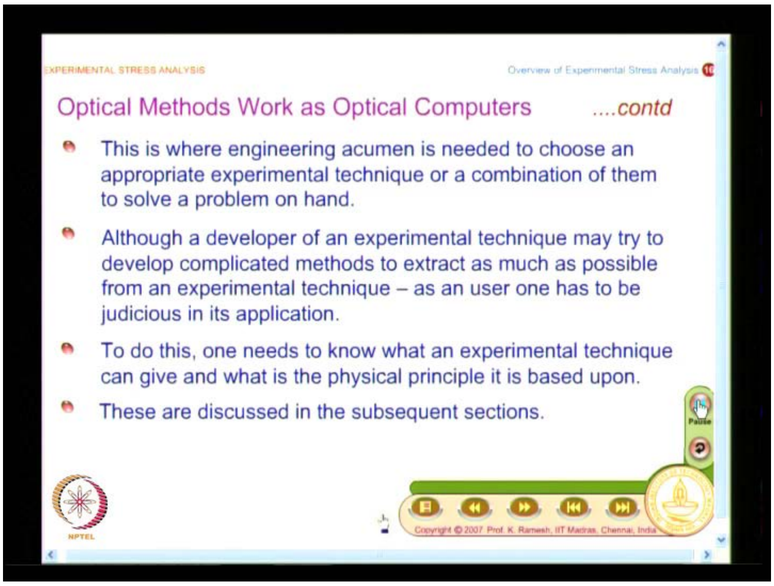
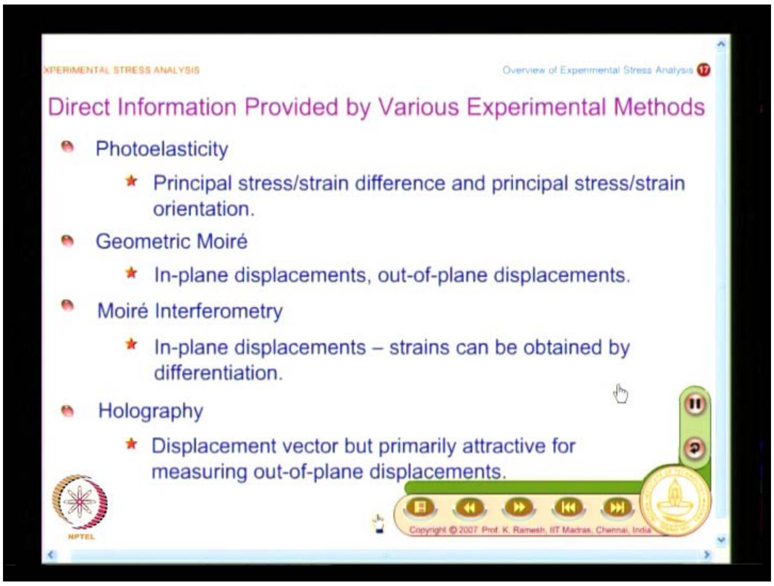


So, to start with you know it will appear oh I do an experiment I do not get everything under the sun; it may look like a limitation. But this is not a serious limitation and this is where you know as an engineer you have to apply your engineering acumen, to choose an appropriate experimental technique or a combination of them to solve a problem on hand. You know this is where the engineering acumen is required and that comes only by practice, say complicating a problem is very simple, simplifying a given problem on hand is the most difficult aspects and that comes only the experience sometimes, very simple methods can solve the complex problem.

So, you should be open to new ideas and you should know what kind of facilities that you have based on that based on the time constraint you decide an appropriate combination of techniques to solve it. On another word of caution I would like to say another word of caution which I have to like to say what I would like to say is see as an experimental person, the person may be interested in developing as much as possible from a given experimental technique. So in the process we may do more than what is really required and then try to say you use complicated steps to extract maximum from the given experiment, because when a new methodology is proposed he would like to get that methodology established and you would like to show that it can used for a variety of problems.

