Experimental Stress Analysis

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Module No # 02

Lecture No # 21

Fringe Thinning Methodologies

In the last class**,** we had looked at how to find out material stress fringe value. First, we saw the conventional method, then we moved on to develop a methodology, which utilizes the whole field information. After developing the methodology, I said, though you can also do by processing the photograph in a conventional way, collecting data manually, the method becomes advantageous when you going for image processing approach, and essentially, aspects of digital photo elasticity.

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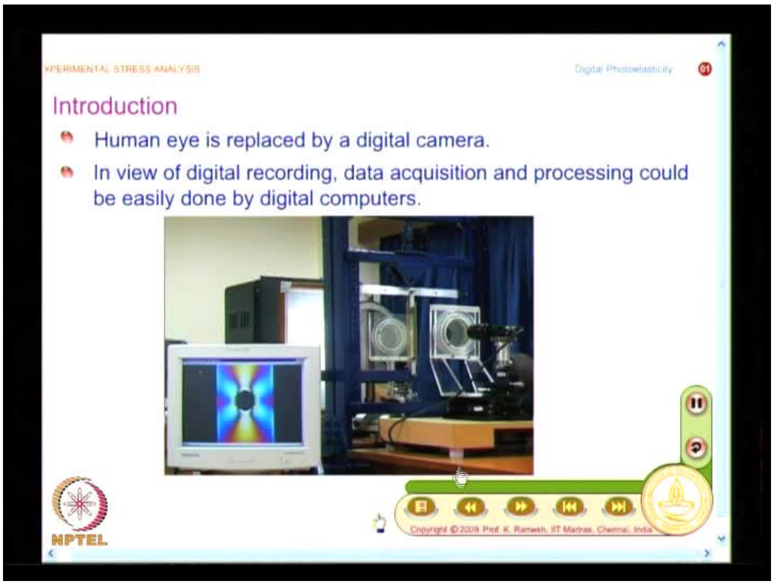

And what we introduced was in the case of digital photo elasticity, you replace the human eye by an electronic eye, you have a digital camera, these are essentially charge coupled devices, you call them as CCD camera. And once you use a CCD camera, it is possible for you to get the image as an assembly of numbers, and this is essentially called sampling and quantization. First, you do a spatial discretization, that you call that are sampling, and you have an optical image, and for illustration, a small zone is taken which is looked at as assembly of very fine small elements known as pixel elements and you call them as pixel - abbreviated as pixel.

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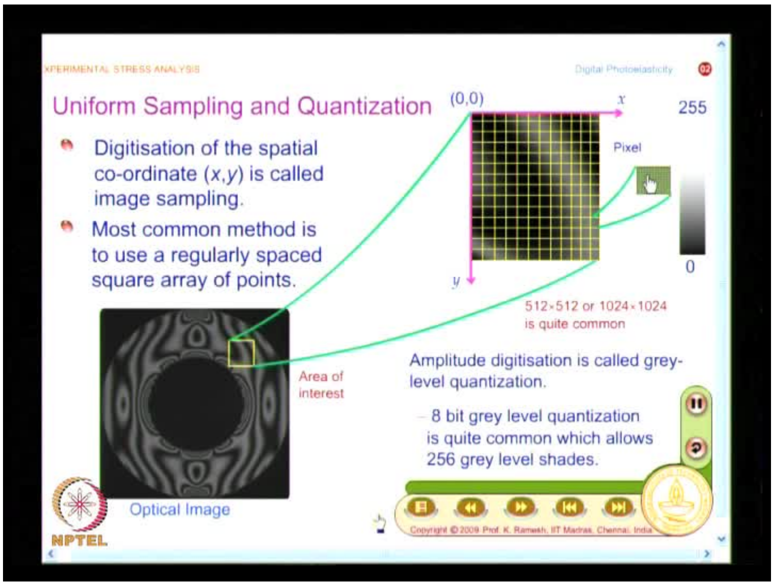

So, you identify the image as an assembly of small pixel elements, and for each of this pixel you assign a number between 0 to 255. If you are processing a negative, it will give the light transmitted, and if you are processing a positive, it will give the light reflected. So, at the end what you get is, by using a digital camera, you are able to get intensity data at video rates, that is the advantage.

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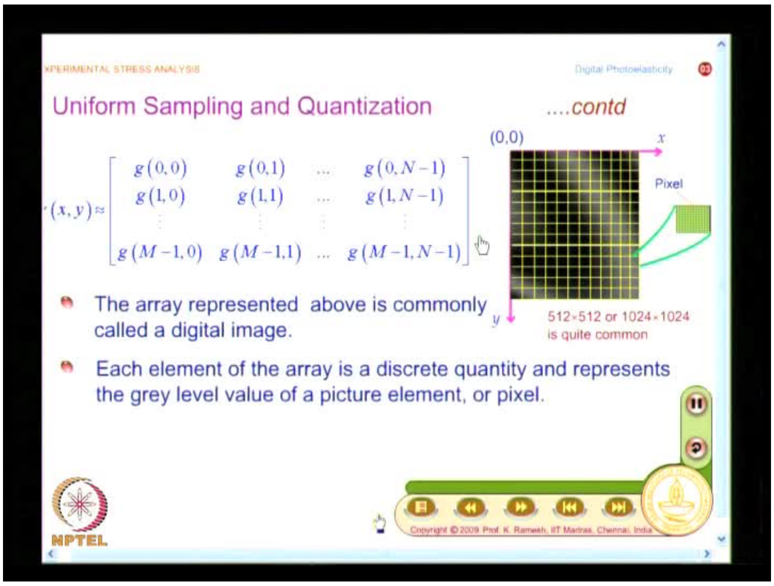

So, what you have here is, finally you get an image representation, this is essentially a matrix of integers. And what you will have to keep in mind is, what we call as a pixel is a very, very, small area; by appropriately using a lens, you would be in a position to even go to stress concentration zone and find out when you have very high fringe density, you have a decent resolution at the camera plate. So, I can have an optical magnification and then, enhance the features in stress concentration zone that is how people solve when you have a very high fringe density, they optically magnify that zone then, take it up in your digital image and appropriately process it. Now, what we are going to look at is, we will essentially look at a very simple digital photo elastic technique, where we mimick what we have been doing it manually.

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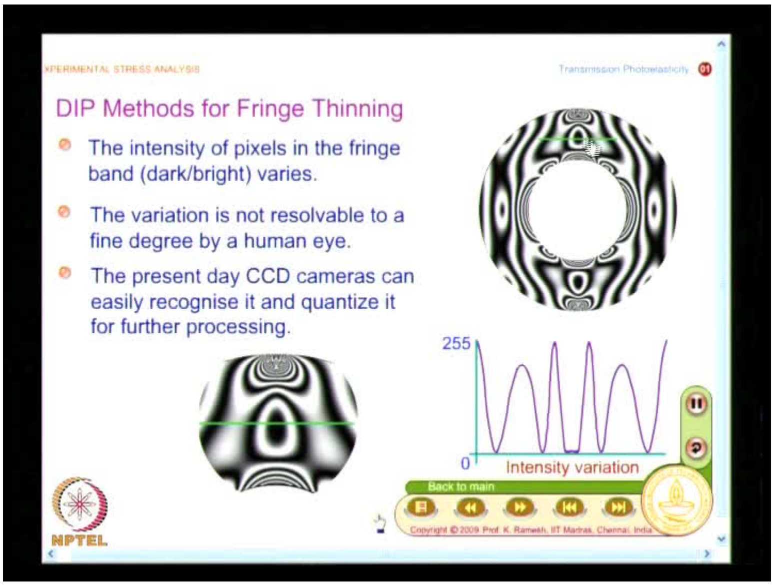

Earlier we will identify fringe skeleton that is what we are going to look at. And what you have here is, I have taken the problem of a ring and a diametral compression, I have already mentioned the fringe features are very complex in the case of a ring and diametral compression. And if you know how to order the fringes, then you fairly understand how to go about a generic problem. So, what I have here is, this is the load application point and what is shown here is, I have taken a line passing through these set of fringes and this portion is enlarged and this is recorded in a digital camera and what you find is, there is variation of intensity along this line which human eye is not able to very clearly distinguish.

