**Experimental Stress Analysis**
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**Lecture – 02**
# Optical Methods Work as Optical Computers

Today, we have a discussion on the overview of Experimental Stress Analysis and in the last class I said that when you say stress analysis in a 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 luxury, from a design point a 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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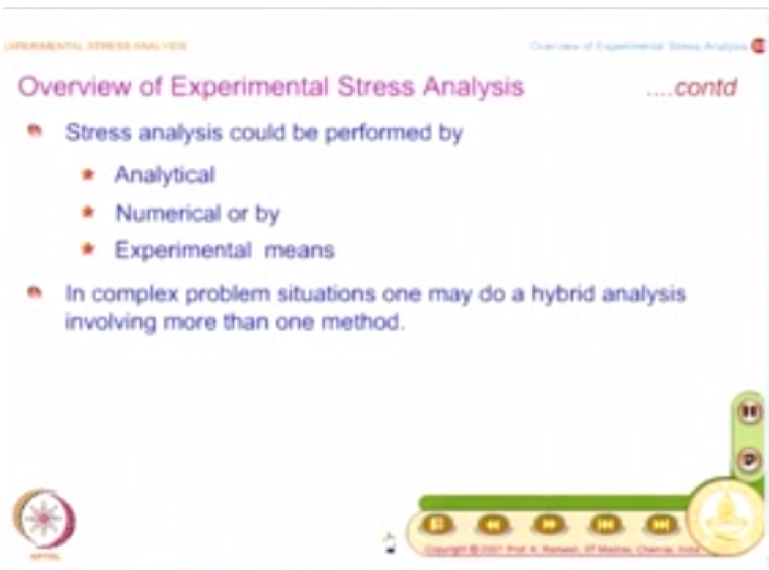


To do the stress analysis, we have also seen that you could do it by analytical methods, numerical methods or by experimental means. In complex problem situations, we may want to use more than one technique so that we get the problem on hand solved satisfactorily; and if you get into analytical methods what we find is you get a conceptual understanding on the nature of stress fields.

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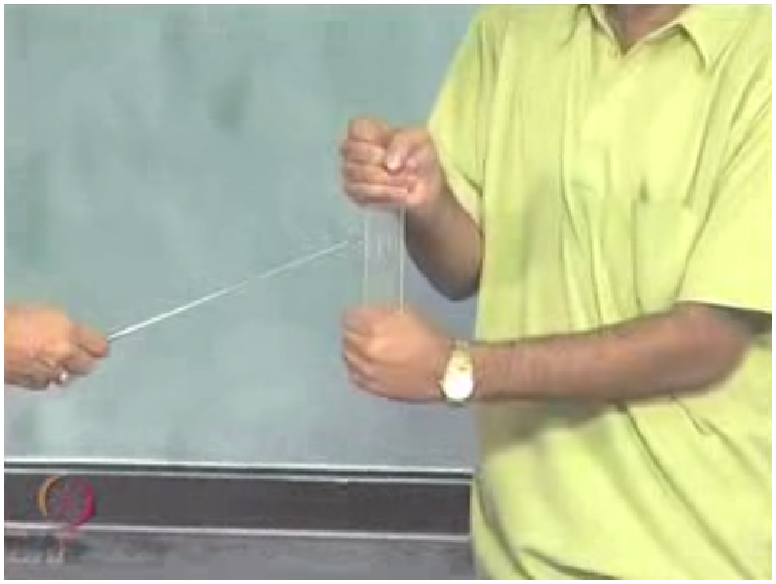

For example, can I have one of the students come here, then show this model and one of the simplest problem that is first taken in the course of strength of materials this is slender bar pulled in tension; and in this zone away from the grips, you all know that stress is constant and that is given by P/A and what I emphasised yesterday was you evaluate only a component and you have to learn that you have to put it in a 3x3 matrix and put the relevant 0's and understand this as a stress tensor and not just as a stress component.

A problem of this nature you have a ready-made solution without solving differential equations from strength of materials. The moment you take another problem for the same plate if you introduce a hole, it is just not possible to solve from strength of material because the moment I put a hole, plane sections do not remind plane before and after loading, before and after loading plane sections do not remain. So, your assumption of strength of materials approach will not help you to solve.

If you ask the question, can this at least be solved by theory of elasticity which is also not possible because the size of the whole 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, if the 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 closed form expression.

So, the size of the hole is very compared to this. Suppose I have a complex object, what do I do. I have a complex object like a spanner and this is a 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. If such a routinely used tool, if you want to solve it from your course on strength of materials, it is just not possible to solve.

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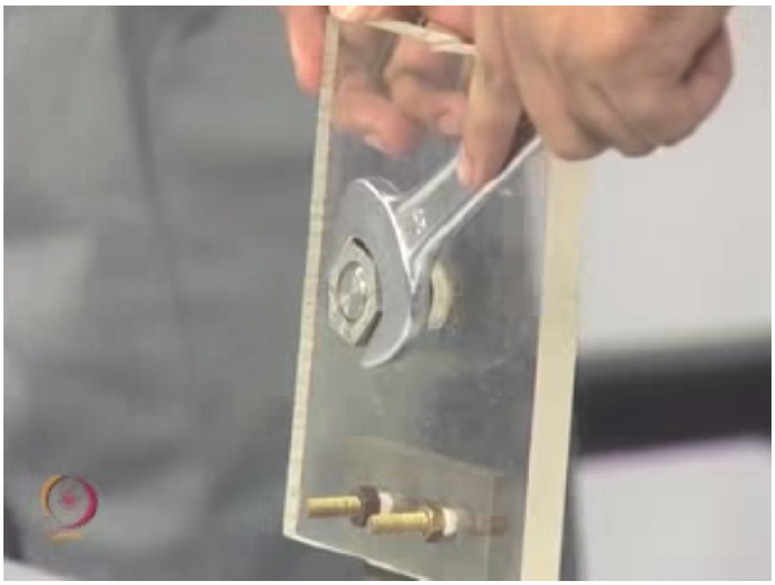

Let it tightened nut. What you find here, I have the spanner and I have the nut here and when I start tightening the nut, obviously you will find stresses are developed. Do you see the stresses here; you do not see the stresses here. What you can say from strength of materials because this is constrained here and you are applying a load here, some sort of a bending takes place in the member and since you all know something about stress concentration, you could at best say there will be stress concentration in this zone and this is the load application point.

