Experimental Stress Analysis

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Module No. # 06

Lecture No. # 41

Discussion Session

Sir, how does the handedness changes when the relative retardation is modified? Now, let us go back and then see this slide. See, you have this expression tan 2 beta equal to 2a x a y divided by a x square minus a y square into cos delta.

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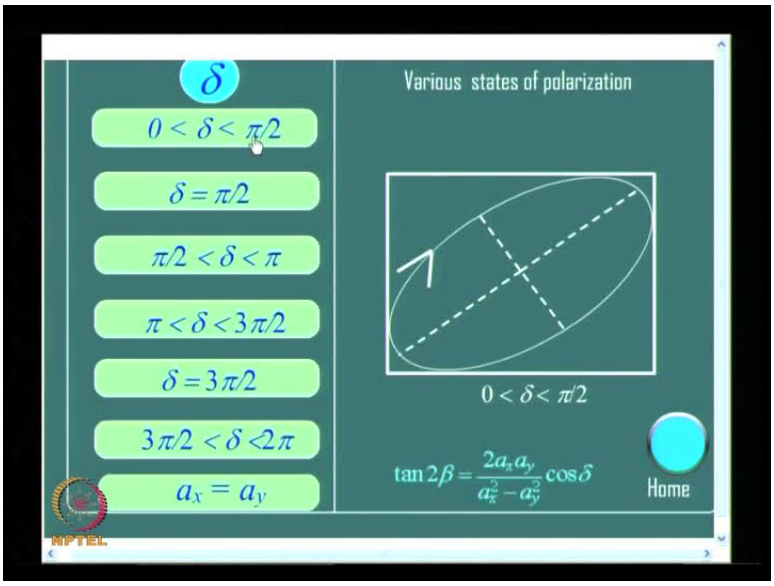

So, when delta changes, you can easily see that beta also changes. In addition what you find is, when I have delta for different ranges 0 to pi by 2 or delta equal to pi by 2, pi by 2 between pi by 2 and pi, what you find is, then you go and actually plot the tracer of the light ellipse. You find the rotation is different and that is what is illustrated in the series of graphs.

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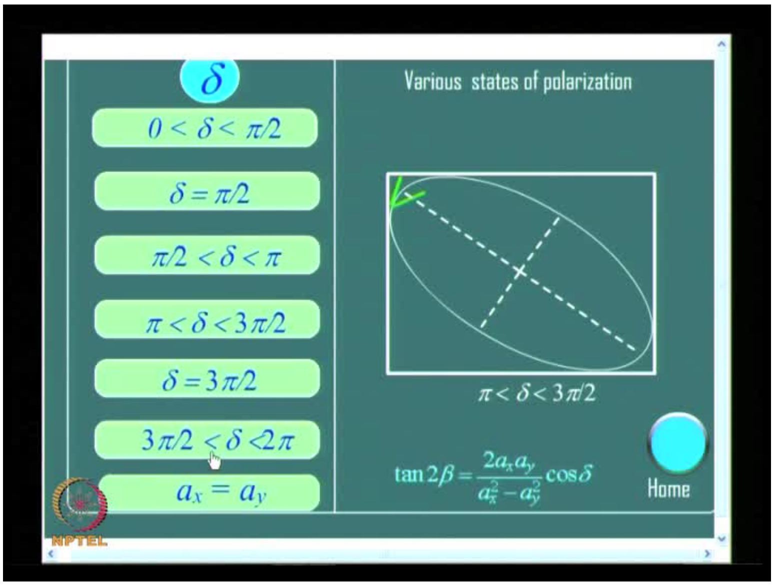

So, when you have delta lying between 0 to pi by 2, I have to go and actually plot the resultant vector. The trace of the light vector when I do it as a function of time, if I see different instance of a time the vector will change like this, so that is what is indicated by the handedness. So, when I have from 0 to pi by 2, I have it like this, but if I go to the other extreme pi to 3, pi by 2 the handedness changes. Azimuth change, you can understand from this expression, but for getting the handedness you need to really plot the trace of the light ellipse. You have to do it for at least two steps, so that the direction, whether it is anti-clockwise or clockwise, I need to do it for two different instances of time and that is what is summarized here.

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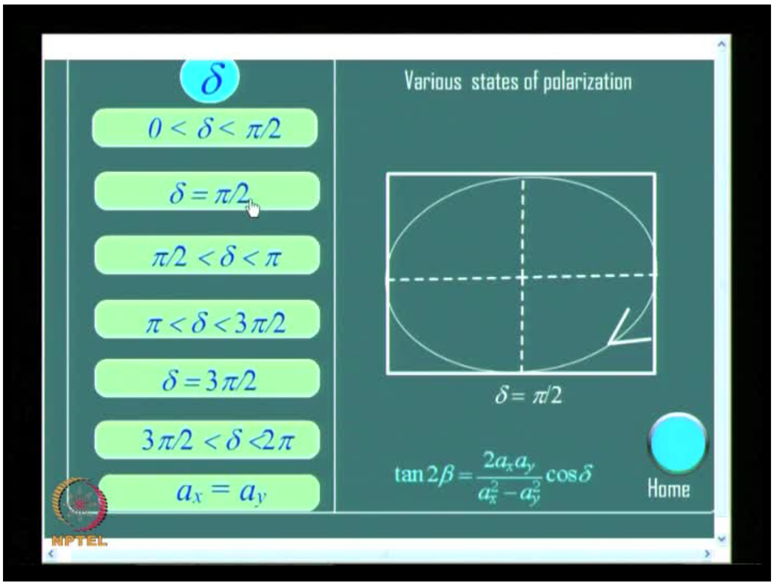

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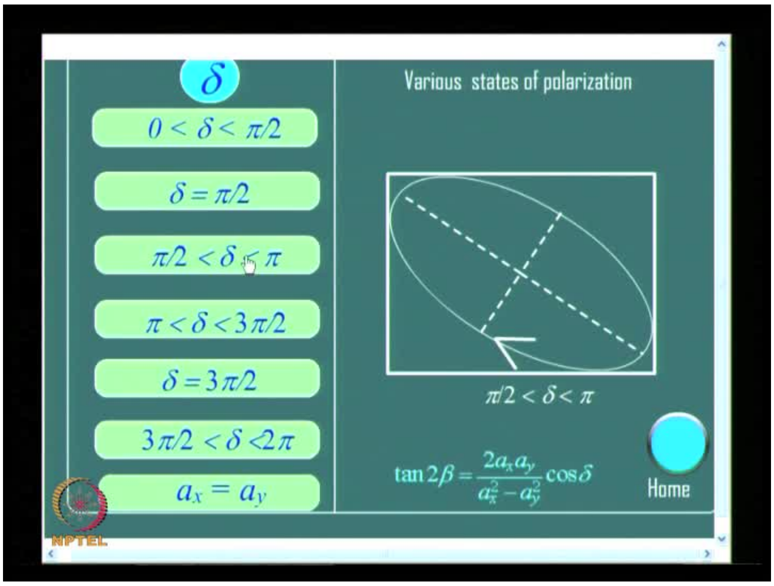