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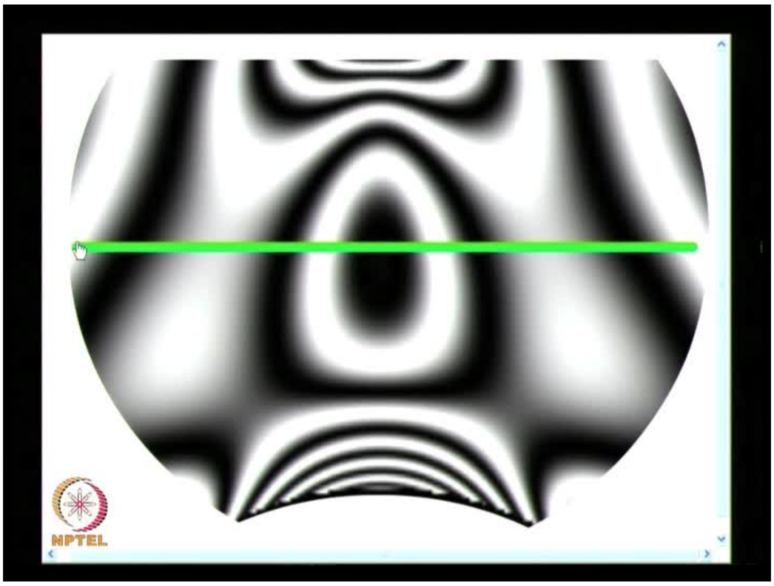

On the other hand, when I go and look at the intensity values recorded, which I will have to take care, you know I may have to do time averaging and then, you know, you want to eliminate electrical noise. So, you take several images in a short time and then take a time averaging. When you do that kind of image recording and when you look at the intensity variation, you get an intensity variation like this.

So, you find that intensity varies across the fringe thickness, what you see as a black fringe, it is not really black, you have a variation of intensity, that is what you see here, and this is decently captured by your digital camera. So, the point here is the intensity of the pixels in the fringe band varies; the variation is not resolvable to a fine degree by a human eye. The present day CCD cameras can easily recognize it and quantize it for further processing.

So, this is what is important, but even before we use intensity information, people also have used only the binary information, identify the fringe area and strip the outer pixels and get the skeleton. If you look at the history of image processing, one of the earliest applications of image processing was in optical character recognition. So, people wanted to recognize when people write a letter, each one may write it differently, so you should know how to identify whether this is letter A, B or C, so they will try to get the skeleton from the handwritten text and then, identify from contiguity of the connectivity of the lines identify as this different letters, so people use that kind of an approach in photo elasticity as well.

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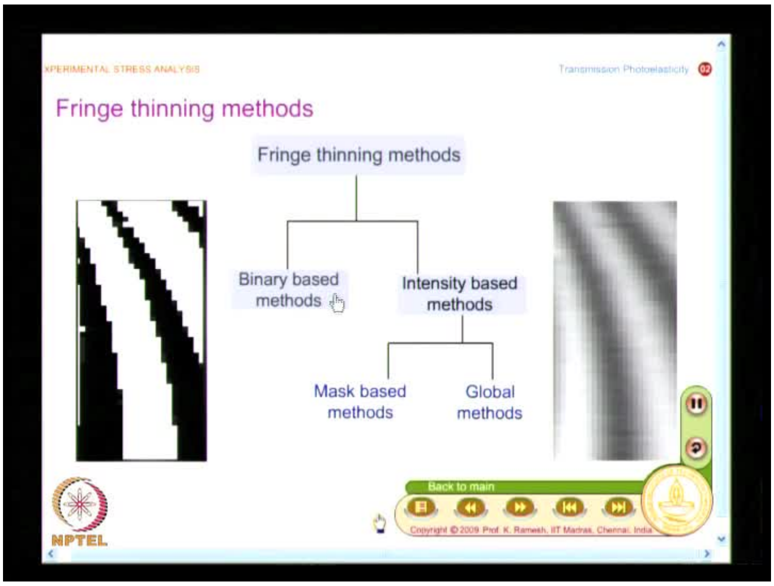

So, I can classify fringe thinning methods broadly into two categories, one is a Binary based approach, another is an Intensity based approach. And we have just now seen that what we see as a fringe has intensity variation over the bandwidth of the fringe. One can view this as black and white picture and that is what is done in binary based method. Essentially, whatever the developments that was an optical character recognition, people directly applied to fringes, and one of the advantages in photo elasticity is, the fringes are having a very good contrast, we have also seen in the initial lectures, how do you get fringe pattern from speckle interferometry; speckle interferometry, I said it has inherent noise, unless you do filtering I would not be able to extract data from this.

On the other hand, when I go to photo elasticity, basic fringe pattern you obtain has very good contrast and that makes your processing of the image much simpler. And if you look at either a binary based method or an intensity based method, you need to first identify from an image what is a fringe, where the fringe is located? See, this is where the human intelligence is very important. See, suppose, somebody gives a picture you immediately, say, I have a fringe, I have a thick fringe here, thin fringe here, I know this is the background, I know all these, the mind immediately tells you even without you recognizing it, the mind processes all the visual information and gives you a feeling that you are looking at a fringe pattern which is very dense here. But the moment you go to computer processing, you need to develop methodologies to do this. How do we find out the fringe areas, how do you identify when a pattern is given, this is the fringe and this is the non-fringe area.

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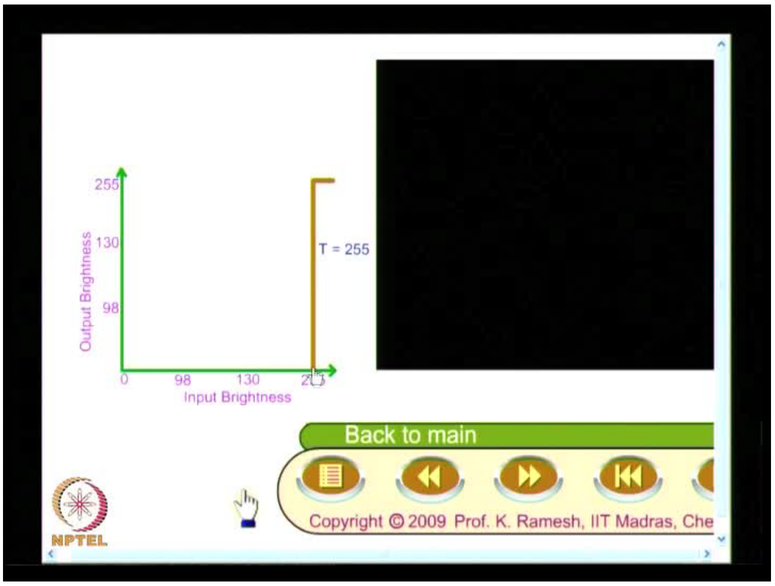

Suppose, I call fringe as the black contours, I should identify the black contours and what we will see here, there is a very simple method, what is known as in image processing literature is called thresholding. And what I have here is, I deliberately had this image area as black, and in thresholding what you do is, I look at the grey level values and I put a kind of a filter, in this what I do is, I have discretize from 0 to 255, up to 255 you make everything as black, at 255 you make it as white, that is why you see this as a black picture, because we have seen that image is having 0 as pitch black and 255 as white. Now, if I make all the pixels black, I will not see the picture at all, because photo elastic images have high contrast, you are in a position to apply a very simple image processing approach called thresholding to identify fringe areas and what we are going to look at is, I would apply the thresholding, I will put a different threshold, I put the threshold, now as 130.