So, sudden 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 recourse that what you can do is you have to do it only from a numerical technique or an experimental method.

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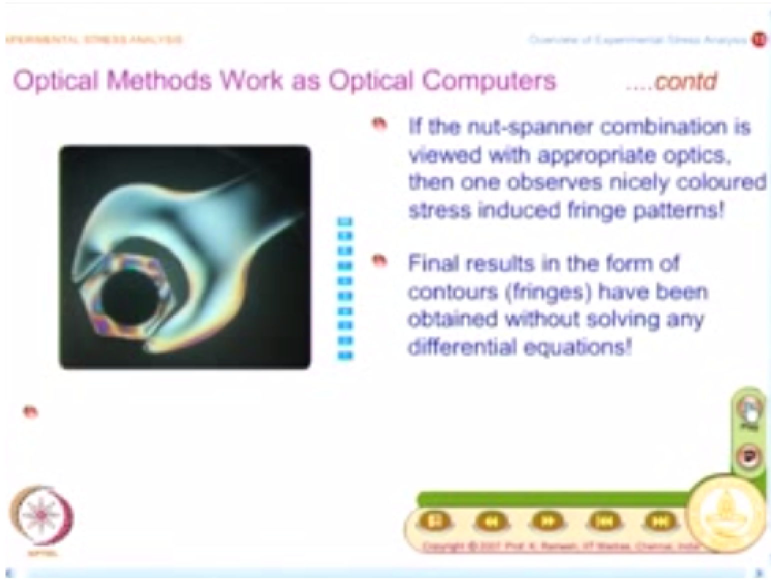


What we are going to see is we are going to introduce a new concept that optical methods work as optical computers and this is what we had seen physically, a nut was tightened by a spanner and it is natural to expect that stresses would be developed in the components and you do not see them. You do not see 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 to show even the stresses as they develop when the nut is tightened by the spanner. So, what we find is a very simple down-to-earth problem, you do not have solution from strength of materials after full course on strength of materials. You can only at best conjecture what could be the stresses not the actual magnitudes and what you have is why I have taken epoxy is the spanner and the nut are made of epoxy and it possess a unique property of stress induced birefringence.

See, earlier I have told you that each of the experimental technique utilise 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. Here what we have done is we have taken spanner and nut which is made of epoxy and it possess a unique property of stress induced birefringence. What I do now is I introduce appropriate uptakes and view the same combination with the optics.

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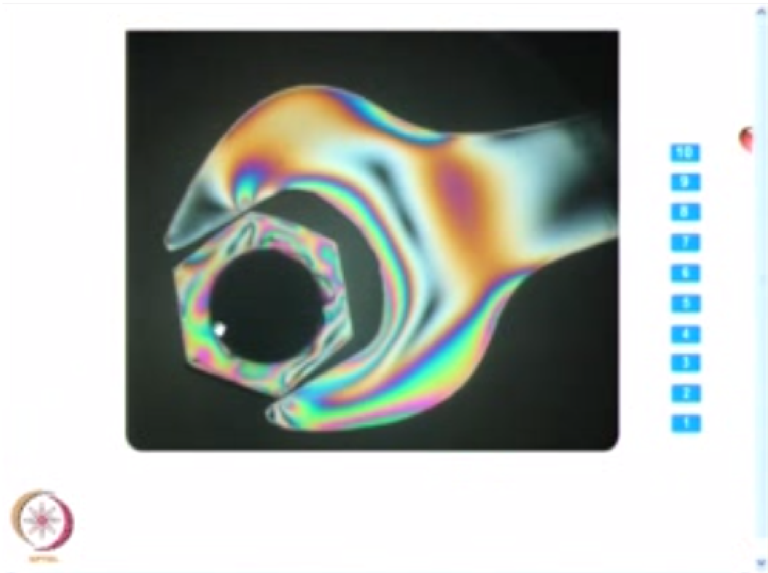

Optics is not shown here in the screen but you will see the effect of optics seen on the image and what you have here is as I change the load, as I keep increasing it, you find that more and more colours are emerging and it is seen. So, what it shows is whatever the colours that you see are a function 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 the spanner and you should thank the nature. These are not artificial colours.

It reveals the stress information in the form of such rich colours. The colours are very nice and normally when you go for computer plot, you usually plot to indicate what is of a high value as red and low value as blue and you have a greyscale suitable for different application, but here the colours are seen naturally and nature wants to reveal the stresses in colours to enthuse the experimental mechanics person to conduct the experiment and I would like a reasonable sketch of it capturing the salient features.

What you have here is you have stress concentration. This is the load contact point and you have stress concentration here and you have birefringence developed on the edges and you have seen very clearly that all these colours have emerged as a function of what you applied as load. For your benefit, I will repeat it again. So, when I have the least load, it is like this. As the load is increased, in stages you find birefringence are formed and we call these as fringes and what you get here.