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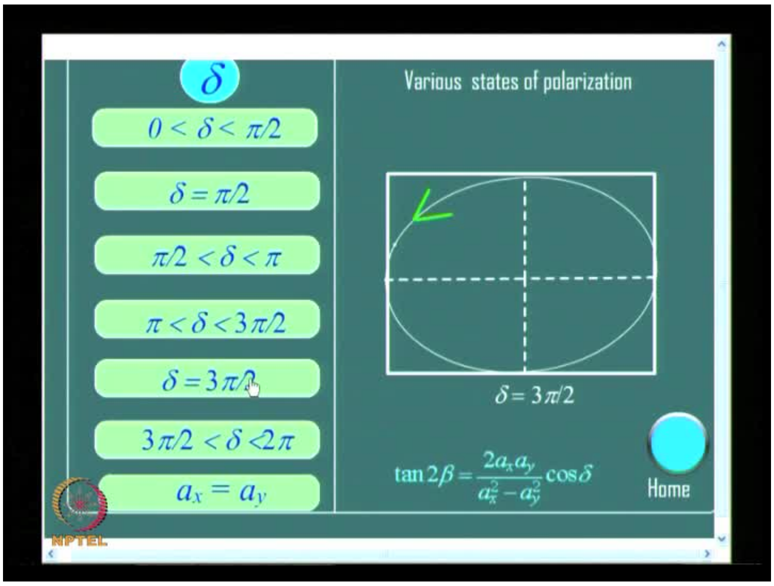

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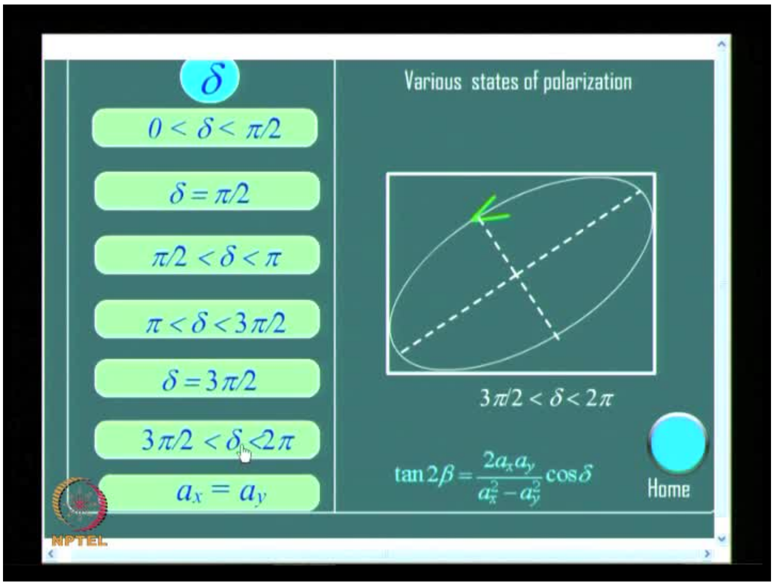

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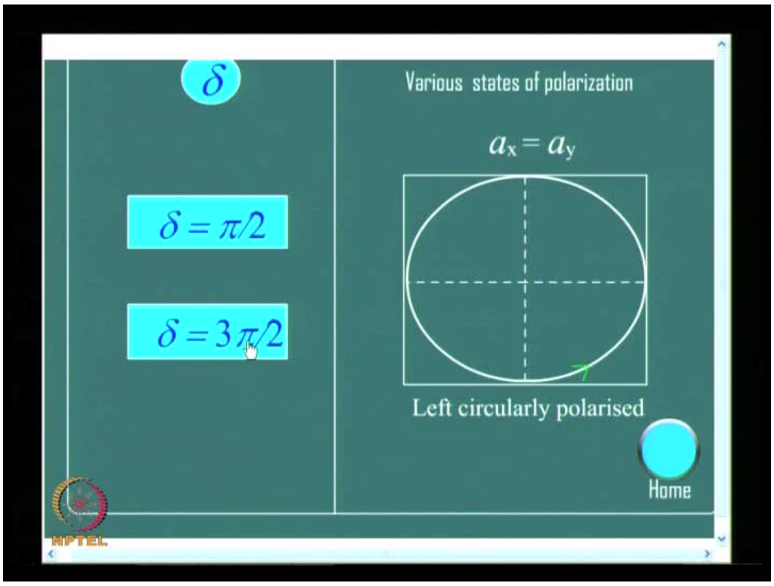

So, if you see one after another, it will go in a sequence, when you have delta equal to pi by 2, the reference axis become the axis of the ellipse, then it is gets tilted like this, then the handedness changes, then it becomes horizontal, then you have this tilted like this. And we also looked at the special case in addition to whatever the relative retardation, if a x equal to a y, what we saw was, you do not have an ellipse but, you have a circle and two types of relative retardations possible, delta equal to pi by 2 or delta equal to 3 pi by 2. You have one type of handedness when delta equal to pi by 2, you have another handedness when you have delta equal to 3 pi by 2.

See, if you look at in conventional photoelasticity handedness has not played a very significant role. On the other hand, when you come to digital photoelasticity, the handedness has played a very important role, in fact, we have looked at 10 step phase shifting technique, which has first 4 step as plane polariscope arrangement to get a isoclinic's. The second set of optical arrangements or 6 in number, they are arranged in a circular polariscope and if you look at very closely in the optical arrangement, the first 4 arrangements will have a left circularly polarized light impinging on the model, the last two arrangement you will have right circularly polarized light impinging on the model.

This made a difference to accommodate quarter wave plate error better, see whatever you say as a quarter wave plate it is matched for a particular wave length. And if that wave length is different from your elimination source, it will not behave like a quarter wave plate. And in many instances we may have to live with a mismatched quarter wave plate, and mismatched quarter wave plate did not play that damaging effect in the case of conventional photoelasticity, where we have also discussed that crossed quarter wave plate arrangements are preferred orientations that automatically took care of minimizing the error. But the moment you go for intensity processing in digital photoelasticity, people found by changing the handedness of the incident light ellipse the influence of mismatch of quarter wave plate could be minimized, it cannot be eliminated but, it can be minimized. So, what you find is, though in conventional photoelasticity handedness has not played a significant role, it has played a very useful role in digital photoelasticity. I suppose, you got some idea of why we discuss handedness, how handedness come into place and where it is useful you need to know complete story behind it.

Fringe altering is one of the important aspect in the photoelasticity as we came from this course, just we want to know what additional precautions we have to take, so that we do not miss the correct ordering and do or is there any way to validate what we do?