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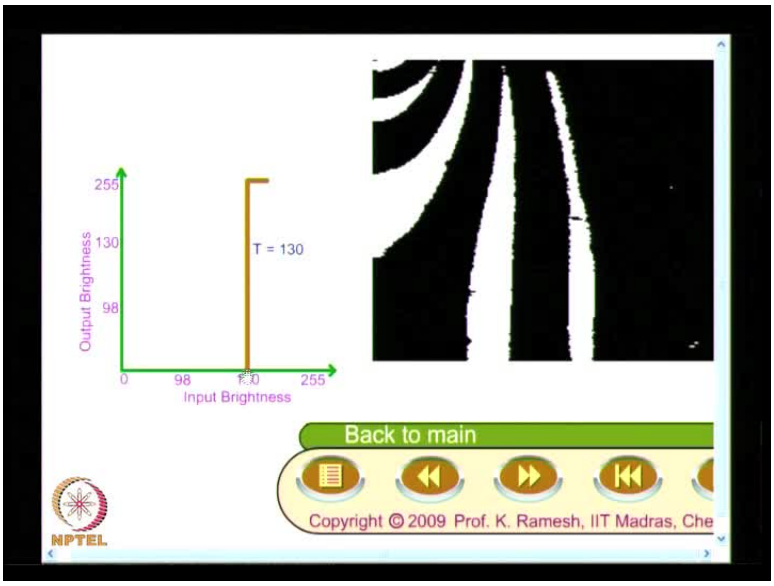

So, what I have done is any grey level value before 130, I make it as black; any grey level value after 130, I make it as white. I start seeing black region and white region demarcated, and black regions are nothing but your fringe contour.

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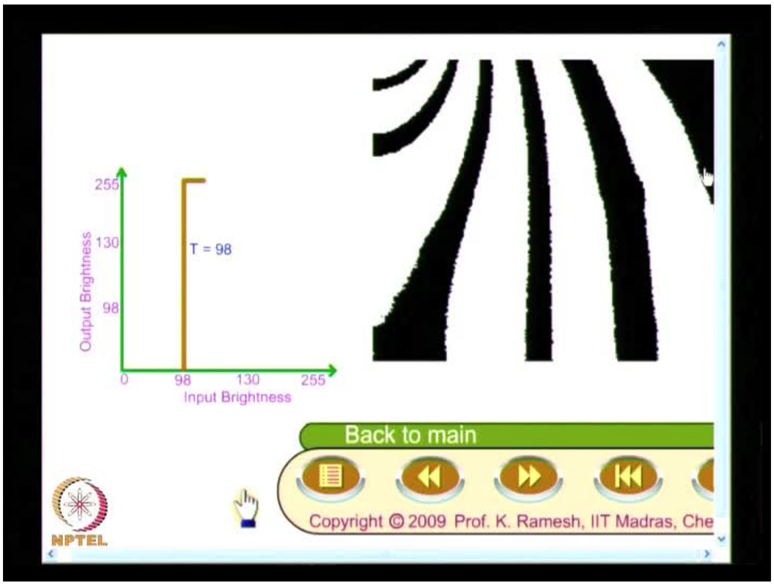

And if I change the threshold optimally, suppose, I make it as 98 which is the very good threshold for this problem, I see so many fringe contours beautifully demarcated. This is one of the greatest advantage in photo elasticity, even a simple thresholding operation you are in a position to identify fringe areas. Because, if I want to do a binary based processing or if I have to do intensity based processing, I must first do identify the fringe areas and within the fringe areas let me do some kind of processing. And in a binary based algorith what we will try to do? We will try to strip these outer pixels until the skeleton is obtained, and one of the very famous algorithm in this is by Chen and Taylor.

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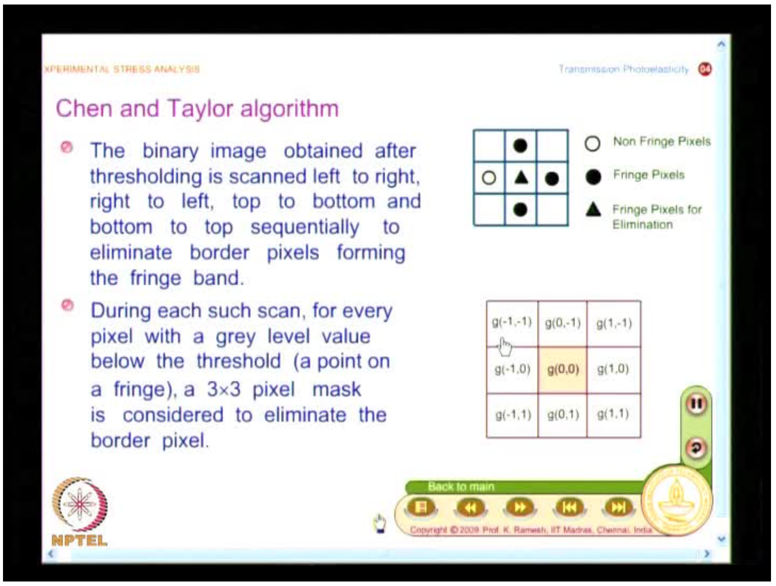

I am going to give you only a gist of what this algorithm is, and also some introduction to how people process images. And essentially, you will have a mask, and this mask is identified as, the centre pixel is as g 0 0, because it is grey level values, it is labeled as g. And then, I have this as g 1 comma 0, x is increase in this way and y is increasing downwards.

So, g minus 1 comma 0, so I have a 3 by 3 matrix, where I want to take a decision on the centre pixels and what is also given pictorially is, I want to identify with a triangle, this is the fringe pixel for elimination in this case. And if I have a white circle, it is a non fringe pixel, when if I have dark circle I consider them as fringe pixels. So, what is done is, you identify a mask and you move the mask over the entire image, and depending on the neighborhood of the centre pixel you write a condition, and based on that condition, the pixel will be retained or eliminated. And these conditions have to be developed very systematically, to some extent your mathematical understanding will help, beyond a point many of the image processing algorithms, they develop filters applied to the particular image, for a class of images you will identify a sequence of operations.

You may A pre processing methodology of a particular kind may work well for some class of images. Even a simple thresholding works in this case, if simple thresholding does not work, people have to go for other methodologies to identify the fringe areas, then, when they develop the filter, they will also have to find out whether this filter really works, it may work in most of the areas, some areas it will not work.

So, you have to have a conceptual development as well as implement it and see whether the methodology really works. So, what you have here is, the image has to be scanned left to right, right to left, top to bottom and bottom to top sequentially to eliminate border pixels forming the fringe. Now, I have to develop a condition, how do I identify that this is a border pixel and how do I remove it. Visually, it is very simple, if I give a photo graph to you and then, if I ask you to mark the fringe skeleton, you will do it. If your hand is not shaky you will do a very good fringe, if an artist you can really pick out that fringe contour very well.

But, once we for image processing irrespective of the user, we want the computer to give you the skeleton. And mind you, any of these processes blindly looks at the fringe area and keeps on stripping out the outer pixels and this you may have to do left to right, right to left, top to bottom and bottom to top, you have to do all these and ensure that any curvature of the fringe portion is not left out that is the reason why you do this kind of different processing.