But, from a user point of view a particular feature of an experimental technique may be more appropriate and that is enough for you to solve whether getting into the ramifications of using that with a constraint. So as an user you should also use only those aspects of an experimental technique which are appropriate for your problem on hand. (Refer Slide Time: 20:10)



And that is what I said to do this one needs to know, what an experimental technique can give and what is the physical principle it is based upon. And these are discussed these will be discussed as we go back. And what you need to know now is, for each of the experimental technique, what is the information that it gives directly. You may want to use this information and use your mechanics of solids or other methods to process this information, to get additional data that is a different aspect, but basically when you exploit the physics what is information that you get out of it.

And that is you need to know and photo elasticity you get principal stress or strain, because photo elasticity has a transmission approach, you get principal stress difference. If you use the reflection methodology for analyzing prototypes you can get the principal strain difference and you can also get the principle stress or strain orientation.

So, if you look at photo elasticity it can give only these information. It cannot give you normal stress components or shear stress components, but shear stress components if you know principal stress difference and the theta you can process it and get it. But directly what it gives depends on the physics, because the physics you have already seen at least partly that it uses stress induced birefringence. And from that you will be able to find out difference in principal stresses directly. So you get only stress information from photo elasticity. And if you go to geometric moire, geometric moire provides directly only in plane displacements or out of plane displacements.

And what you will have to do is if you want to get a in plane displacements you should go for a particular optical arrangement, if you want to go for out of plane displacement you should have some modification in the optical arrangement. And even if you want to get U displacement, you should have grating oriented in a particular way. So you are exploit in the physics, so you should also know what is f, how you use it?

So at a time you will get only one information by enlarge, but there are also technique which uses more than one combination and you get combine information as comfortable as possible. And the next is moire interferometry, in moire interferometry you can get in plane displacements here you can go and make very precise measurements compare it geometric moire. Because the displacement is very accurate, strains can be obtained by differentiation like I said in the case of photo elasticity you could get it in plane shear stress, if you know the principal stress difference and principal stress orientation in moire interferometry because displacement information is very precise, because you use high density grating strains can also be obtained by differentiate in the displacement and you should know numerical differentiation is error prone than integration.

So even my small error is in displacement you get more will become more when you do a numerical differentiation. And you have holography and essentially gives the displacement vector. And you all know that you will as a security device, but it is from a stress analysis point of view the displacement vector and very attractive for out of plane displacement.

In fact in the early days when they were developing turbine blades, the vibration modes of turbine blades where recorded by holography. And it was very revealing and holography is very sensitive as well, the amounts of effort that we need to do holography is much more than do an experiment using photo elasticity.

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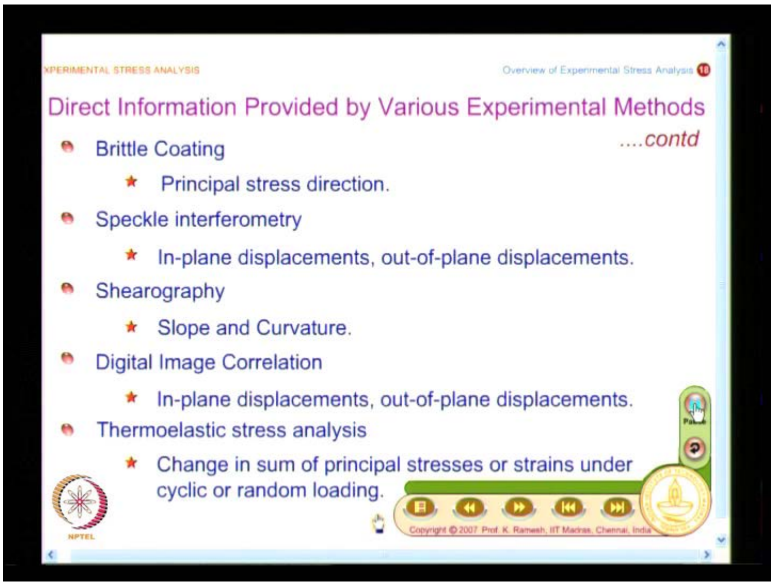

And you have another experimental technique, the name itself signifies I use a coating which is a brittle and this directly provides principal stress direction. So, I think right now you will know that we have seen variety of experimental techniques, some give only stress information, some give only displacement and some give only principal stress direction. So depending on what you want, so from as an analyst you should know what you want and based on that you should select the experimental techniques.