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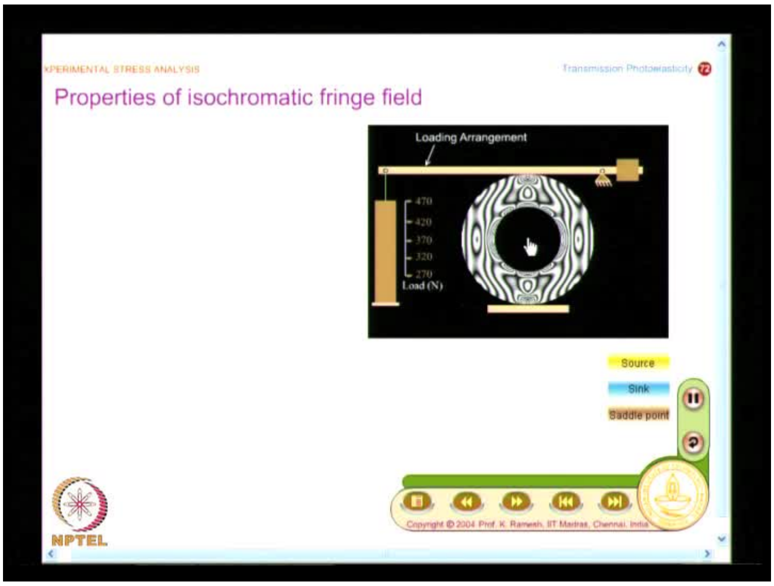

See, have set correctly that the fringe ordering is one of the crucial steps in photoelasticity, not only in photoelasticity in all the optical methods fringe ordering is very important. Since, we focused on photoelasticity, we will go and discuss what ways you can salvage your problem. It depends on the problem that you handle and the kind of facilities that you have access too. See, suppose you have a situation, where I can repeat the experiment by changing the load, then I could get a picture like this. So, even if you have made some numbering of fringes, those numberings could be checked, because when I change the load I am able to look at that fringe order vanishes here. So, it is a sink and fringe order does not vanish the fringes become denser and denser. So, it is not a sink but something else, and if you are also in a position to go and look at a plane polarize scope, I could verify that all isoclinics passes through this point.

So, it depends whether you are given a photograph, if you are given a black and white photograph it is very difficult to do, you do not have to feel dishearten that you are unable to order a fringe given a photograph that is not possible. On the other hand, if somebody gives you a color isochromatics a single photograph and if you refer the color code, there is some way to find out the ordering of fringes. The best one is, you have the model on hand and you are also able to have access to the polariscope and, then and there you verify whether the labeling of fringes is correct, that is the most simplest case which you can do by varying the load, by rotating the polarizer and analyzer combination.

So, you have a via media to do that, but in complex problems fringe ordering is checking, you have to accept that fact. And you know, by looking at several problem see for example, if I take a internally pressurized cylinder, that is typically a lames problem; in a lames problem, you all know that inner boundary is loaded to the maximum, so, you will have maximum fringe order on the inner boundary.

What is the fringe order on the outer boundary? It is a very special case, because the outer boundary it is not 0, because you have looked at a circular disk and a diametric compression where you have outer boundary is 0, you cannot simply extrapolate that kind of understanding a wrong understanding to a generic problem. Say, I have also mentioned, there are general rules and exceptions, on the circular disk the boundary is 0 was an exception, you have a beam under 4 point bending, you have a neutral axis zeroth fringe order is like an axis. And we also solve the problem of ring under diametric compression where you had fringes on the outer boundary and you had only 1, 2, 3 and 4 points on the outer boundary and 4 points in the inner boundary where fringe order was 0.

So, we also saw a counter example, see one danger what is possible is, when I have a free surface you temp to think fringe order is 0, that was the case in the case of a circular disk which is a special case. We also solve the beam under 4 point bending, you also had tops and bottom surfaces as free but, they had fringes depending on what is the load that you have applied. So, on a internally pressurized cylinder also on the outer boundary finding out fringe order is difficult.

So, you have to look at a color code, in fact, you know people solve that kind of a problem by finding out the inter fringe distance and developed a methodology how to order a fringe. So, if somebody gives a photograph alone, if you are unable to find out fringe order, do not feel dissolution, you need additional data at least you know, with your training, you should ask for additional data, you know that is what are the training is. Because, you are definitely solving very complex problems in experimental mechanics, you are not talking about simple problems with simple loading.

So, in complex problem situations you may have to use different strategies. So, you are able to look at the isoclinic fringe field, iso chromatic fringe field or principles of solid mechanics or use color code or in the worst case, you also go and post process your finite element result and then plot the fringe contours, from there also you can verify whether your fringe ordering is correct. So, you have to take multiple paths, when the problem is complex, you will also have to be ready to spend time and money. And fringe ordering is crucial and that is where you have modern techniques in digital photoelasticity, which simplifies to a greater extent on identifying the fringe order. But even there, I caution many of this software modules are developed based on certain example problems.

If your practical problem falls within that domain of complexity than that is software will work, if you go beyond that level of complexity the software may not have a module to look at it. So, it is always better that you get trained even though you use digital photoelasticity for fringe ordering learn the conventional methodologies on how to identify the fringe order. So, that will complement your result from digital photo elastic analysis, you can verify. You need to know whether the software has work correctly for the class of problem that you have handling with.

Sir, what are the fringe tinning methods and what are the various algorithms involved in it?

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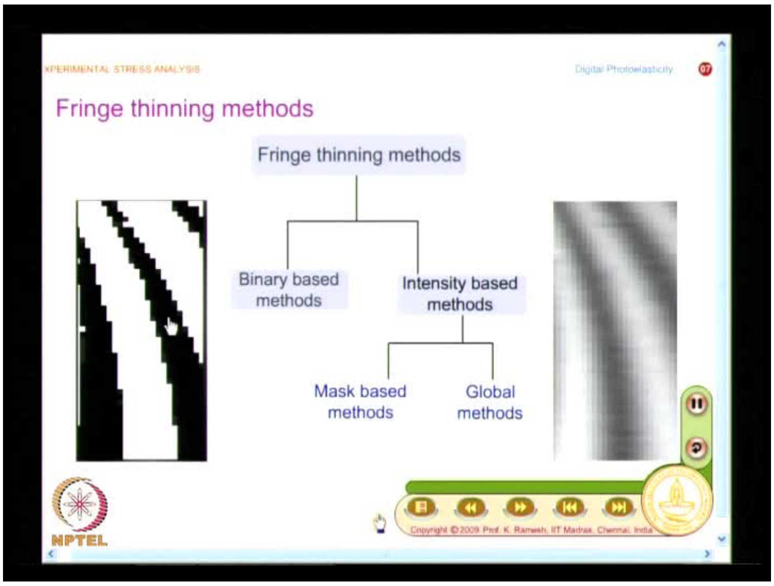

See, fringe tinning methods are used in the early development of digital photoelasticity where people wanted to mimic what you have been doing, it in conventional photoelasticity with the help of computers and scanner, that you will have to understand. Whether fringing methods are essential these days for solving the problem, it depends on what question that you want to get. In certain class of problems, it can be useful in certain other class of problems, you can go for phase shifting techniques and find out the fringe order.