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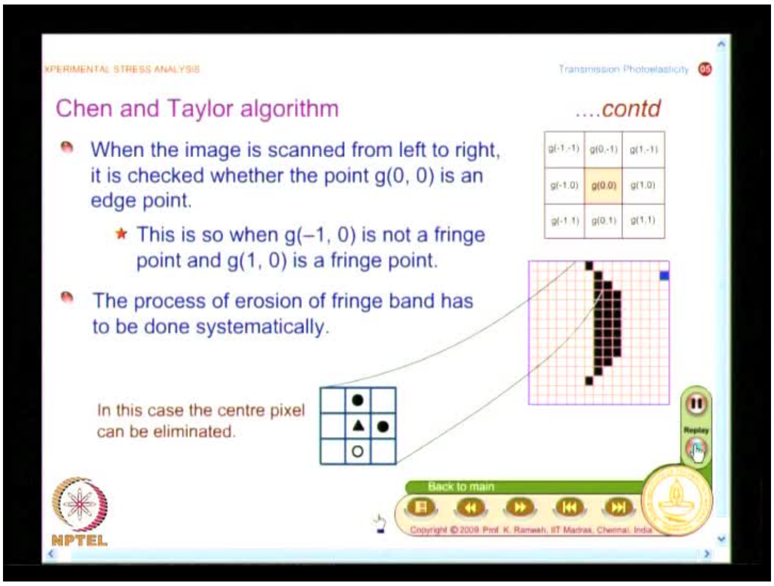

And we will look at what is the kind of condition that you need for one such scanning direction, and what I have is, this is the pixel that is under consideration and we want to look at the image is scanned from left to right, and I want to find out whether the pixel g 0 comma 0 is a border pixel and do I have to retain or eliminate. And I have shown a typical fringe, where it has different kind of thickness, and what I have this as the blue pixel is, it repeats scanning process and I will read to the animation then, you can have a look at it. So, we are scanning the image from left to right, we want to find out whether g 0 comma 0 is to be eliminated. And what it does in the first this one, it has retains this pixel, and now, the blue pixel is in this region.

Now, we will have to look at a 3 by 3 mask around it and investigate whether this pixel can be retained or eliminated. And what we want to do is, we want to look at g minus 1 is not a fringe point, and g 10 is a fringe point, what happen? g minus 10, g 00 and g 10. So, this is not a fringe point and this is a fringe point that is what is pictorially shown, if you look at this mask, you have this pictorially shown. This is not a fringe pixel and this is a fringe pixel, so I can eliminate this and when I eliminate it, I still retain a contiguity of the fringe.

So, you have a process of erosion initiated and likewise, you write it for left to right, right to left, top to bottom and bottom to top. So, if you do the image scan in all these four direction, it would eliminate some pixels, and it depends, and we have already seen when you look at a fringe, the thickness of the fringe varies dictated by the gradient. In low stressed areas fringes will be very broad; in a high stressed zone fringes will be very sharp. So, depending on the fringe width, the process will take time, I have shown this as a thick fringe here and this is the thin for illustration and essentially, this is a process of iteration.

So, when you are going for a binary based algorithm, it is essentially a process of iteration repeatedly, it has to do until fringe skeleton is identified, and how does it identify this as a fringe skeleton? It merely finds out the middle point. It is not necessary when you have a very broad fringe, the centre coincides with points of minimum intensity, what you will have to really look at is, points of minimum intensity. Now, what we will look at is, we will find out how this intensity information could be effectively used, and what are all the issues involved. Because, when I have to go and do this, I have to develop an appropriate algorithm for me to do that.

So, we will take a very simple fringe, we will take a fringe which is essentially vertical then, we look at essentially horizontal, then find out what are the parameters that are very important, then we take up a generic fringe, and then find out what is required. And when you look at the problem statement like this, you will find it becomes mathematically more and more complex, but fortunately you know me and my students have developed a logical operators which work fantastically for these classes of images and that is what we are going to look at. So, we have looked at a binary based algorithm, we had a sample that, we will find out for one scanning direction, what is the criteria to eliminate the border pixel, you must have fairly understood what is a physics behind it.

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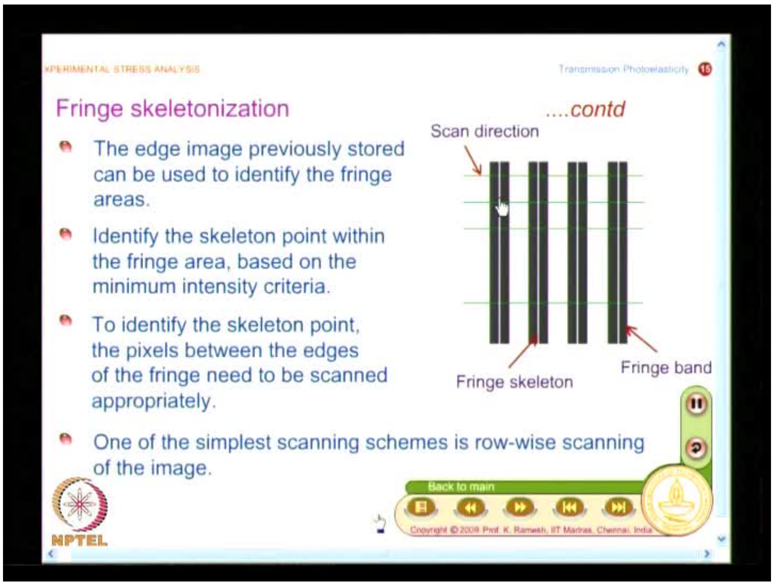

We identify this as a border and then, you are able to establish it, and remove it depending on the condition. Now, we will look at a intensity based algorithm and what we call this as fringe skeletonization, and what is shown here is, we have already seen I can get a fringe areas identified by a simple process of thresholding. And I have that as a edge image, which is previously stored, it can be used to identify the fringe areas. Now, I have a very simple fringe band, and I am sure when I have this as vertical, you can think of a beam under bending, kept in the vertical direction, and you can get fringes which are horizontal, instead of horizontal because I kept the beam vertical, I will have vertical fringes, and the fringe areas are easily identified. And if I want to pick out the minimum intensity point, it is enough I scan it horizontally, suppose, I scan the image horizontally and within the fringe band if I identify the minimum intensity point and make that as a fringe area - fringe skeleton - then my job is done.

So, I need to develop a scanning mechanism which is appropriate to the image, and within the fringe area, that is, start of the fringe, end of the fringe, within that pick out the minimum intensity. So, here, we are using the important heuristic information at the fringe contour intensity is 0. So, you are really looking at the minimum intensity, so this is mathematically much more precise than a simple binary based algorithm. Binary based algorithm is useful when somebody takes and gives a photograph and they want you to process it, it is not recorded with care to identify intensity variation.

So, you need both, in some case you may have to use an existing photograph to extract information. In other cases, you record the photograph yourself, then I can go for intensity based processing. So, this is what we are going to look at, we have to decide on the scanning direction. So, here, we scan it row wise, that is what it is illustrated here, and when I do the scanning like this, what I am going to do? Between the edges of the fringe, identify the skeleton point having minimum intensity, so that is determined. And what I have here is, I have nicely determined the fringe skeleton.

And this was possible this scanning was simple enough to do, because the fringes are vertical, I could have a horizontal scan possible. Suppose, I have fringes which are horizontal, what I can do? I can have a vertical scanning, I can repeat the same process, so when the fringes is horizontal or fringes is vertical, simple column wise scanning or row wise scanning can do the job of identifying the minimum intensity points. And in one of the earlier classes, we have already seen in stress concentration, we have compared what is the fringe pattern in the case of a plate with a hole, plate with an elliptical hole and plate with a crack. And if you look at the fringe pattern, the crack which has the maximum fringe width, it has a minimum fringe width as well as maximum fringe width in one fringe order. And a typical shape is like this, so what you have here is, the typical shape in a crack is like this.