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. The whole field information from an experiment and what I have here is the result in the form of contours have been time and I have got it without solving differential equations because the effort that I have done is I have to make the model of the spanner as well as the nut and then put it in appropriate optics and reveal the pattern.

If I had 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 of differential equations, solve it either in enclosed form or at least in the form of approximate approach. Then, re-plot, got to your computer, use a plotting software and re-plot the values. Then, I will get this contour. 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 you will have to do is you have to make the model. There is no escape. There is some price you have to pay for it. In a case of numerical method, you have to pay a price in formulating the problem. In the experimental method, you have to pay a price in fabricating the model.

Now, what is important is I have seen this rich contours and what these contours are, how do I know what this contours represent. So, here only you have to look at what is the physics behind the problem. 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 the fringe patterns.

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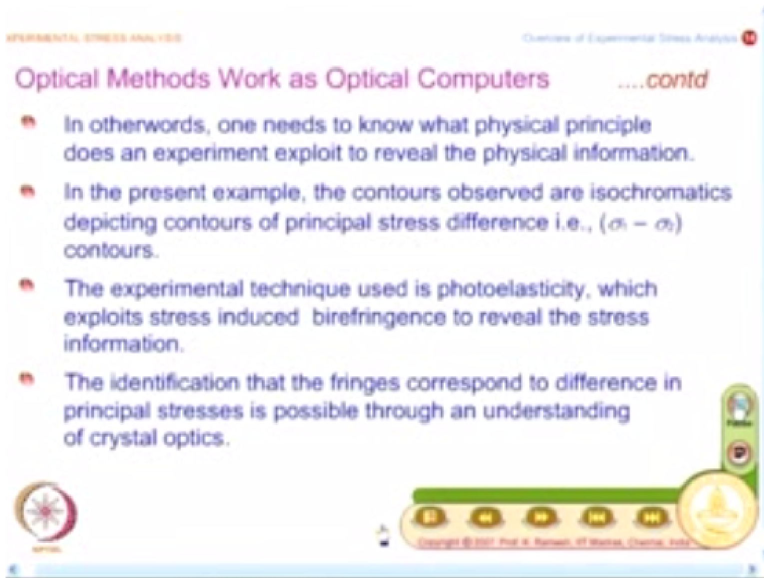


That is what is summarised here and what you have is one needs to know what physical principle does an experiment exploit to reveal the physical information. In fact, the purpose of this course is get into the physics of a problem and understand for yourself completely that this physics is exploited and what I see is this in the contour, but what I will do now is you take my word for granted at this stage of the course.

And in the present 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 a view how one can say that these contours are sigma 1-sigma 2 contours and the technique that is used for this photoelasticity and as I 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 it is loaded, that is what the epoxy that has a phenomenon of stress induced birefringence and because stress has induced the changes in the optics, so by analysing 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 in the part of the course.

Currently, the interest is to focus when you look at any experimental technique, you need to understand the physics behind it and physics would be different for different techniques. Only if you know the physics, you would be able to interpret getting coloured contours is very nice, but experiment does not stop there. After getting the coloured contours, you should know how to interpret it.

The interpretation is possible only when you have an 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 acquisition and processing methodologies where they would like to minimise the interaction of the person conducting the experiment.

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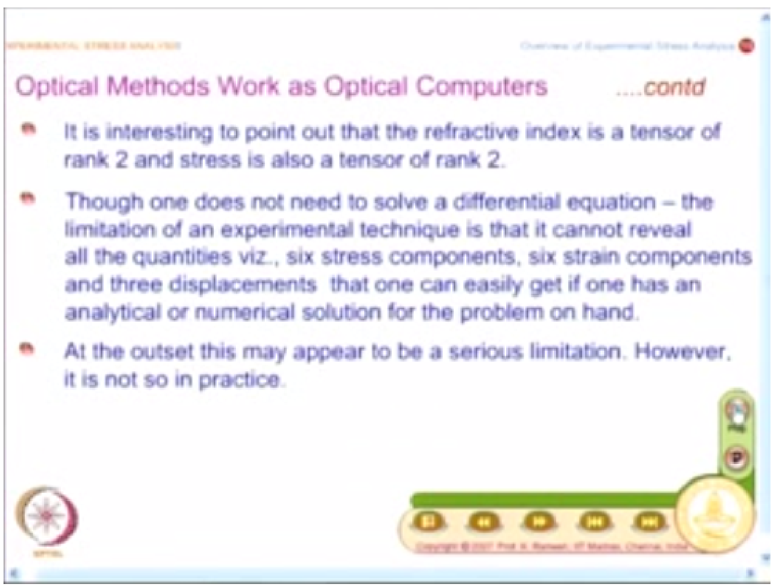


You will be surprised many of you have done in your physics course, you would have done an experiment on finding out the refractive index of a glass and you would have just got a number. You would have thought like in the case of introducing strength of materials, you take a slender member and then pull it and then you find out stress introduces P/A, you think 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 that refractive index is also a scalar. In fact, it is not so. Refractive index is also direction dependence and it is 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 this was developed way back in 1816 or so in Bristol as first set of experiments, he was able to do that, all those details we will see later part of the course. So, this is what I would like to emphasize again.

If you do not solve a differential equation from the point of its advantages, but the limitation of experimental technique, it cannot reveal all the 6 stress components. It cannot reveal all the 6 strain components. It cannot reveal all the 3 displacement components. In this particular experiment, we have been able to get only sigma 1-sigma 2 that too you are taking my word. At the end of the course, I would like everyone of you to say convincingly that this is so because we know the physics behind the experiment.