And if you look at fringe tinning methods, they can be broadly classified into two categories; you have what are known as binary based methods and you have intensity based methods. In binary based methods, if you look at the genesis, one of the earliest image processing application was on optical character recognition. So, the challenge was when somebody writes, you should have the computer to recognize yes, he has written the letter a, letter b, letter c and depending on each ones handwriting the shape may slightly differ but, there would be certain connectivity that would decide whether it would letter a or o, if you take two extremes.

So, in those cases they essentially looked at the characters as a binary image and they had developed algorithm to look at the connectivity and also look at the skeleton. So, people thought why not this algorithm could be employed for fringe tinning, that was the first step. It slightly crewed in its approach and the philosophy in that was, recognize the fringe area as a binary image. And how to get this fringe area, we also saw that it can be done by a simple thresholding process. Then, you use the method of optical character recognition and strip these boundary pixels progressively, you know, it cannot be done in one step, because you have thin fringes and thick fringes, you have to keep removing the boundary pixels. And how to identify that this is the boundary pixel and remove, we saw the algorithm of Chen and Taylor.

You may have a question how he arrived at that kind of criteria that this is the boundary pixels, if the pixels are arranged in this fashion, if we have fringe pixel, non-fringe pixel and if this satisfies this condition remove it or retain. These conditions are obtained by trial and error. If you really look at they are not directly apparent, you get some idea implemented then improve upon it and you take some time to develop that algorithm and apply to a class of problems, then improve your performance of the algorithm, you get the basic idea is strip the outer pixels, so that is what is done in binary based algorithms.

On the other hand, when we go to intensity based methods, you retain the fringe field as gray scale images and from your analytical development, what was the fringe point? The fringe point was the point of minimum intensity. So, if I have intensity recording, then I can pick out those minimum intensity points and there form the fringe scale methods.

Now, the question comes whether it is a global minimum or local minimum? See, when you go out to any experimental arrangement you have a light source, which is the diffuse light source, so light may not be uniform. Even though for your eye, it looks uniform is put a CCD camera and measure it there may be small variations. And similarly, when you have the optical elements, when you have the model, uniformity may not be guaranteed on the entire area. So, you cannot say that a particular value of intensity will be the fringe skeleton globally, you will have to go for the local minimum.

And here again there are several methods, you have mask based methods as well as global methods. In fact, the class I did not discuss about mask based methods, I directly discuss that global methods. And if you look at mask based methods, they would take a mask of a particular size, and within that mask they will try to find out how to identify the minimum intensity. It will find out the minimum intensity within that mask, and you have many algorithms for that, in fact, the literature has about 50 to 60 publications on this.

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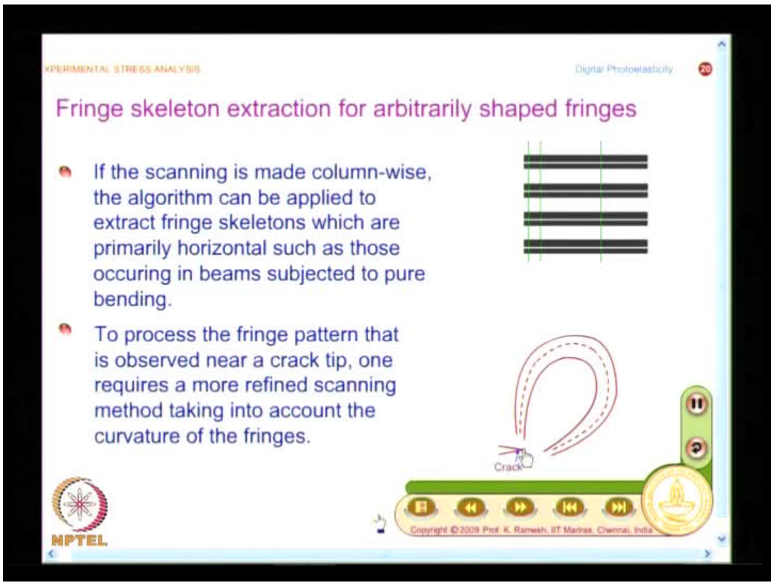

And what we saw was in the global methods, we took two simple examples, one is vertical fringes and horizontal fringes. Suppose, I have horizontal fringes like in a beam, I can develop a scanning methodology which is perpendicular to the fringe areas, it will automatically pick out the minimum intensity, so when we join them you will get a fringe skeleton.

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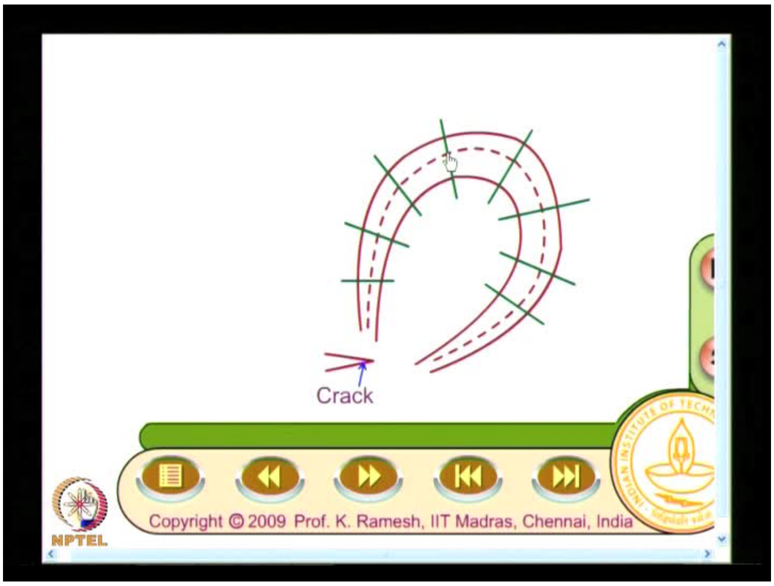

Suppose, I have a complex fringe pattern like this, which you see at the tip of a crack the fringes are very sharp near the tip of the crack and they are very broad here. I cannot take a horizontal scan, I cannot take a vertical scan and pick out this skeleton. What I need to do is, I need to take tangents and then draw the normals. So, I should scan for this portion only along this direction to pick out this point, for picking out this point my scanning direction should be altered.