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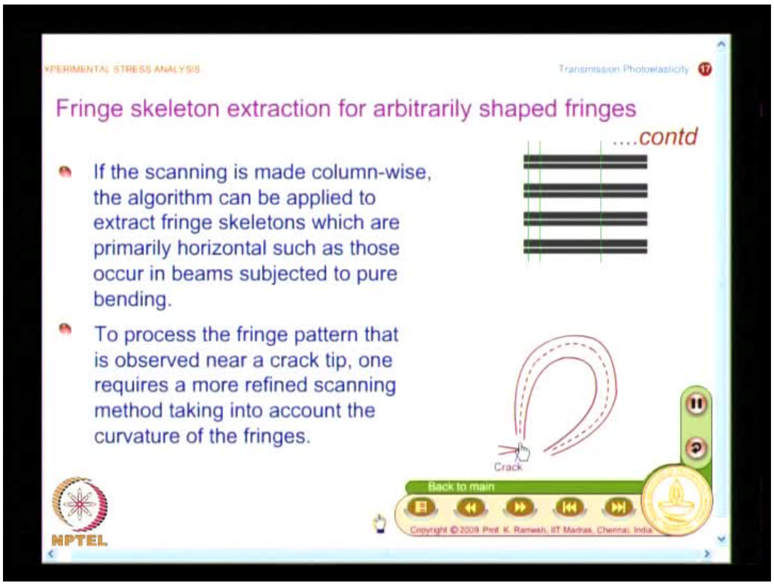

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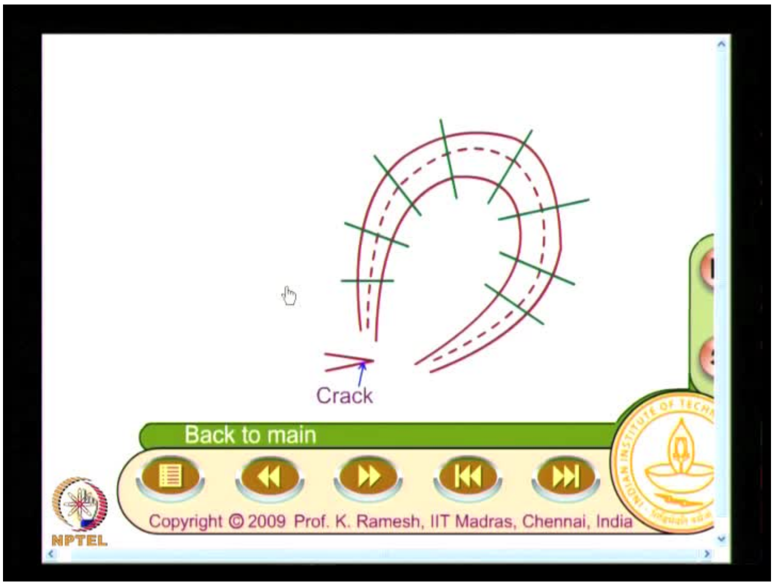

I enlarge the picture and what I have here, if I have to identify the minimum intensity point, I need to find out the edge normals, only then I can do that. So, when I do that, my scanning has to be done appropriately for each of this segment. So, a simple horizontal or vertical scanning will no longer be sufficient. The vertical or horizontal scanning was sufficient because, we had fringes essentially horizontal or vertical, but in a generic problem, once we developed a methodology, I should be able to apply to fracture mechanics problem, that is one of the very important practical requirement where experimental mechanics is needed.

And you have fringes of varying thickness only and you need to make an decent sketch of it, you need to have this and you need to find out, see because, if I do a scanning like this, I will not be in a position to pick out the exact minimum intensity point. So, I must find out the edge normal and then, do the scanning and this becomes mind boggling, how to implement this kind of a scheme digitally. Even if you want to implement it digitally, the mathematics involved is high and it is mostly a repetitive type of processing. And this is not advantageous from developing an algorithm, so you have only identified what is the difficulty in processing a generic fringe pattern, and here only what we found was this logical operator has really helped.

So, the key point here is, one has to do enormous amount of computations to extract the fringe skeletons. The reason is, we have to find out the edge normal from geometric considerations of the fringe which could be greatly simplified if you adopt a scheme which employs logical operators, which took sufficient time for us to develop, and which is very fast, and that is what we look at it.

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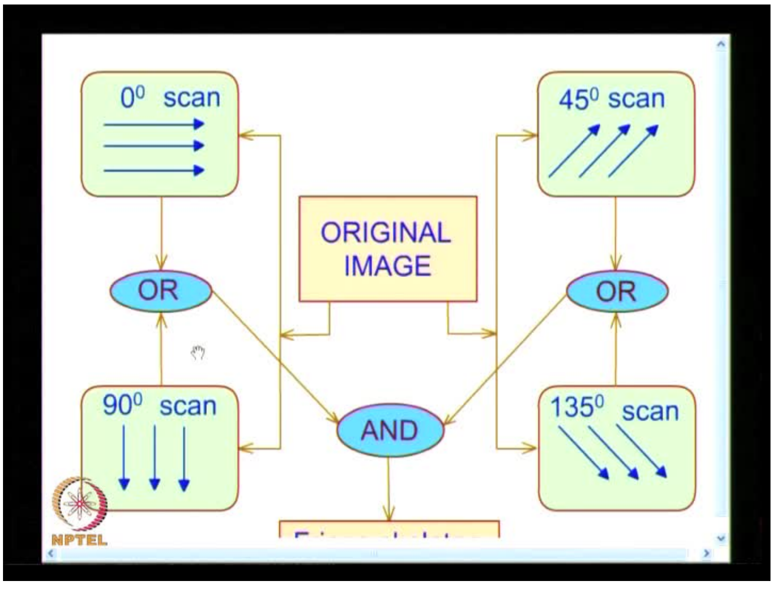

And let us look at the… I will take the original image, when I say the original image I will have the edges identified then, I will scan it horizontally, get the skeleton image, scan it vertically, get the skeleton image and process this by a OR operator, make a sketch of this, you need to have this algorithm. The algorithm is very simple and straight forward and I am doing a set of orthogonal scans only to appreciate that this scan helps.

We have looked at fringes which are vertical; this scan alone can provide you the complete skeleton when the fringes are vertical. On the other hand, when I have fringes which are horizontal, 90 degree scan alone can provide you the fringe skeleton, but in a generic image, what we have found was, I need to have a 0 degree scan, I need to have a 90 degree scan, I need to have a 45 degree scan as well as 135 degree scan. So, in essence, once I have an original image, I will globally search the image only 4 times, one in 0 degree, 90 degree, 45 degree and 135 degree.

Because I do it only 4 times, no iteration involved, the number of operations are fixed, and what we what is the advantage of this approach is, by the use of appropriate logical operators, you are able to successfully remove the noise that is generated in each of the scan, each scan will give you skeleton as well as some noise. What we do is, by doing the logical operators retain the fringe skeleton and remove the noise. And what are the logical operators? I have a 0 degree and 90 degree scan and I do a OR operation between the two, and I have a 45 degree scan and 135 degree scan I do a OR operation between the two, now I do the logical AND of these two results.

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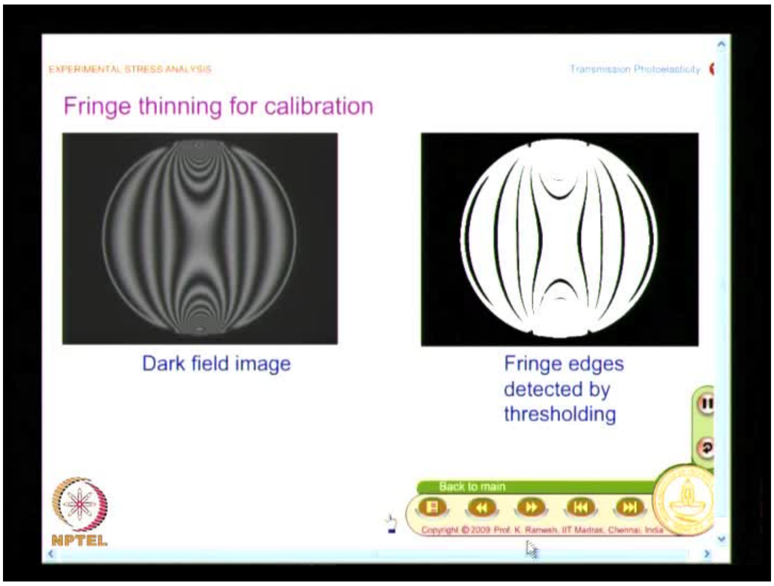

So, 2 OR operation and 1 AND operation provides you fringe skeleton, free of noise. This is only a statement; the statement has to be verified from actual processing of the fringes that we will see. And what I have here is, I have the disc under diametral compression, fringe pattern and this is the edge identified image, and I have this edges are identified. And what I have to do is, I have to go and find out the fringe skeleton and here what you find is, the fringes are not only either horizontal or vertical, it has an arbitrary shape, primarily vertical.