Then you have speckle interferometry which is the variation of holography, and which gives in plane displacements. And you can also get out of plane displacements.

Yes

See when you are looking at three displacement components u v and w, in plane displacement means you are essentially looking at u and v displacements. And if you are looking a if you want out of plane displacement it is a w component, then it is out of plane displacement. Particularly in a mode shape you have essentially vibration perpendicular to it and then you will see that easily captured by holography. And for each of this we need to have appropriate optics, the optical arrangement this very important which tells you which when you get and we will definitely spend time on each of this technique later, to see what is a optical arrangement.

The initial exercise now is, to know in our mind that what an experimental technique can give directly. And then you have a stereography which is a variation of speckle interferometry and which is very popular in non destructive testing where you can find out slope and curvature. For example, when we make honeycomb panels for satellites, all of these honeycomb panels have to go through a screening test before it is assemble on the satellite. Though you do not want to have any surprises on the satellite launched and you have to see whether that honeycomb panel the top sheet is grooved properly with a honeycomb.

And if it is not grooved properly you have to use an non destructive testing stereography is a very ideal tool where you could do the test on the complete panel satisfy yourself that it is free of defects or defects within permissible limits, then you allow the satellite fabricated. Then the next technique you have which is a very recent origin it is about 10 years old is digital image correlation, and this again gives in plane displacements, out of plane displacements. Even also one then you know, I do not have one experimental techniques which gives a only give in plane displacement, I have many experimental techniques to measure plane displacements.

And for example, even you go on yesterday I mentioned that you have to measure the length, length you can measure by tape, length you can measure by scale, you can measure by venire and you know when you are using a venire, you have a least count. When you go to screw gauge you have much finer least count and when you go to optical methods you still talk in terms of wave lengths. So similarly, when you look at an experimental technique also, you can get information of variant accuracies from each one of this. So you will also have to know see suppose I want to work on rubber, I am want have large displacement, this correlation is very ideal I do not want to measure large displacement with a very fine measuring instrument.

Suppose I want to work on nanostructures and I want to see in nano devices what is a kind of displacement, I would naturally go to holography and then find out the displacements. So, though each technique gives seemingly similar information, the physics what we have used or what we are exploited dictates the possible level of accuracy. And what I would say is physics as well as technology physics may be same, but technology is improved then also you can improve the accuracy of evaluation. And another non contact technique, what you have is thermo elastic stress analysis and this gives only change in some of principal stresses or strains, under cyclic or random loading. And you all know fetid loading is a very commonly natural structures, so for handling problems of this nature, thermo elastic stress analysis has come into play particularly for high temperature measurements, you want to have a non contact measurement this method has been developed.

So, direct it can we change in some of principal stresses, photo elasticity give difference in principal stresses, thermo elastic will give only change in difference in principal stresses. That means the physics what you are use demands are it gives it is capable of meanings only that information, and here it uses the temperature develop, because of stresses applied that is what you basically the information used.

Yes.

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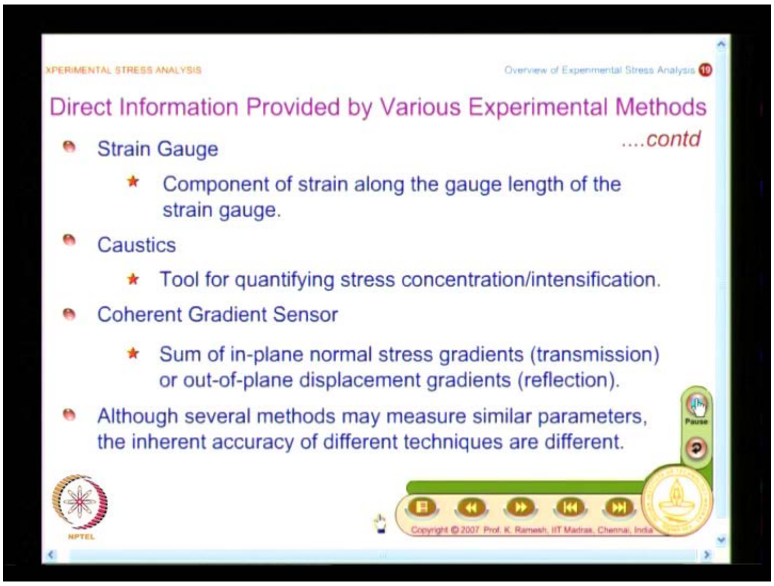

See most of the optical techniques are non contact, if you look at the optical techniques there all non contact techniques. Now I am showing a strain gauges when you go to strain gauge what you do? You actually take a strain gauge paste it on the specimen.