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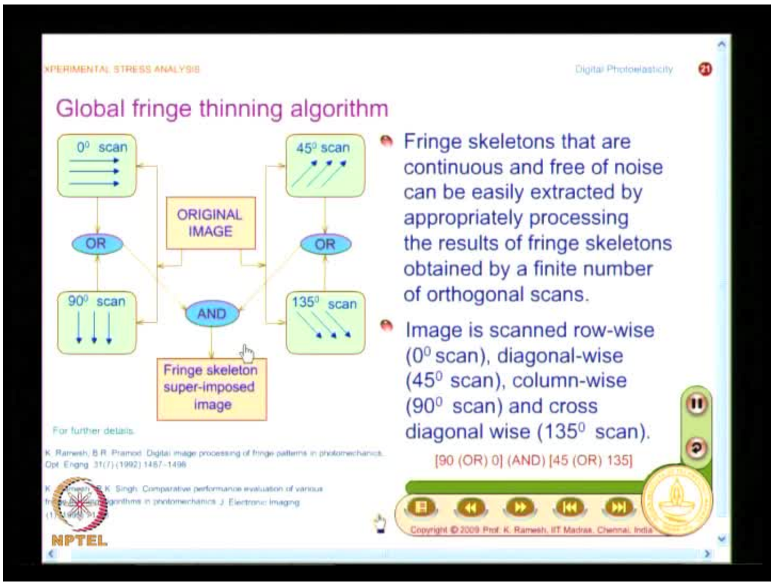

So, this scanning direction changes as the function of the curvature of the fringe, which is very complex. Conceptually picking out minimum intensity point was simple and the algorithm of simple and straight forward when you had horizontal fringes or vertical fringes, but when I have a complex fringe, you may even think let us give up, let us go and use mask based methods that kind of thinking is possible, but what we found was, a finite number of orthogonal scans and clever use of logical operators have simplified the whole process. Even when I have an arbitrary geometry, it is enough I scan the image horizontally, I scan the image vertically, the scanning direction is simple and straight forward, the implementations is also very simple. And you take a logical OR of these two, you get a fringe skeleton completely, but this will have noise.

And you have another set of orthogonal scans 45 degree scan and 135 degree scan, here again when I do this, I get the fringe skeleton complete but, noise is in a different orientation fortunately. And when I take a AND of these 2 results, I get the fringe skeleton totally free of noise. And this took as almost the year to develop, it was not was there, it takes me 5 minutes to explain and I will also show you the results.

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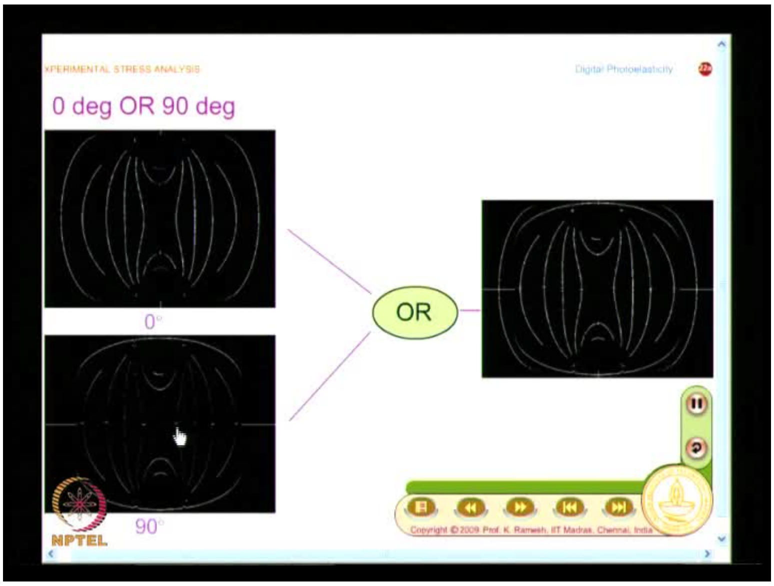

If you see the results you will know, and this is what you shown I have a 0 degree or 90 degree result, individually when we look at some portions are not having fringe skeleton and you have those fringe skeletons available in the other orthogonal scan. And when I take the OR of this I get fringe skeleton as well as noise, is the idea clear, are you able to see, that individual scan does not give you complete fringe skeleton. Some portions are missed in this, some portions are missed in this, in fact, many portions are missed in this because the fringes are primarily vertical.

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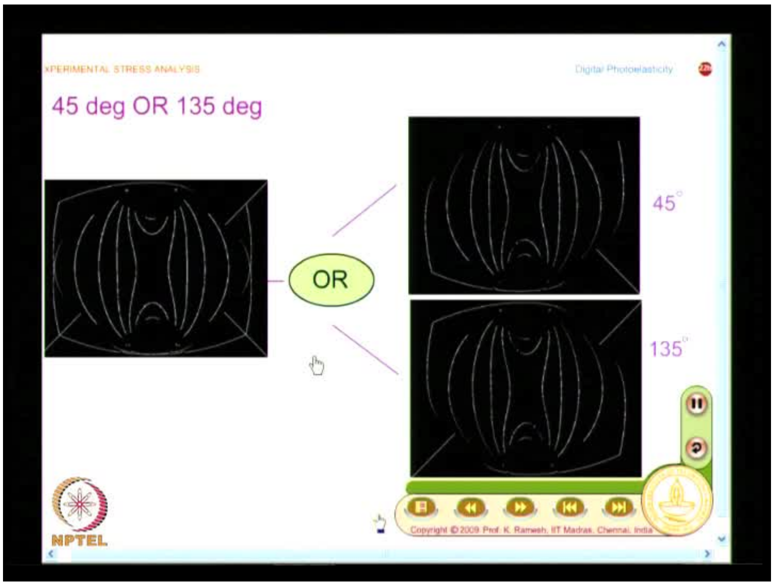

So, when I have a vertical scan it does not pick out those portions, when it is become tangential you do not get the result. And when we look at the other set of orthogonal scans, here also you will find when the direction is tangential to the fringe area as those areas are missed when I take a logical OR either this or this, that is what it will do. Say, I essentially have a binary image here, I have black background and white points of the fringe skeletons, that is how it is handled. So, applying the logical OR operation is also straight forward.