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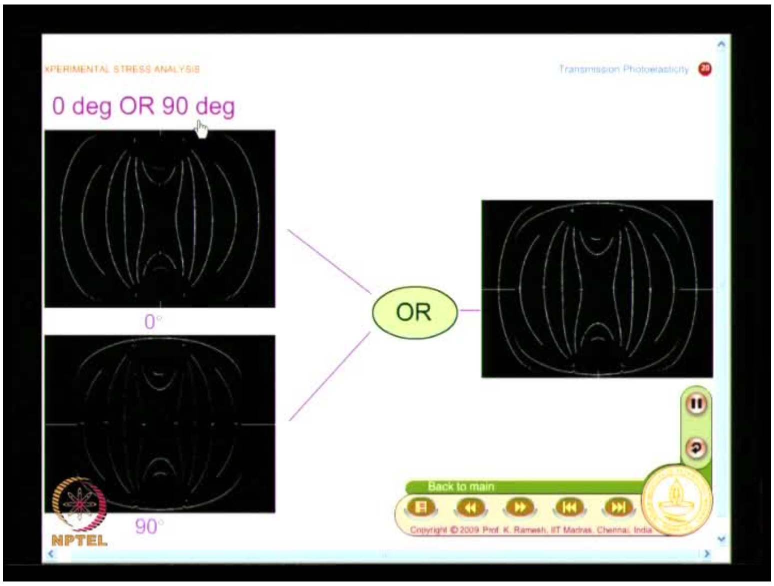

So, what you will find is, one of the scans it will pick out, horizontal scan will pick out more points, vertical scan will pick out only some points, that is the kind of information that you will have and we will see that. So, I have this, two scans are done, 0 degree scan and 90 scan, and I will enlarge this picture, so what you find here is horizontal scan, because the fringes are primarily vertical, it has picked out quite a number of points but whenever the fringe becomes tangential - the scanning direction becomes tangential - you lose some data you lose some data here.

And we will also see the other scan, I mention that this gives you only small information, and has identified in the zone where the 0 degree scan has not returned you the value, that is advantage. So, this is complementary, but it introduces noise, it introduces noise in some other direction. So, now what I do is, I do a logical OR operation, I take a logical OR operation of these two, I get a fringe skeleton which is reasonably complete, but it still has noise, you have unwanted information like this. So, what you find is, scan the image horizontally and vertically, each scan provides you some fringe points and some noise, and a logical operator helps you to connect all the fringe points, all the fringe points are now connected but you also have noise, and what you find is, you go to another set of orthogonal scans, you are able to get all the fringe points but noise in a different direction.

So, when I do the logical AND, the noise is eliminated, that is a principle behind it. So, we will go and see, this is the OR operation 0 degree scan and 90 degree scan, I have a OR operation, I have this fringe pattern. Now, I go and see the other orthogonal scans, I look at the 45 degree scan and 135 degree scan, and here again I will enlarge the picture, and what you find is, it is able to identify the skeleton in these portions, it is not able to identify in some zones.

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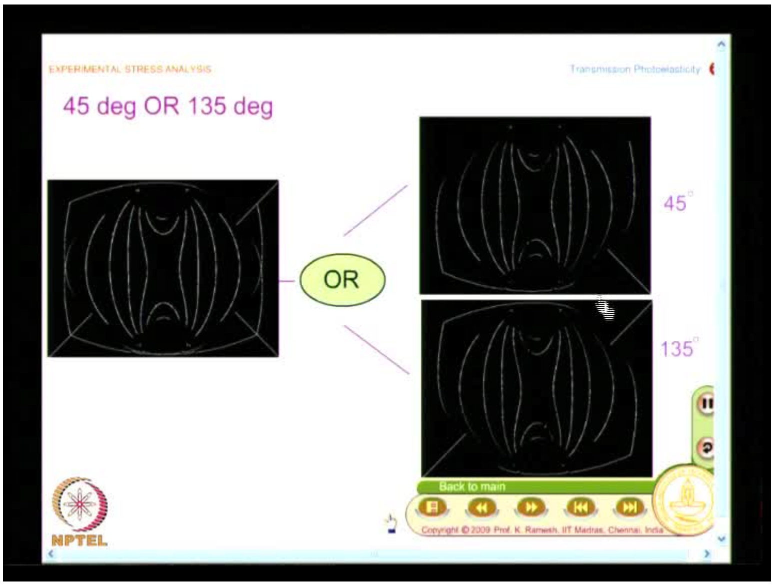

You are actually doing the scan like this, 45 degree like this, and it identifying some noise here. And if I look at the other scan 135 degrees, it compliments where I got information in 45 degree scan I do not get information in 135 degree scan, but I get what is the information missing in the other scan, you are able to get it here. So, I do orthogonal scans, I am able to get the data complimentary from each of this and do a logical OR operation, so when I do a logical OR operation, I get this.

And what you find here, the fringe skeleton is reasonably comprehensive and it has branches of noise, and in the zone you do not see much noise. In some other applications you will also see noise even in this depending on the fringe orientation. The fringe orientation is a key point, so depend, so in a very generic problem a 0 degree, 90 degree, 45 degree and 135 degree scans really help. Now, what I do is, I do the AND operation of these two OR results, and that is what I am going to see here. So, I have this 0 degree, 90 degree, scan image 45 degree, 135 degree scan image and I get finally the skeleton as good as this, you see only the fringe in the area where you have seen the fringes and of course, the information in the stress concentration zone is lost and which was not that even in your edge detected image.

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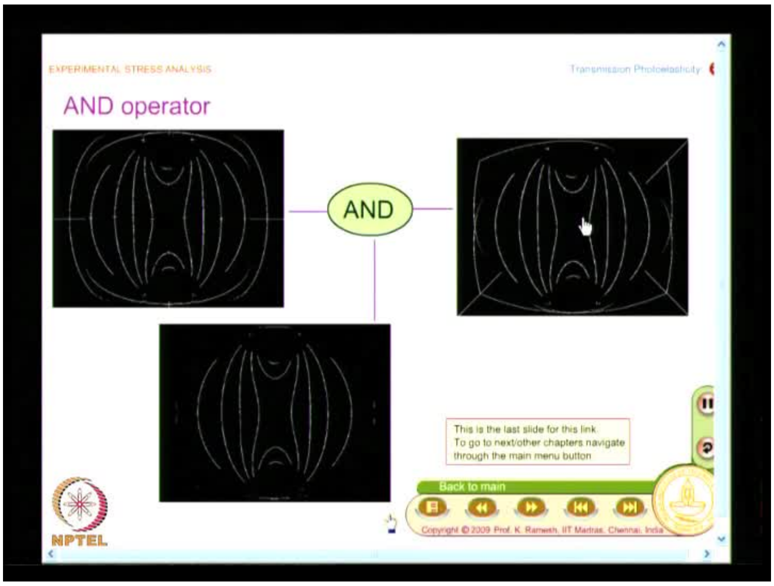

Even when you had the edge detected image, you did not have fringes in the stress concentration zone, and how to circum this, you take a photo graph with a higher optical magnification in that zone and repeat the same process. You will be able to extract information why that is not attempted here, because my focus is to find out f sigma. And f sigma we have already seen, we will collect data in an annular region near the centre 0.35 odd to point 5 r, so I am not interested in the data the load application point, so for our application this is good enough.