So, if you paste it on the specimen you are disturbing it, any coating technique whether it is brittle coating or photo elastic coating on strain gauges, it modifies a stress pattern to on extent. On the other hand, if I do not make any contact with this specimen I just send only light waves and then receive the light waves like what I do in transmission photo elasticity or what I do in a digital image correlation or in holography, you have the non contact application.

And this is what I would like emphasize see when you look at strain gauge people thinks strain gauge use strains, they talk loosely it does not to strain, it gives component of strain. There is the fundamental difference between strain and component of strain, strain is a tensor of rank 2, when you say strain you indirectly imply it is strain tensor, but a strain gauge, a single strain gauge can give you only component of strain along the gauge length of the strain gauge, this is a very shuttle and very important information.

So, if I have to find out strain tensor, in a two dimensional situation I need to use three strain gauges, I cannot measure strain tensor and one strain gauge. So, if you only if you understand a single strain gauge gives a component of strain, so you have to come out of your earlier understanding the strength of material. You look at as components many of you may not even recollect that stress is a tensor and strain is a tensor, you still think and terms of that as one in numbers the danger is that may even think that is a scalar like a temperature it is not show is a tensor. Tensor of rank 2 whether you understand or not material understand tensor, because if you break the material the failure planes are dictated by whatever the failure criteria that depends on stresses a tensor.

And we have also noted what is caustics, we saw the caustics of tea cup I said a caustic is the name of the physics behind it, and this is particularly used for stress concentration and stress intensification problem. See if I take photo elasticity I can do it on region which is not under stress concentration uniformly loaded also I can get the information.

Only when I have stress concentration that is suppose I have a load application point, near the load application point you have a concentration of stress. And for only in that zone I would be able to get information by caustics, because what it uses it uses the specimen becomes divergent the specimen becomes divergent because of Poisson effect. And whatever the light to send the light is reflected you would see that so in a sense it is also localized information you get. And a variation of caustics what you see is coherent gradient sensor and in this it is it is an optical method and sum of in plane normal stress gradients you get it in a transmission arrangement or out of plane displacement gradients in reflection arrangement.

And as I said earlier, although several methods may measure similar parameters, the inherent accuracy of different techniques are different. So is there is any question at this stage. So key point here is although several methods may measure similar parameters, the inherent accuracy of different techniques are different and this knowledge you need when you want to solve a problem on hand.

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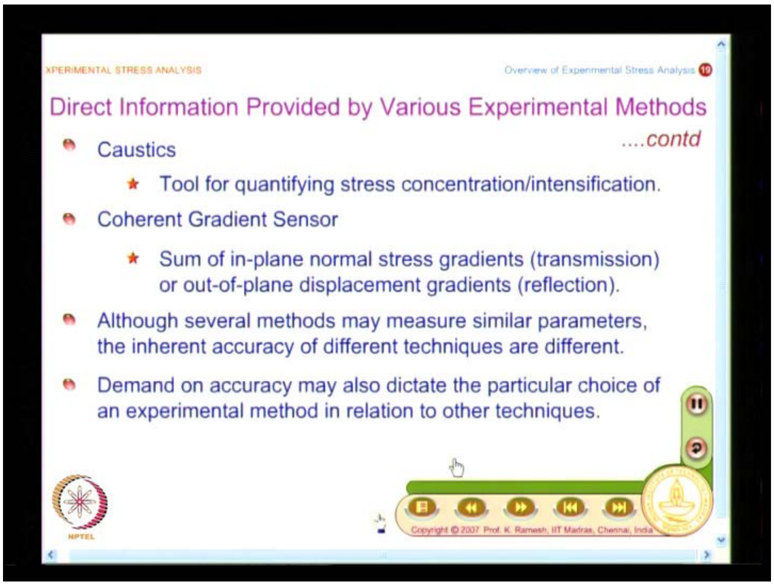

And you know sometimes you may want high accuracy, so demand accuracy may also dictate the particular choice of an experimental method in relation to other techniques. And everything cause money if you want more accuracy you need to pay more it may also take little more time for you get the result. So the idea is there is the fundamental difference, if you are able to solve the problem analytically there is nothing better than like that, but reality is the number of problems you can solve analytical method is very much limited you cannot live with an analytical methods alone.