So, to start with you know it will appear I do an experiment, I do not get everything under the sun.

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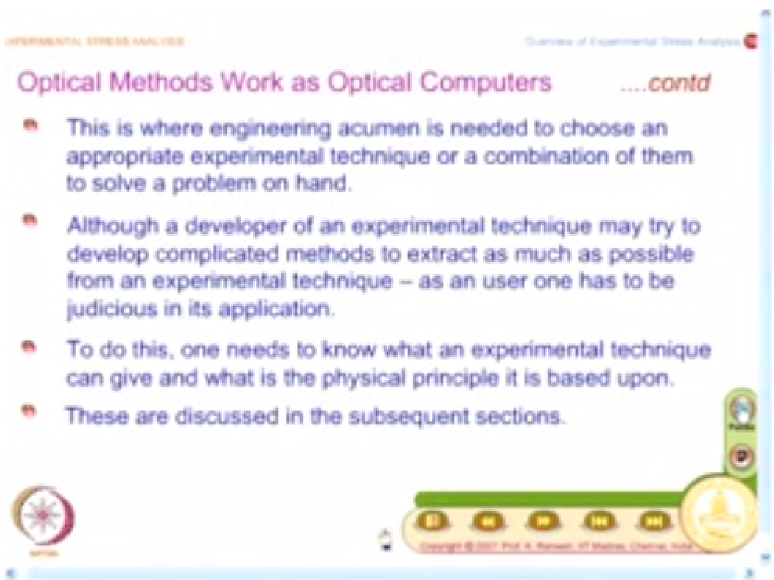


It may look like a limitation, but this is not a serious limitation and this is where you know as an engineer you have to apply your engineering acumen to choose an appropriate experimental technique or a combination of them to solve the problem on hand. This is where the engineering acumen is required and that comes only by practice. See complicating a problem is very simple, simplifying a given problem on hand is the most difficult aspect and that comes only by experience.

Sometimes, very simple methods can solve a 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. Another word of caution which 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, you would like to get that methodology established and you would like to show that it can use 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 without getting into the ramifications of using that with a constraint.

So, as a user, you should also use only those aspects of an experimental technique which are appropriate for your problem on hand and that is what I said to do this one needs to know what an experimental technique can give and what is a physical principle it is based upon and these will be discussed as we go by.

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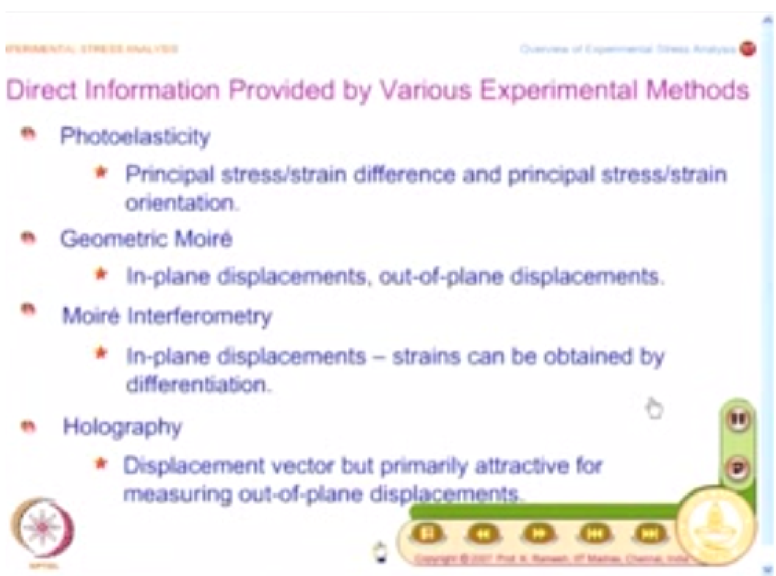

What you need to know now is for each of the experimental technique what is the information that it gives directly. You may want to use this information and use your mechanics of solids or other methods to process this information to get additional data, that is a different aspect but basically when you exploit the physics, what is the information that you get out of it and that is you need to know and in photoelasticity you get principal stress or strain because photoelasticity has a transmission approach.

You get principal stress difference. If you use a reflection methodology for analysing prototypes, you can get the principal strain difference and you can also get the principal stress or strain orientation. So, if you look at photoelasticity, it can give only these information. It cannot give you normal stress components or sheer stress components but sheer stress components if you know principal shows difference in the theta, you can process it and get it, but directly what it gives depends on the physics.

Because in physics we have already seen, at least partly that it uses stress induced birefringence and from that you will be able to find out difference in principle stresses directly. So, you get only stress information from photoelasticity and if you go to geometric Moire, geometric Moire provides directly only in-plane displacements or out-of-plane displacement and what you have to do is if you have to get in-plane displacement, 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 you displacement, you should have gratings oriented in a particular way. So, you are exploiting the physics. So, you should also know how you use it, so at a time you will get only one information by and large but there are also techniques which uses more than one combination and you get combined information as comfortably as possible.

The next is Moire interferometry. In Moire interferometry you can get in-plane displacements. Here, you can go and make very precise measurements compared to geometric Moire because the displacement is very accurate, strains can be obtained by differentiation. Like I said in the case of photoelasticity, you could get in-plane sheer stress if you know the principal difference and principal stress orientation.