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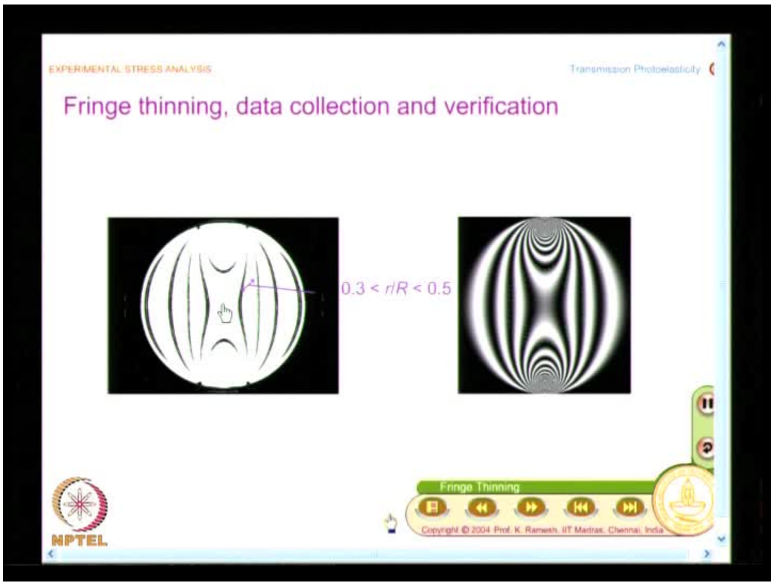

And this is what we have here, I have the data to be collected only in this zone, and this is the annular zone I wanted - and I can also zoom it further - so what I see here is, I have the black fringe in which I see the white line as fringe skeleton. And in this zone, I can definitely find out 40 data points, because our requirement is only 40 data points. So, for the problem on hand, I do not have to go and worry about information extraction in stress concentration zone, I have the necessary data.

So, once I have these 40 data points, what is that I can do? I can go to my Gauss elimination procedure and find out the f sigma value by simply processing that matrix that you have got. And we can also make it insensitive to the data points which is not done in the present application, you know, I want to show you what is the difference, the choice of data points also matters.

And what is shown here is, I have the fringes reconstructed, because we know the stress field in a circular disc, using the theoretical information, it is possible for me to reconstruct. And this is to illustrate if you do only 1 le square analysis your choice of data points matters. You know, I have this choice of data points, and this choice of data points do not lie precisely on the fringe skeleton. In some points it has matched, some points it has not matched, but nevertheless you are able to see the collection of data points lying on the fringe contour, the accuracy can be improved slightly better.

So, for this, it is better that you go for a sample le square analysis, so you are able to make the process of identifying f sigma, independent of the data points collected, but this illustrates what is the basic procedure. Now, my interest is to tell you how do I do a theoretical plotting of fringes and why this is needed. See, in the case of f sigma I am essentially solving a linear problem; in a linear problem reconstruction of fringes is not that critical, you will definitely have the fringes to what is seen in experiment. The same method of processing data in a le square sense is also extended to finding out stress intensity factor in fracture mechanics problems, in those problems, it is essential that you reconstruct the fringe pattern to ensure that your iteration has given you the correct minimum value.

We saw a linear square methodology for f sigma calculation, the le square methodology becomes non-linear when I go for fracture mechanics problem; in non-linear problems, I have do an iteration; iteration you will not know, whether it is a local minima or a global minima, the essence is you have to identify the global minima not the local minima. And people have reported in some of the cases, you get the parameters converged, but it gives a fringe pattern different from what is the actual experimental fringe pattern. So, it is a must that you always reconstruct fringe pattern and you need to know how to reconstruct fringe pattern, and the reconstructed fringe pattern how does it look like? I have a beautiful thickness variation, this is not experimentally recorded but it is very close to what is experimentally recorded.

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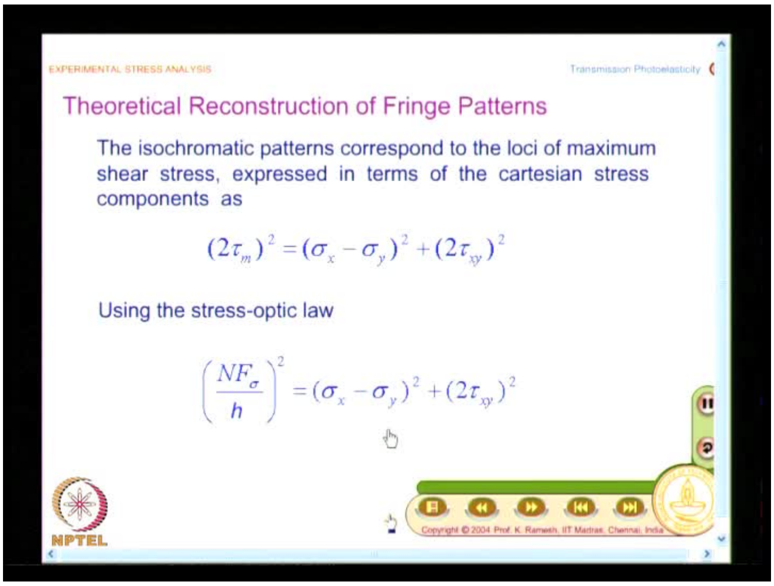

I see thin regions, the same fringe becomes very broad here, how is this achieved? In fact, I raise this question when I talked about fringe bands, I said, how to do it, I will reserve it for one of the later classes and I will tell you how do you mimick the thickness variation also. And even the thickness variation you can do it by a very simple mathematical step, you do not have to worry depending on the fringe, I should go and tell the program that make the thickness as so much, nothing of that sort is required.

And how do I do the theoretical reconstruction, this is what we will see and we know what do these isochromatic patterns correspond to? They correspond to loci of maximum shear stress, expressed in terms of the cartesian stress components as 2 tau m whole square equal to sigma x minus sigma y whole square plus 2 tau x y whole square. Note the difference, this is in plane shear and this is maximum shear stress. And in any problem where you have an analytical solution, it is possible for you to find out the right hand side, I know sigma x sigma y and tau x y, even if you do not have a analytical solution, suppose, I solve the problem numerically, then also I have the right hand side.

So, I can get it from numerical or analytical solution, only the plotting basics is similar, the implementation will be slightly different. And what do we get from stress optic law? You get enough sigma by h, so this is related to this. Now, what you see as fringe pattern? You see, as fringe pattern only the fringe contour n, suppose, somebody gives you a problem and ask you to plot a contour, what is the normal way which you will do? A contour is one where the value remains constant.

So, you will go and find out the x y coordinates of that; that is how anyone will try to do. Suppose, I look at this expression, I have n f sigma by h whole square equal to sigma x minus sigma y whole square plus 2 tau x y whole square, I have sigma x is a function of x comma y, sigma y is a function of x comma y, and if you really plug in those values invariably this will be a non-liner equation. And if you have a non-linear equation, when I want to do the estimation of x comma y for a given value of fringe order n, it becomes iterative. And let us look at what is the difficulty there, and I would get for a fringe order 2 some points like this, in my domain and I will essentially join them by a line. So, when I do like this, then I will have to worry how do I bring in fringe thickness variation, how do I do the calculation all that you have to think of.