It is definitely given you are understanding, that trust you have axial force members where the material is fully utilized in load sharing. The moment you come to bending the inner core or the material is not contribute to the load sharing, so you can have I beams for rails and when you go to torsion the inner core can be removed and you have hallow shares. And if you go and look at is it human being is intelligent enough would understood mechanics of solids, and there able to say for a bending member you do not have to have material in the core. If you go look at nature is very surprising, nature is much more intelligent then what we think of and you have bones which have hallow portion which actually you have a bone narrow where you have a hemoglobin developed.

And you have birds they fly because of hallow bones and if you look at nature you have a new branch of science biometrics, in fact people go and look at various natural creature as well as plants and how do they function. And we only medicate in our engineering and you should not feel, yes nature is great in a shown merit, human beings also great there one merit, because I always considered all these stress analysis you are understanding of fluid mechanics solid mechanics vibration if you look at what is the product that you can really think proud of is an aero plane, a huge metallic bird flies and come back such a heavy weight is not a joke. In fact all these techniques are contributed to it is develop, you have taken certain advantage from numerical techniques you have verified many of this from experimental approach only and now people want to fly compose it aircraft, because they would like to have the least weight it has it own advantage as well as problems.

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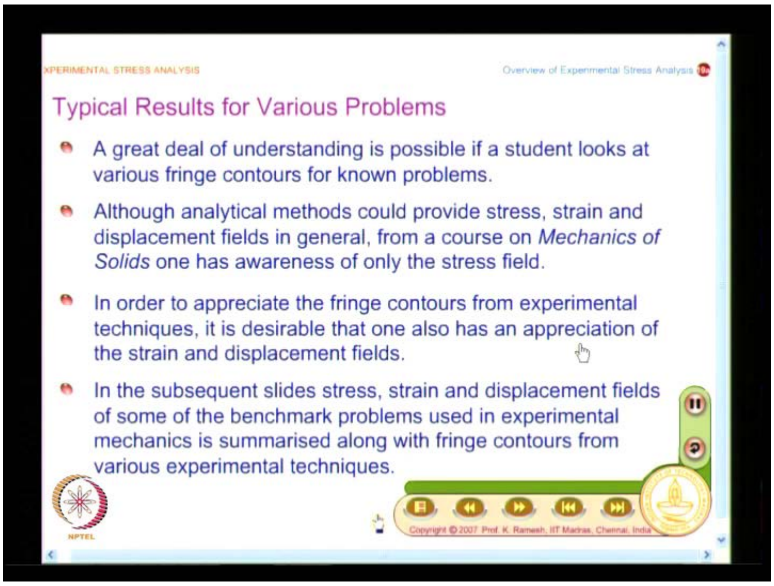

And for all that you can say that we learn from nature, but we also have done reasonably good with our understanding of mechanics of solids. And what we are going to now focus upon is there is the fundamental difference, see when you do a course in strength of materials you find out what is stress and your focus is essentially based on stress at a point. Rarely you come across how does this stress vary from point to point and you have ever had on opportunity in a first level course to even plot, how the variation is and look like.

Because you are concentrating more on stress at a point, at best you would have done a more circle where you find out as a function of orientation, how does this stress component vary at a point of interest. On the other hand if people are using numerical technique you have many many prose processor that has been developed which actually display the result in a form where I human being react, if you see red color you find it is more so that is the danger signal you have to do some correction in it.