In Moire interferometry because the displacement information is very precise because you use high-density gratings, strains can also be obtained by differentiating the displacement. You should know numerical differentiation is error prone than integration. So, even my small error in displacement will become more when you do a numerical differentiation. You have holography and essentially it gives a displacement vector and you all know that it is a security device but it is from a stress analysis point a view, it is a 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 were recorded by holography and it was very revealing and holography is very sensitive as well the amount of effort that you need to do holography is much more than you do an experiment using photoelasticity.

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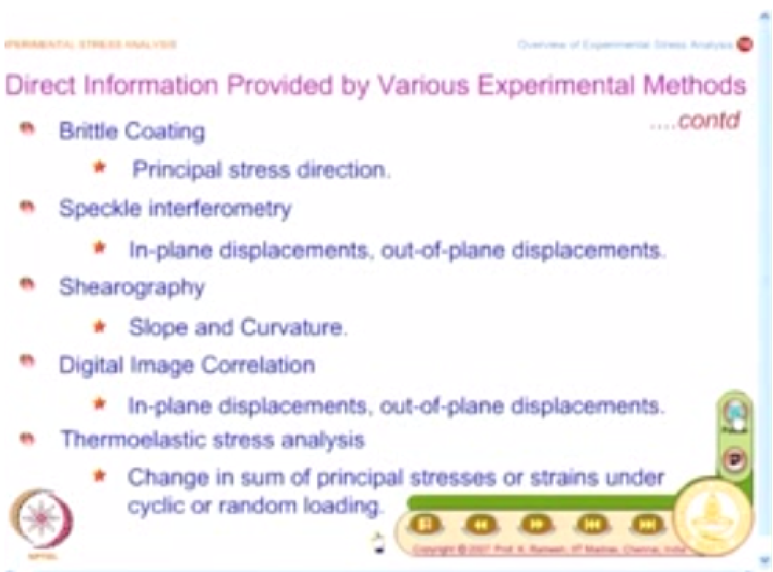


You have another experimental technique, the name itself signifies I use coating which is brittle and this directly provides principal stress direction. So, I think right now you will know that we have seen variety of experimental techniques. Some give only stress information, some give only displacement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

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

**“Professor - student conversation starts”** Yes. Could you explain (()) (25:40). See when you are looking at 3 displacement components U, V and W, in-plane displacement means you are essentially looking at U and V displacements and if want out-of-plane displacement that is W component, then it is out-of-plane displacement, particularly in mode shape you have essentially vibration perpendicular to it and then you will see that easily captured by holography and for each of this you need to have appropriate optics. **“Professor - student conversation ends”.**

The optical arrangement is very important which tells you which one you get and we will definitely spend time on each of these techniques later to see what is optical arrangement. The initial exercise now is to know in our mind that what an experimental technique can give directly. Then you have a shearography which is a variation of speckle interferometry which is very popular in non-restrictive testing where you can find out slow open curvature.

For example, when they make honeycomb panels for satellites, all of this honeycomb panels have to go through a screening test before it is assembled on the satellite because you do not want to have any surprises when the satellite is launched and you have to see whether that honeycomb panel, the top sheet is glued properly with the honeycomb and if it is not glued properly, you have to use a non-restrictive testing and shearography 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 to be 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 displacement and out-of-plane displacements. You may also wonder you know; I do not have one experimental technique which gives only in-plane displacements. I have many experimental techniques to measure in-plane displacements.

For example, 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 vernier and you know when you are using a vernier, 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 wavelengths. So, similarly when you look at experimental techniques also, you can get information of varied accuracies from each one of this.

So, you will also have to know, see suppose I want to work on (()) (28:31), I want to have large displacement. Digital image 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 the 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 you have exploited dictates the possible level of accuracy and what I would say is physics as well as the technology; physics may be same but if technology is improved, then also you can improve the accuracy of evaluation. Another noncontact technique what you have is thermoelastic stress analysis and this gives only change in some of principal stresses or strains under cyclic or random loading.

You all know fatigue load is very common in actual structures. So, for handling problems of this nature, thermoelastic stress analysis have come into play, particularly for high temperature measurements, you want to have noncontact measurement, this method has been developed. So, directly it can give change in some of the processes. Photoelasticity gave different in principal stresses, thermoelastic will give only change a difference in principal stresses.

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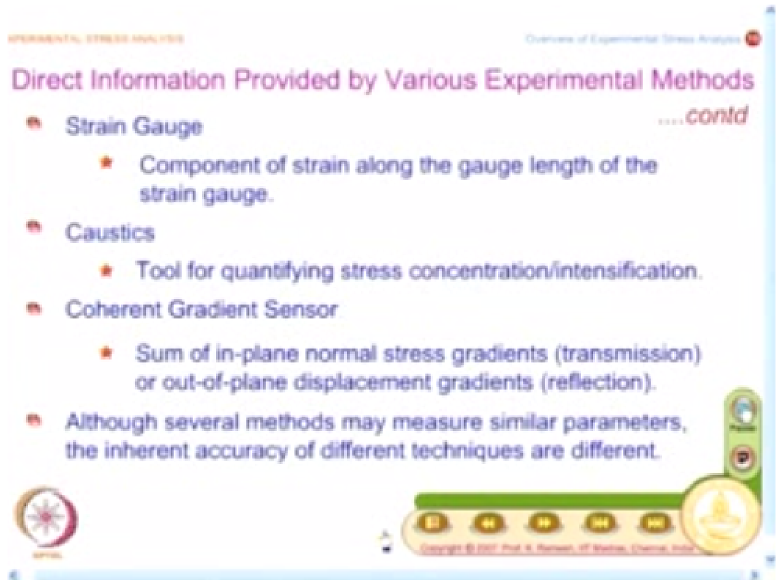


That means the physics what you have used demands or it is capable of giving only that information, okay and here it uses the temperature developed because of stress applied.