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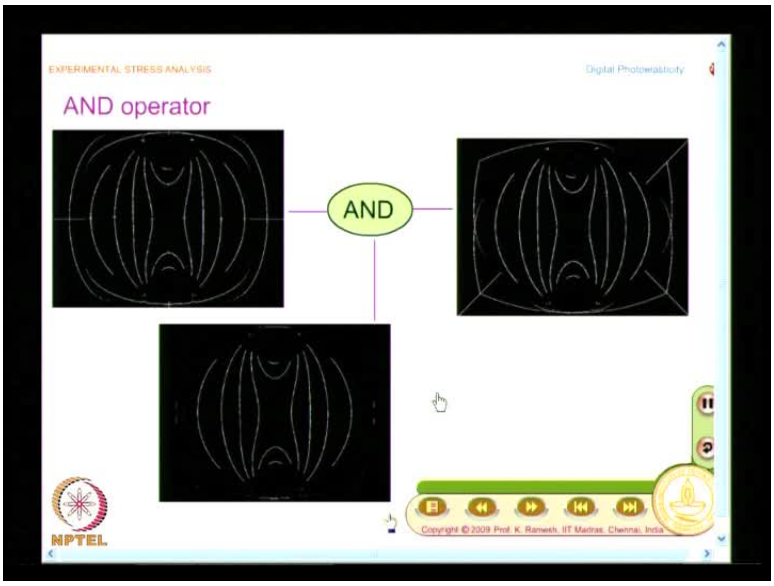

So, what I see here is, I get the complete skeleton plus noise, and now what I do is, I have looked at these individual results, I will find there is correct result plus some noise, and noise is different, see, when nature wants to reveal something it also provides you a methodology. Suppose, you have a case where noise is same, then I cannot take the and operation and it will do.

So, you have to find out what kind of trick works, and when I do the and operation, I get the fringe skeleton free of noise. And we have later that done a work which showed comparison of various fringe tinning methodologies and we found that this takes one tenth of the time, and in those days we were having only a PC XT computer, it is to work very slow. In fact, you can allow a 0 degree scan and go for a cup of coffee and come back, by the time you come back the computer would have done that 0 degree scan.

Now, the whole process done in a second. So, when those days, when time was at the premium, even the methodologies which reduces the processing time is significant. So, the message here is, look for new ideas, see people have will never use logical operators earlier in these occasions. We looked at that logical operators provided this giant leap and we were able to get very good skeleton, but before we apply this fringe thinning process, you need to do certain preprocessing of the images. And one of the aspect I said is, you have to have a time averaging, you take 16 frames or 32 frames and then take a average of this and then do some kind of a spatial averaging, some kind of histogram equalization, when we do all that the final fringe skeleton will be of one pixel width and it also be continuous. And this has application in certain domain now, with phase shifting techniques, fringe thinning methodologies are becoming to a coal store.

Sir, how does the photoelastic strain gauge work?

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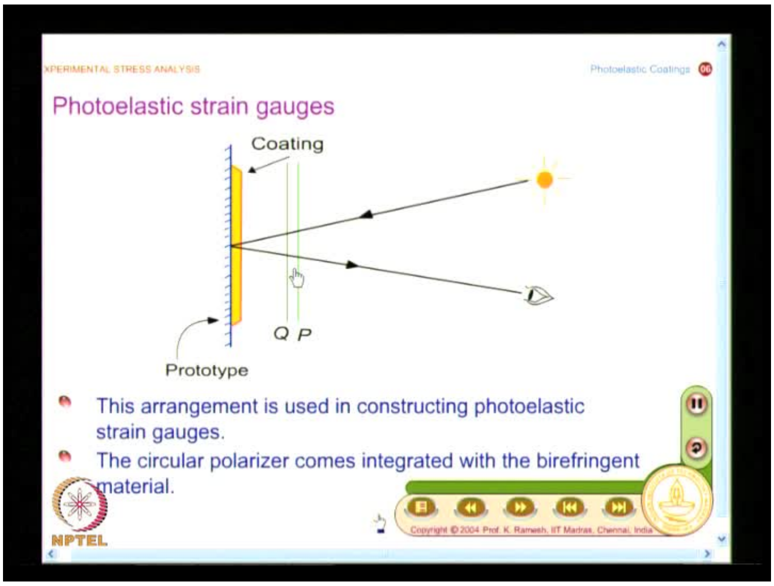

See, in a photoelastic strain gauge is, what you have is, I have a polarizer and quarter wave plate we are shown here separately but, in actual manufacture this will be pasted on the coating itself. You have a separate plastic base which will have the coating with the polarizer and quarter wave plate integrator. And if you look at in circular polarize scope, you have what is known as the bright field and dark field, I can have the quarter wave plate parallel as well as crossed. So, when you put it on this, you will see one of those fields when there is a light goes in tune and comes back, so that is the difference.

In the case of a normal reflection polarize scope arrangement, I have polarizer quarter wave plate here, I have another quarter wave plate and polarizer here. Here, I have a control for me to view the bright field or the dark field, in a photo elastic strain gauge I do not have the that control, I would see one of those fields - I think that answers your question.

Sir, in that case, will thickness of the quarter wave plate and polarizer plate sufficiently will give the required retardation and to get the enough fringe orders.

See, the polarizer and quarter wave plates are optical elements, they do not provide you retardation. So, your question is whether the quarter wave plate provides you a retardation of 90 degrees for you to get the circularly polarized light. And you have such thin plates available and even if you look at the polarizer, you have polarizers of various thickness as available. The quality of polarization may be better in a thicker polarizer, but here in the case of a photo elastic strain gauge, you are not making a very precise measurement. There you have only looking at a pattern, and in those days when the photo elastic strain gauges were develop, they were essentially trying to find out whether you have a uni-axial stress field or a bi-axial stress field, the focus was only that, for that kind of a focus even reasonable amount of quarter wave plate is good enough for you to reveal that information.

It depends on what level of accuracy you are really looking at, and it may not be 100 percent quarter wave plate, and we have also seen even in conventional polarize scope, you have a mismatch of quarter wave plate that become significant when you go to digital photo elasticity. So, when you have working in conventional polarize scope, the quarter wave plates arise are naturally observe, because you are having crossed positions. And in the case of photoelasticity strain gauges because you are only looking at the overall pattern to find out whether it is a uni-axial and bi-axial stress field, these whatever the thickness that you come across or reasonably sufficient to give you the pertinent information.

How do we select the suitable gauge length for a given class of problems?

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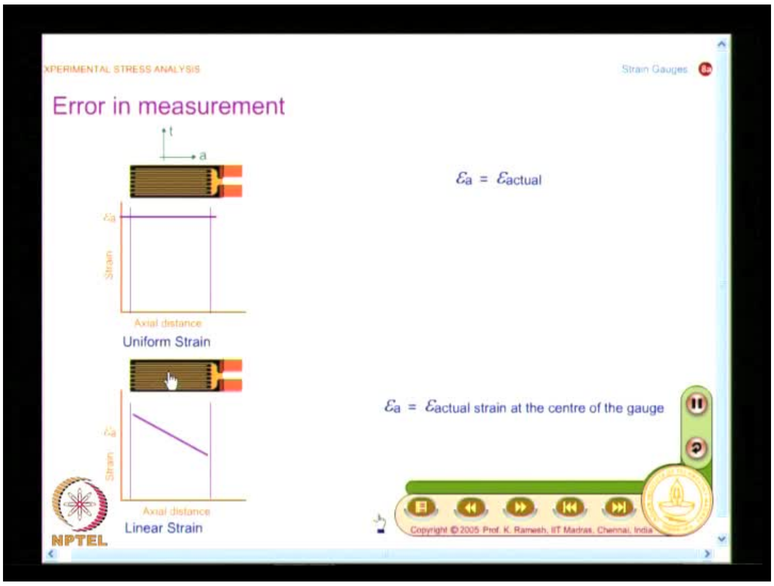

See, in strain gauges, we saw we want to measure strain at a point, if I have a magic material which I can take a speck of it, prove it at the point of interest, and somehow make the measurement that is well and good, unfortunately you do not have that kind of a material. So, I need to take a wire and then make that as the grid, because I need to have some base resistance for me to make the measurement comfortably. So, I essentially have a grid, so when I have a grid like this, the strain variation over the grid is going to affect my measurement.