So, only when you had come to numerical technique and we postprocessors you have been able to see those that happen somewhere in 80s you can say though computers are developed in 1960s the postprocessors develop for a plotting results, became user friendly, and became easily available only in 1988s. You can experimental technique they have always been giving only whole field information they would not giving point by point technique most of the optical technique you have been information. So, as an experimental is when you want to go, and look at you need get sensitize how to react to this optical patterns. So for example, you go to a doctor and then he finds out your temperature, he find it 105 you should react immediately that you have varying a temperature, even as individual you should know that you should react you should take some ice and puts some cold bath and remove the temperature.

He should not go to the encyclopedia of medicine and then find out what is one not degree means then you never go to the doctor. So, numbers are very important engineering and you should react to that so similarly, when you come to optical technique you should react to when you see when you see high density fringes you get a understanding that a there is something wrong. The stress levels are very high and you should also develops certain affinity towards, how these patterns develop, how they are distributed, what kind of piloted information you can get out of it. So, the idea here is also analytical methods provides stress strain and displacement fields in general, from a course of mechanics of solids one has awareness of only the stress field. This is in another point which are like to mention we are said that you want stress components, strain components and displacement components.

You go back and look at your notes in strength of materials except reflection of beams, you could have only worried about stress information everywhere. So, you learnt in a first level course, only that pertinent information which is required for you to apply in normal simple problem where you come across in and around you. Only when you go to advance level of studies where you would like to make certain decisions based on strain or based on displacement then you look for how to get all this information.

Though you are solve all these problems you may not have the solutions of stress strain fields or displacement field, because I have already pointed out that is experimental methods do not give only stress see if you go to strength of materials, you you find out by force balance and condition find out only stress. And if you go to theory of elasticity you have stress formulation, so you first find stress by the by you find out stress you have tired you do not want look at strain and displacement.

And if you go to finite elements essentially there are methods which you stress, but essentially it is the displacement based. Initially you find out displacement then your software itself converts to displacement to strain and also converts the stress and with modern postprocessors. You also shows the variation like what you see from the experimental techniques dynamically. So what you need is when you want to have appreciation of experimental technique for simple problem you also need to know stress field, strain field and displacement fields.

So, you becomes sensitive to appreciating field information rather than point information, see why developing stresses are tensor you need to know how does change from plane to plane. If you take a point how does it change from plane to plane is very very important, so from that that was the focus and you know a rudimentary knowledge that is stress concentration you do not go beyond that. But ones you come experimental technique, you need to have this appreciation and I want you to be good engineers and not refer the reference books for simple things.

So what we are going to look at is we are going to look at subsequent slides, stress as well as strain and displacement information for some of the benchmark problems, because it always better you go from known to the unknown. You are already done some of these problems in course and strength of materials and look at again those problems from different perspective, see what all you have got and how the contours we look like. So this is also indirectly say, that whatever the contours I will see an experiment by pattern matching you can say that yes I if I plot sigma minus sigma 2 it looks like this and I see the same think there, so this should be sigma minus sigma 2 I can go. And I have taken in all 5 problems.

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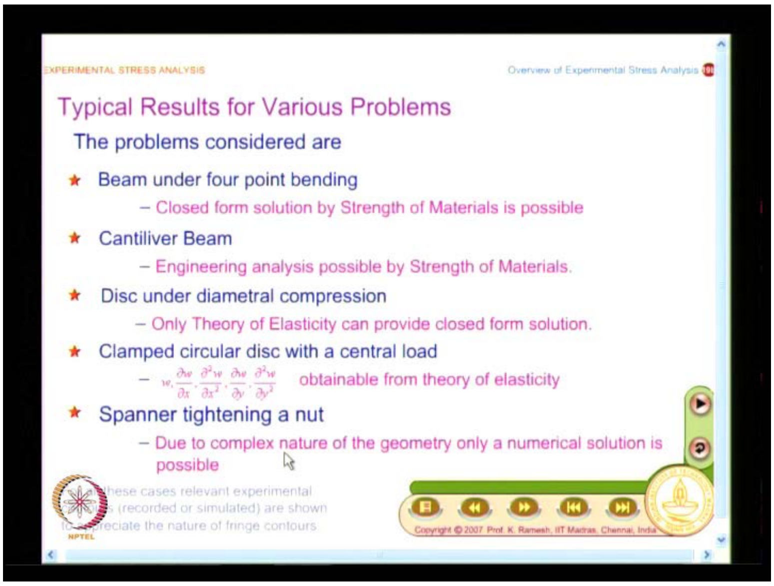

And there also done with graded level of complexity, so one of the simplest problems, which I which I have taken is beam under four point bending, that is the first problem to start with. And why I have taken this is you having closed form solution by strength of materials, so that is what you done in a course in strength of materials. So you know completely the story of beam, leaving the points of loading regions away from it you know, what happens in beam. And I am sure you would have just looked at stress field, I do not think you might have looked at strain field or displacement field, we would see all that.