**“Professor - student conversation starts”** Yes. It is non-contact (()) (30:28). See most of the optical techniques are non-contact. If you look at the optical techniques, they are all non-contact techniques. **“Professor - student conversation ends”.** Now I showing 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 on the specimen, you are disturbing it.

Any coating technique whether it is brittle coating or photo-elastic coating or strain gauges, it modifies the stress pattern to an extent. On the other hand, if I do not make any contact with the specimen and I just send only light waves and then we receive the light waves, like what I do in transmission photoelasticity or what I do in digital image correlation or in holography, you have non-contact application, okay.

This is what I would like to emphasize. See when you look at strain gauge, people think strain gauge gives strain. They talk loosely, it does not give strain. It gives component of strain. There is a 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 single strain gauge can give you only component of strain along the gauge length of the strain gauge. This is a very subtle and very important formation.

So, if I have to find out strain tensor in a 2-dimensional situation, I need to use 3 strain gauges. I cannot measure strain tensor with one strain gauge. So, only if you understand a single strain gauge gives component of strain. So, you have to come out of your earlier understanding of strength of material, you have looked at the components. Many of you may not even recollect that stress is a tensor and strain is a tensor.

You still think in terms of that has only numbers and the danger is that you may even think that it is a scalar, like a temperature, it is not so, it is a tensor, tensor of rank 2. Whether you understand or not, material understands the tensor because if you break the material, the failure planes are dictated by whatever the failure criteria, that depends on stress is a tensor. We have also noted what is caustics. We saw the caustics in a tea cup.

I said caustics is the name of the physics behind it and this is particularly used for stress concentration and stress intensification problem. See, if I take photoelasticity, I can do it on regions which is not under stress concentration, uniformly loaded also I get 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 because of portion effect and whatever the light you send, the light is deflected, you would see that. So, in a sense it is also localized information you get and a variation of caustics what you see is the coherent gradient sensor and in this it is an optical method and some of in-plane normal stress gradients you get it in transmission arrangement or out-of-plane displacement gradients in deflection arrangement.

As I said earlier although several methods may measure similar parameters, the inherent accuracy of different techniques are different. So, is there any question at this stage. So, the 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 the problem on hand.

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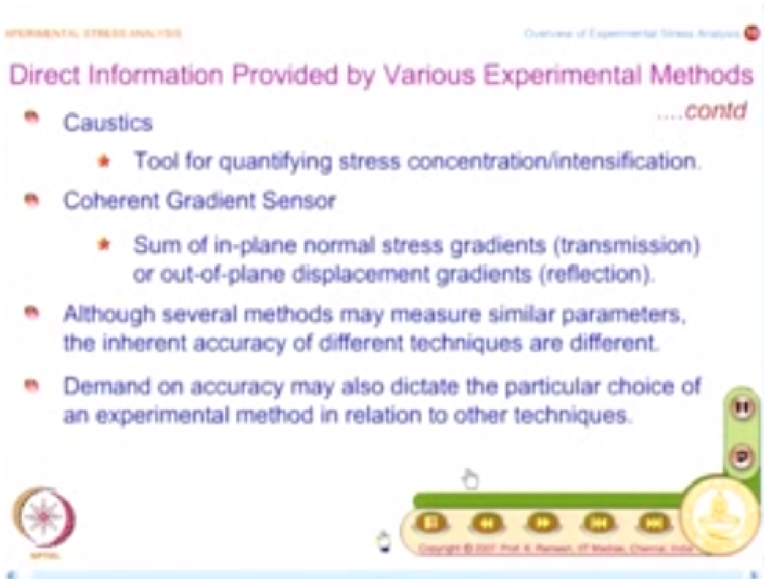


You know, sometimes you may want high accuracy, so demand on accuracy may also dictate the particular choice of an experimental method in relation to other techniques and everything costs money. You know if you want more accuracy, you need to pay more. It may also take little more time for you to get the result. So, there is a 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 by analytical methods are very much limited.

So, you cannot live with analytical methods alone. It has definitely given you an understanding that trusts you have axial force members where the material is fully utilised in load sharing, the moment you come to bending, the inner core of the material is not contributing the load sharing. So, you can have high beams for rails and when you go to torsion, the inner core can be removed and you have hollow shafts; and if you go and look at is it human beings which are intelligent enough who have understood the mechanics of solids and they are able to say for a bending member, you do not have to have material in the core.

If you go and look at nature, it is very surprising. Nature is much more intelligent than what we think of and your bones which have hollow portion which actually you have the bone marrow where you have haemoglobin developed and you have the birds, they fly because of hollow bones; and if you look at nature, you have a new branch of a science biomimetic. In fact, people go and look at various natural creatures as well as plants and how do they function and we only mimicate in other engineering and you should not feel, yes nature is great in its own merit.

Human beings are also great in their own merit because I always consider all the stress analysis; your understanding of fluid mechanics, solid mechanics, vibration if you look at what is the product that you can really think proud of is an aeroplane. A huge metallic bird flies comes back with such a heavyweight is not a joke. In fact, all these techniques have contributed to its development. You have taken certain advantage from numerical techniques.

You have verified many of this from experimental approach only and now people want to fly composite aircraft because they would like to have the least weight. It has its own advantages as well as problems 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.