Suppose, I have a uniform stress field and when I have a uniform strain, when the strain value is constant the length of the grid element does not matter. So, the gauge length does not play a role, you essentially measure the actual strain, whatever the strain at the point of the center of the grid would be the one which is measured by a longer grid also. Suppose, I go to a problem of bending where strain varies linearly over distance, even there the gauge length does not play a role, because the average value of this will match with the strain at the center.

And mind you, when I have a strain gauge, I have markings and what I do is, I align the strain gauge at the point of interest. So, what I essentially do is, at the point of interest when the grid lines or whatever the guidelines on the carrier pattern are aligned, I say that this is the strain I measured.

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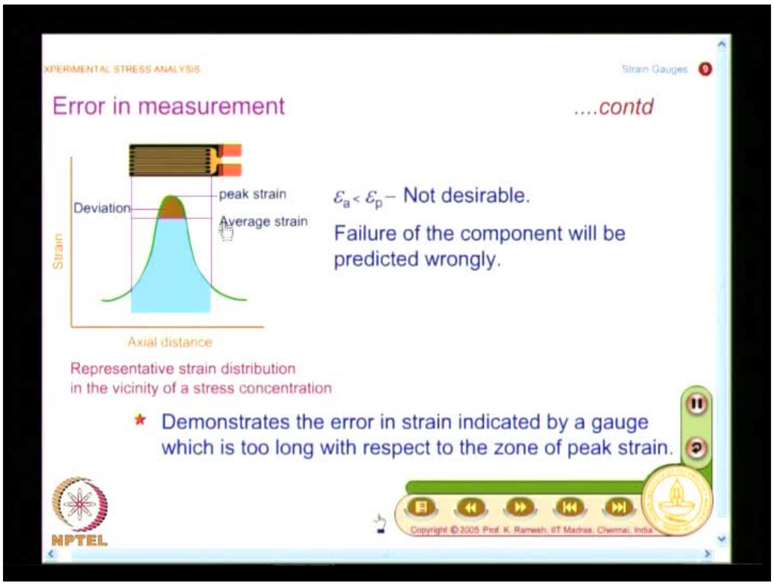

And when you are looking at the gauge length, when it is uniform or varying linearly, the strain measured at the point of center is same as what you measure on the strain gauge. Suppose, I have a sharp variation, I am not having uniform or linearly varying strain picture then what I sends on the gauge length would be different than the peak strain. See, at this the point of interest, where is I would interpret the strain result to be, for this point because of sharp variation, you have a very high value of strain which is not same as the average strain which is measured by the actual strain gauge.

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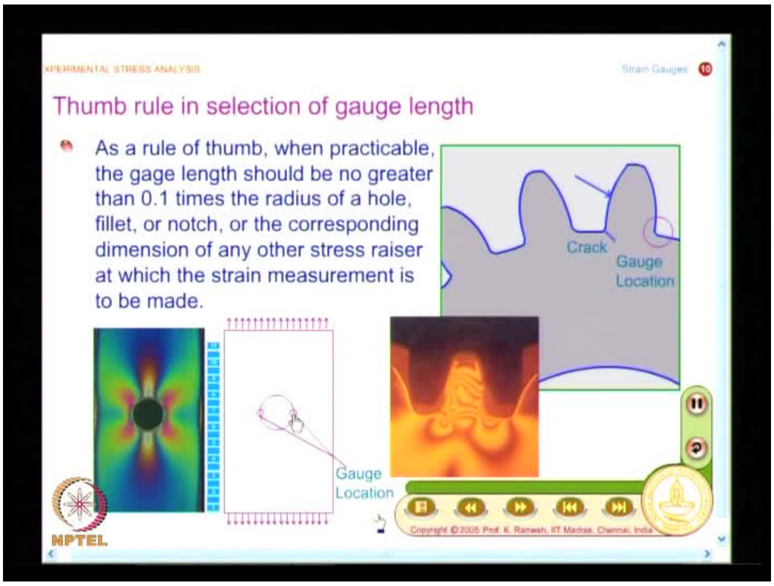

Suppose, I keep reducing the width of the gauge, that is essentially the length, then I will make it smaller and smaller and I can approach this peak strength very closely. So, it is actually dictated by the gradient of the strain variation and how do you do that? You have a thumb rule available. The thumb rule is, we have seen two problems, one is a gear teeth, I want to find out the stress concentration region, this value of strain, it is very very small, and thumb rule is the gauge length should be no greater than 0.1 times the radius of a hole fillet or notch. This is only a recommendation, if you are able to match it, well and good.

And you have stress concentration in the case of a plate with a hole and I also said instead of pasting it on this surface, paste it in the inner surface of the hole. And we have also noted, it is always proved and to go for a 3 milli meter gauge length for general purpose. When I go for shorter gauge length, stability becomes the problem, range of strain measurement becomes the problem, bonding is the problem, shouldering and heat dissipation, all these are issues.

So, if you address them correctly then, you can choose the smaller gauge length for problems where they really demand. As the thumb role, for metals go for a 3 milli meter gauge length, only when I work on concrete, because there is heterogeneous you want some kind of averaging, you go for a longer gauge lengths. So, selection of gauge length is closely related to the problem on hand. And what is the strain variation that you have anticipated, so this is where you find optical techniques are far better because gauge length is 0 there, but strain gauge has an advantage because of its versatility, it can be applied for a variety of problems even though I make approximations I get some answers for my design.

When initialing the strain gauge, why you are rubbing in 45 degrees by using emery paper?