Then a next problem is cantilever beam, why I have taken this is, see in a cantilever, though you apply structure formula and so on, you actually have shear, which makes the planes do not remain plane before and after loading, because shear effects and bending effects are not coupled still the solution from it strength of material is valid. And that is why good books terms this as engineering analysis of beam. There is a separate difference between analysis of beam where you say mathematically correct engineering analysis on understand engineering means approximation. We cannot do engineering without approximation and you do that right at cantilever beam, and you know done in cantilever beam, simple supported beam, clamped trapped beam all those problems except beam under four point bending there are only engineering analysis so you make approximation.

And the next problem is disc under diameter compression, see what you have is this is what we have seen in the last class, I have a I have a shape, I have a shape like this when I have the bar when I pull it strength of material is good, the moment type of put a hole I cannot do the strength of material.

Suppose, I change the shape I change the shape to a circle and I put compression and this is the most celebrated model that use in a photo elasticity. You do not have a solution from strength of materials, but you can definitely find out a close form solution from theory of elasticity. I can use push a solution and get the stress field at every point in the model, every point in the model I can find out. I can find out every point in the model.

And this solution is also very important for you to note it down, then I will have clamped circular disc with a central load and to show this little bigger and what you have here is, I can find out w that is the out of plane displacement dou w by dou x is slope, dou square x by dou x square is curvature similarly, I have a curvature the other direction dou w by dou y and dou square w by dou y square. Because this is a standard benchmark problem when you want to go and establish techniques to measure out of plane displacement.

And for this also you can get the solution available from a from a theory of elasticity is possible to find out solution. And finally, we compact our celebrated problem spanner tightening a nut and due to complex nature of the geometry only a numerical solution is possible. Experimental solution is always possible for all these problems, understand this analytical problems gives you conceptual understanding, if you are able to solve it analytically they are the best, but the reality is beyond certain simple geometry and simple loading conditions analytical methods are not possible to attack all problems on hand. Numerical methods solve it approximately, when you go to experimental method it gives you truth it is my numerical method does not match with experiment I should go and find out have I apply the boundary condition correctly, it is my analytical method does not match with experiment when I should go and verify whether analytical method has made certain approximation and you have to refine that approximation.

So finally, experimental methods of the truth, it provides you truth so you have to judge other technique based on experimental methods alone. And for the all these cases relevant experimental contours are also will have a look at it, so the idea is to get yourself sensitize on appreciating whole field visual information.

I want to do react, see as towards end of the course you will see the necessity optical arrangement, will also mathematically develop how these contours are all these developments will give, but this knowledge will becomes reinforce even to start with for simple problems, how these contours look like. That gives certain level of familiarity and also makes you comfortable for you to go and involve in yourself experimental techniques. And so, this class what we have covered is we are really look at what experimental techniques, why physics is very important in experimental technique, and you have also look at what basic information which each experimental technique kit.

I have focus only on basic information, if you use mechanics of solids or combine combination of more than one experimental technique, we could derive many of the quantities that is not they see here why we look at direct information provide by experimental technique is we would like to know, and relate what is the relationship between the physics and what is the information we get. And in the subsequent classes, you will see for the simple problems to start with what each experimental technique will give not only this, we will also look at stress field, strain field as, well as displacement fields. And you also have to understand that is stress strain or tonsorial quantities.

So, all that we will look at, and you know for us to carry forward you need to have certain basic understanding on a solid mechanics, some of this concept have to be recapitulated. And in this with this in a I have the first assignment sheet ready, and this you submitted to about in a week’s time. Thank you.