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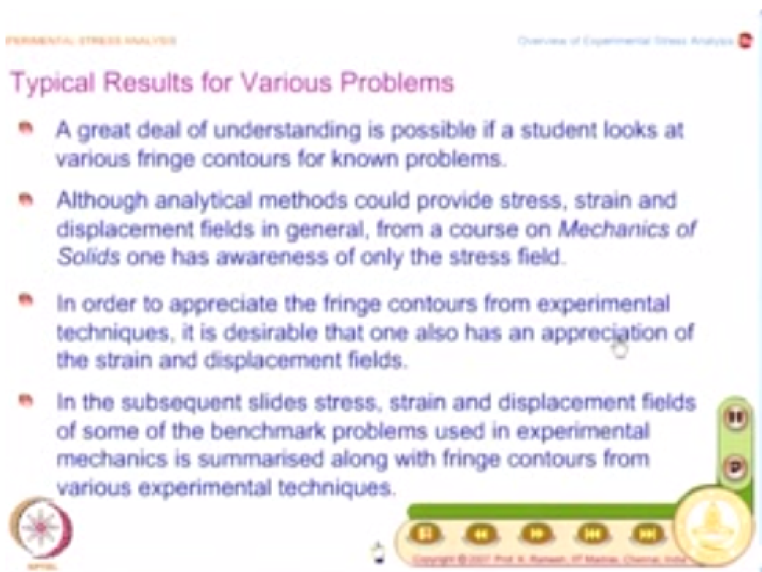


What we are going to now focus upon is, there is a fundamental difference. See, when you do a course in strength of materials, you find out what is stress and your focus is essentially based on stress at a point. Rarely, you come across how does this stress vary from point to point and you have ever had an 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 Moire circle where you find out as a function of orientation how does this stress component vary at a point of interest. On other hand, if people are using numerical technique, you have very many post processors that have been developed which actually display the result in a form where a human being can react. If you see red colour, you find it is more, so there is a danger signal you have to do some correction.

So, only when you had come to numerical technique and with post processors, you have been able to see those and that happened somewhere in 80s you can say, though computers are developed in 1960s, the post processors developed for plotting results became user-friendly and became easily available only in 1980s, but if you look at experimental technique, they have always been giving only whole field information.

They were not giving point by point. Most of the optical techniques you will (()) (39:36) information. So, as an experimentalist, when you want to go and look at, you need to get sensitised how to react to this optical patterns. So, for example you go to your doctor and then he finds out your temperature, he finds it is 105, he will react immediately that you have a very high temperature. Even as an individual, you should know that you should take some ice and put some cold bath and remove the temperature.

He should not go to the encyclopaedia of medicine and then find out what does 105 degrees means. Then, you will never go to the doctor. So, numbers are very important in engineering and you should react to that. So, similarly when you come to optical techniques, you should react to when you see high-density fringes, you should get an understanding that there is something wrong.

I mean the stress levels are very high and you should also develop certain affinity towards how these patterns develop, how they are distributed, what kind of qualitative information can get out of it. So, the idea here is although analytical methods could provide stress, strain and displacement fields in general, from a course of mechanics of solids, one has awareness of only the stress field. This is another point which I would like to mention.

We have said that you want stress components, strain components and displacement components. You go back and look at your notes on strength of materials, except deflection of beams, you would have only worried about stress information everywhere. So, you learned in a first level course only that pertinent information which is required for you to apply in normal simple problems where you come across in and around view.

Only when you go to advanced 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 have solved all these problems, you may not have the solution stress field or the displacement field because I have already pointed out that experimental methods do not give only stress.

See, if you go to strength of materials, you find out by force, balance and equilibrium condition, you find out only stress and if you go with theory of elasticity, you have stress formulation. So, you first find stress. By the time you find out the stress, you are tired, you do not want to look at strain and displacement, okay; and if you go to finite elements, essentially there are methods which you stress but essentially it is displacement based.

Initially you find out displacement, then your software itself converts the displacement into strain and also converts this as stress and with modern post processor, this also shows the variation like what you see in an experimental technique dynamically, okay. So, what you need is when you want to have appreciation of experimental technique, for simple problems you also need to know stress field, strain field and displacement fields.

So, you become sensitive to appreciating field information rather than point information. See, while developing stresses of tensor, you need to know how does it change from plane to plane, it is very-very important. So, that was the focus and you know a rudimentary knowledge that is stress concentration, you do not go beyond that but once you come to 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, okay.

So, what we are going to look at in the subsequent slides, stress as well as strain and displacement information for some of the benchmark problems because it is always better you go from known to the unknown. You have already done some of these problems in your course on strength of materials and look at again those problems with a different perspective. See what all you have got and how the contours will look like.

So this also indirectly say that whatever the contours I have seen and experiment by pattern matching you can say that yes, if I plot sigma 1-sigma 2, it looks like this and I see the same thing there, so this should be sigma 1-sigma 2, it can go.

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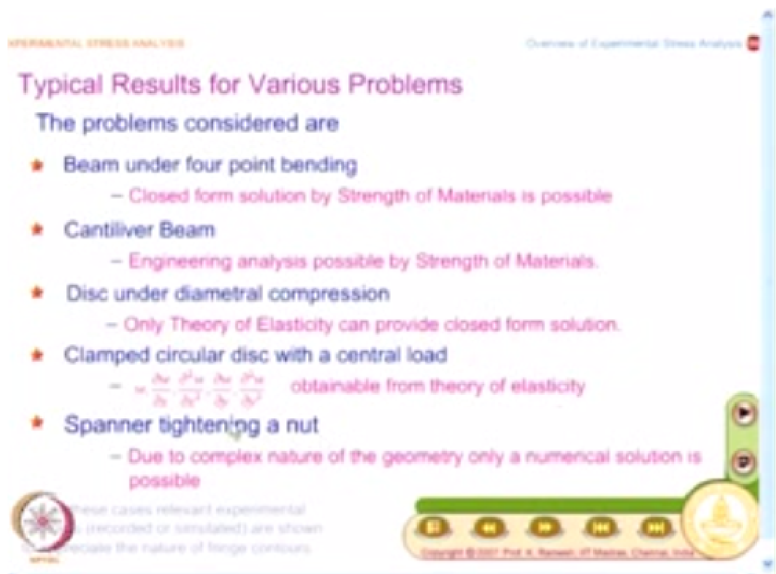