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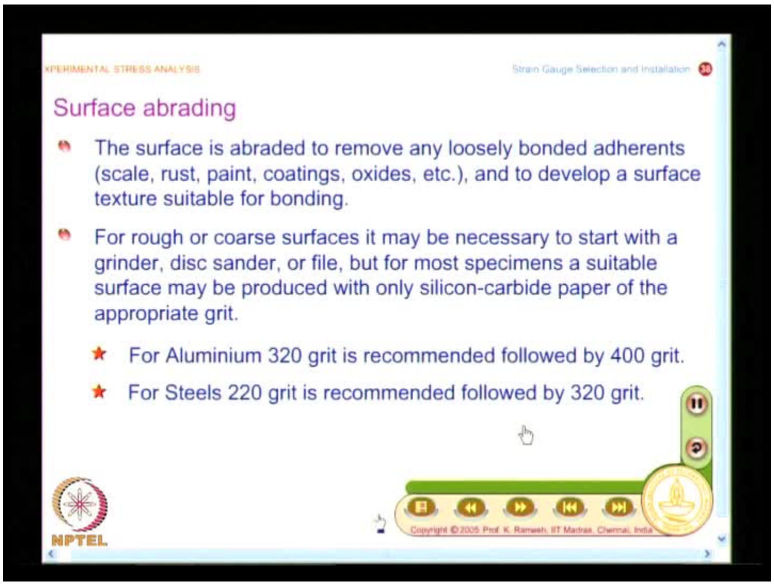

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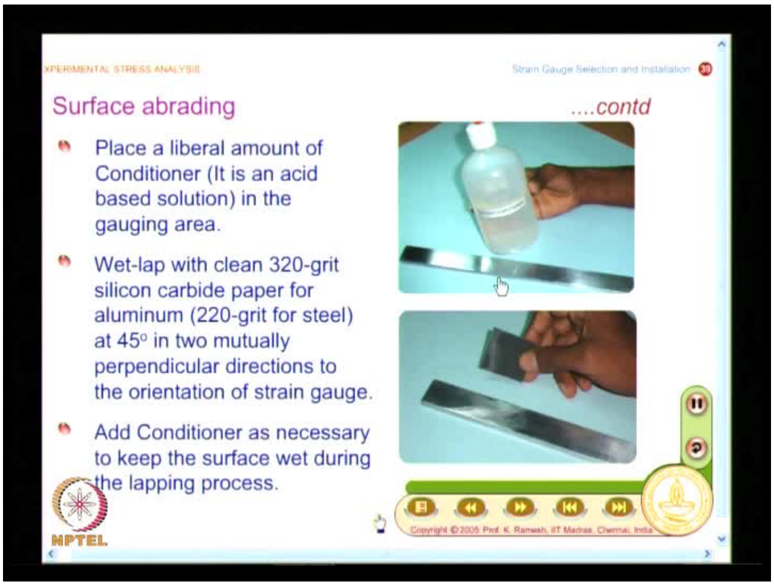

See, the essential requirement for surface abrading is to prepare the surface, so that I have a surface roughness of a desired magnitude, so that the strain gauge can be bonded comfortably. And what we looked at was, in the case of aluminum use of a 320 grit followed by a 400 grit is recommended, and for steels you need to select 220 grit followed by 320 grit. The next stage is, how do I go and really do this process? You are actually doing a wet lapping, you have a conditioner and then you need to do the wet lapping of the surface, and the specimen which I have taken is very small, I also need to have some area for me to do the rubbing action, if I do it I need two orthogonal directions because it is very thin and narrow, if I take at 45 degrees, I will have equal amount of rubbing length possible. And here, I also caution that you are not testing your muscle power, you are only supposed to do the wet lapping, 12 strokes this way and 12 strokes this way, that will provide you the necessary roughness for strain gauge bonding. And depends on, I need only a orthogonal directions, here because that is narrow I go for 45 degrees.

In determination of boundary stresses what different stress it you make when you paste their tensile specimen parallel to the model or perpendicular to the model.

Say, let me put it this way, we are not pasting the tensile specimen on the boundary first thing. And the other one is, we are not finding out the boundary stresses, we have only finding out the sign of the boundary stresses. We are not evaluating the magnitude here, and you have to understand in all the retardation discussion which we had, you have reference axis in this point of interest, and these reference axis coincide with the principle stress directions at the point of interest and you add or subtract retardation only along those axis and we are looking at a free surface.

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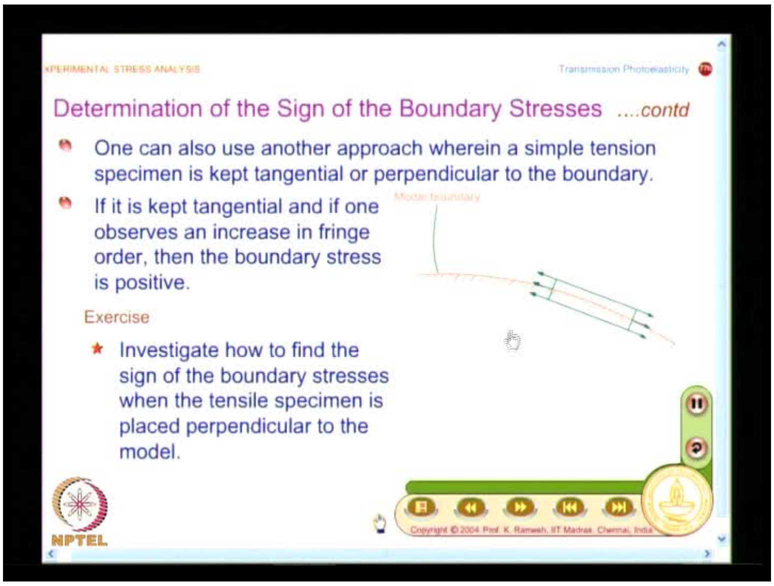

So, when you are looking at a free surface, at any point on the free surface tangent on the boundary and perpendicular direction on the boundary are the reference axis. So, you need to add or subtract retardation along those reference axis. When I keep a tensile specimen tangential to the boundary, you are adding retardation in the horizontal direction or tangent to the point of interest. And when I keep it vertical, I add retardation in the direction perpendicular to it, you have only seeing the fringe order as sigma 1 minus sigma 2 and if sigma 1 minus sigma 2 increases or decreases, you will see that by a change in color, because thus variation is very small only a color change can give you whether sigma 1 minus sigma 2 increases or decreases.

And what we saw in the class, suppose I keep the model tangential, and if you find the fringe order increases, then the boundary stresses positive. Because, I have already retardation in this direction, I add in addition to that another retardation, is the original one was positive, because when I have a tension specimen, I am applying a positive retardation, is the original one was positive, it gets added to that when I keep it tangential.

Suppose, for the same point I keep it vertical, that becomes sigma 1 minus sigma. So, you have to look at what way sigma 1 minus sigma 2 changes. You will actually get a complementary answer here, if I say in the case of keeping a tangential with the fringe order increase I say positive, if I keep it perpendicular when the fringe order increases the boundary stress will be negative. When it is negative sigma 1 minus sigma 2 will become sigma 1 plus sigma 2, so the fringe order will increase. And here, you are only keeping this specimen close to the model, you are not attaching it, is like a external compensator.