I have taken in all 5 problems and they are also done with graded level of complexity. So, one of the simplest problem which I have taken is beam under 4-point bending, that is the first problem to start with and why I have taken this you have closed form solution by strength of material. So, that is what you have done in a course in strength of materials. So, you know completely the story of beam, leaving the points of loading region away from it you know what happens in beam.

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, the next problem is cantilever beam. Why I have taken this is, see in a cantilever though you apply flexure 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 a strength of materials is valid and that is why good books term this as engineering analysis of beam.

There is a subtle difference between analysis of beams where you say mathematically correct, engineering analysis and understand engineering means approximation. We cannot do engineering without approximation and you do that right at cantilever beam. You know you have done cantilever beam, simply supported beam, clamped (()) (45:55) beam, all those problems except beam under 4-point bending, they are all only engineering analysis. So, you make approximation.

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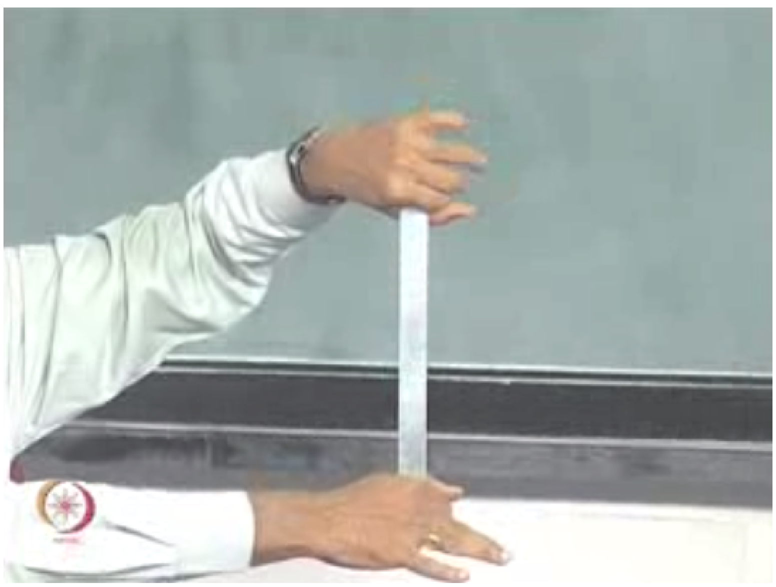

The next problem is disc under diametral compression. See, what you have is, this is what we had seen in the last class. I have a shape like this. When I have the bar, when I pull it, strength of material is good. The moment I put a hole, I cannot do by strength of material. Suppose, I change the shape, I change the shape to a circle and I put compression and this is the most celebrated model that you use in photoelasticity.

You do not have a solution from strength of materials but you can definitely find out a closed form solution from theory of elasticity. I can use Bushnell's solution and get the stress field at every point in the model, every point in the model I can find out 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 I will show this a little bigger and what you have here is I can find out W that is out-of-plane displacement, duo W/duo X is slope, duo XW/ duo X is curvature.

Similarly, I have curvature in other direction duo W/duo Y and duo XW/duo Y. Because this is standard benchmark problem when you want to go and established techniques to measure out-of-plane displacement and for this also you can get the solution available from theory of elasticity possible to find a solution; and finally we come back to where the celebrated problems spanner tightening a nut and due to complex nature of geometry only numerical solutions is possible.

Experimental solution is always possible for all these problems, understand this. Analytical problems give 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 method are not possible to attack all problems on hand. Numerical methods solve it approximately. When you conduct experimental methods, it gives you truth.

If my numerical method does not match with experiment, I should go have applied the boundary condition correctly. If my analytical method does not match with experiment, then I should go and verify whether the analytical method has made certain approximation and you have to define that approximation. So, finally experimental methods are the truth. If provides you truth. So, you have to judge other techniques based on experimental methods alone.

For all these cases, relevant experimental contours also, we will have a look at it. So, the idea is to get yourself sensitised on appreciating whole field visual information. I want you to react. See, towards the end of the course, we will see the necessary optical arrangement. We will also mathematically develop how this contours are, all those developments we will do, but this knowledge will become reinforced even to start with for simple problems how this contours look like.

That gives a certain level of familiarity and also makes you comfortable for you to go and involve yourself in the experimental technique. So, in this class what we have the covered is, we have really looked at what experimental techniques, why physics is very important in an experimental technique and we also looked at what basic information which each experimental technique give. I have focused only on basic information.

If you use mechanics of solids or combination of more than one experimental technique, we could derive many of the quantities, that is not the issue here. Why we look at direct information provided by experimental technique is we would like to know and relate what is a relationship between the physics and what is information we get, and in the subsequent classes we will see for 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 field; and you also have to understand that stress and strain are tensorial quantities, so all that we will look at and you know for us to carry forward, you need to have certain basic understanding on solid mechanics. Some of these concepts have to be recapitulated and with this in you, I have the first assignment sheets ready and this you submit it in about a week’s time.