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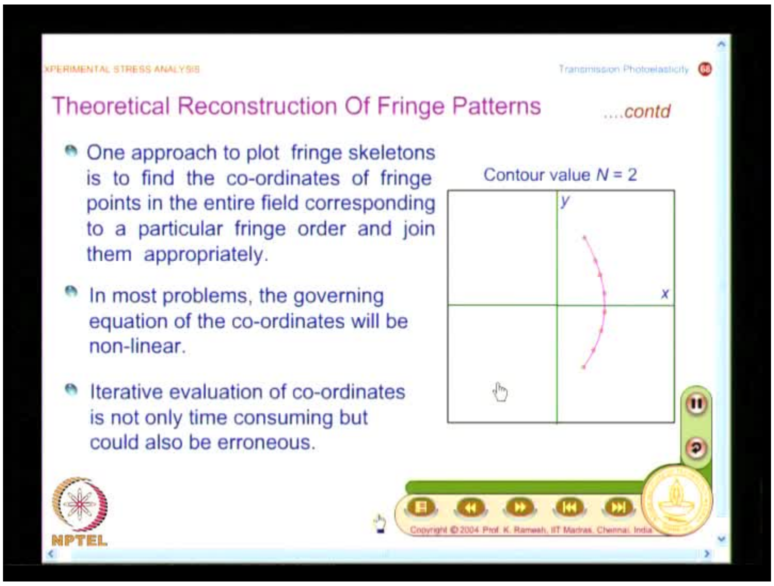

And in fact nowadays fringe plotting is so simple, people have developed and established programs also published, and it is not a big deal. In early days there was several research papers are written, how to plot fringe skeletons, it is not so simple. So, the important aspect is… In most problems the governing equation of the coordinates will be non-linear, iterative evaluation of coordinates is not only time consuming but could also be erroneous.

So, an approach like plotting a fringe contour, like taking a fringe order n equal to 2, collecting all the data points and connecting them as a contour is not the solution. This is not the way that we have to approach the problem of fringe contour; we will have to go by a different approach, that approach also should ensure even mimicking the fringe thickness.

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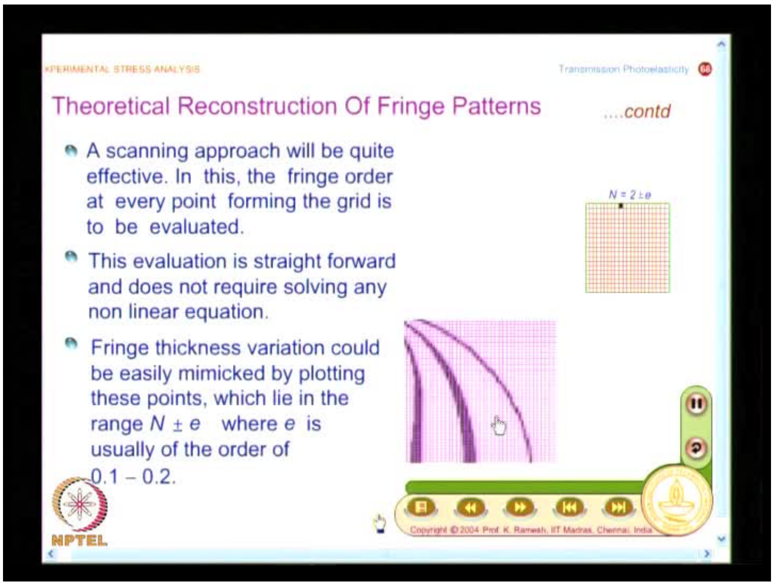

So, what we will do is, see computers are very faithful servants, if you ask them to do repeated calculation, it will do without a (()), that is a greatest advantage, so what we will do is, we will use the computer that way. So, you will do a scanning approach, is very will be very effective, fringe order at every point forming the grid is to be evaluated, because you and I have to do the calculation, scanning approach is not the right way to do, scanning approach would be boring and time consuming after 2, 3 calculation, you will say forget about it, a computer will not do that and it will faithfully follow what you say.

So, we will we have already seen that a image can be identified as assembly of pixels, so if you bring in that pixel level of scanning and plot it, you will get fringe contours which are continuous and what you need to check here, the first advantage is, the evaluation is not iterative, this evaluation is straightforward and does not require solving any non-linear equation.

What you essentially do here is, you find out the fringe order at every point forming the grid and I said the grid could be at the pixel level. And I also said, I must be in a position to mimick the fringe thickness, and fringe thickness variation could be easily mimicked by plotting these points which lie in the range N plus or minus e, and e could be on the order of point 1 to point 2, it automatically picks out fringe width, when fringe gradient is very high fringes will be very narrow, when fringe gradient is small fringes will be very broad and this is automatically taken care of by your mathematical step.

So, you do not plot a fringe of fringe order n, but you plot a fringe order of n plus or minus plus or minus e a small value. If I take a very large value of e, you know I can adjust, it is equivalent to like you know high contrast processing or low contrast processing of your images, that kind of an effect it will show and that is what shown here as a animation, I have essentially fringe identified this as assembly of pixels and this is what we would see here. And essentially, I want to plot a fringe of n plus or n equal to 2 plus or minus e, so I keep on doing this calculation repeatedly.

So, whenever I find this satisfies this, automatically the fringe thickness is also identified. And in this plot I have shown only for one fringe order and in fact, you can develop the logical condition in a manner; in one shot, it plots all the fringe patterns, so that is the greatest advantage. And in some of you are good at computers, please go and develop the fringe contour for at least circular disc under diametral compression, you can take it as a home exercise and try to do that. And that will give feeling, once you do for one problem, you will feel like doing it for several problems, and you will get a visual appreciation of how the fringe contours look like. So, what we have seen is, we have also looked at the f sigma calculation. And now we have to go to the very important topic, which I said that I will reserve it separately how to identify fringe orders.

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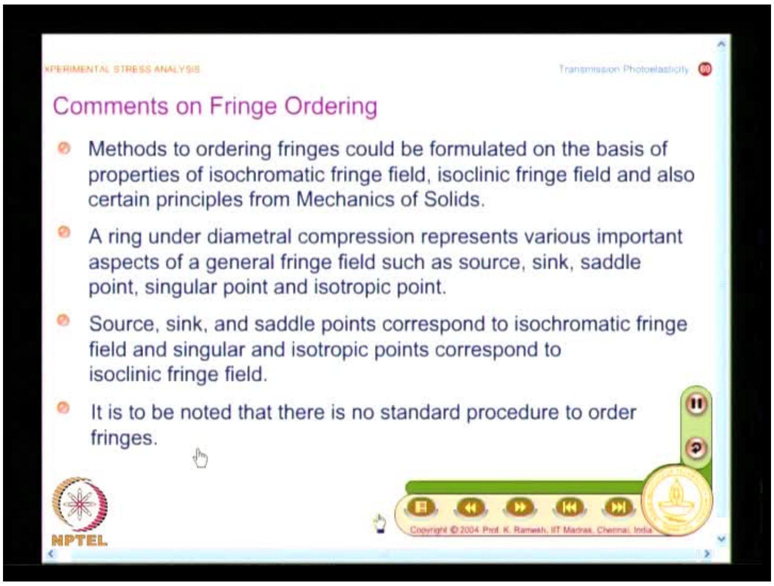

Because, I need to get fringe order n and f sigma for me to get stress values in any one of the actual problem, I need to get f sigma, f sigma calculation we have just now seen and we have to get the fringe order N. If somebody gives fringe order N is very simple, but you have to identify for complex problems, how to label the fringes.

And you know, certain aspects could be understood if you look at properties of isochromatic fringe field and also properties of isoclinic fringe field and you can get some kind of a help from principles of mechanics of solids. So, what I need to do is, I have to go and see what are all the properties of isochromatics, what are all the properties of isoclinic and I am going to take problem of ring under diametral compression to illustrate the properties of isochromatic fringe field as well as isoclinic fringe field. And even before we look at those properties, let me list only the names I am not going to explain them; I want you to look at the fringe pattern and try to figure out yourself.

And if you look at the problem of ring under diametral compression represents various important aspects of a general fringe field such as source, sink, saddle point, singular point and isotropic point that is why we want to go for ring under diametral compression. So, when I understand all these features that serve as guide points for me to order the fringes that is what is very important, and these points could be classified certain belonging to isochromatics and certain group belonging to isoclinics.

If you look at source, sink and saddle points correspond to isochromatic fringe field singular and isotropic points correspond to isoclinic fringe field. And now, I go and look at the last aspect, it is to be noted that there is no standard procedure to order fringes, you must keep that in mind.

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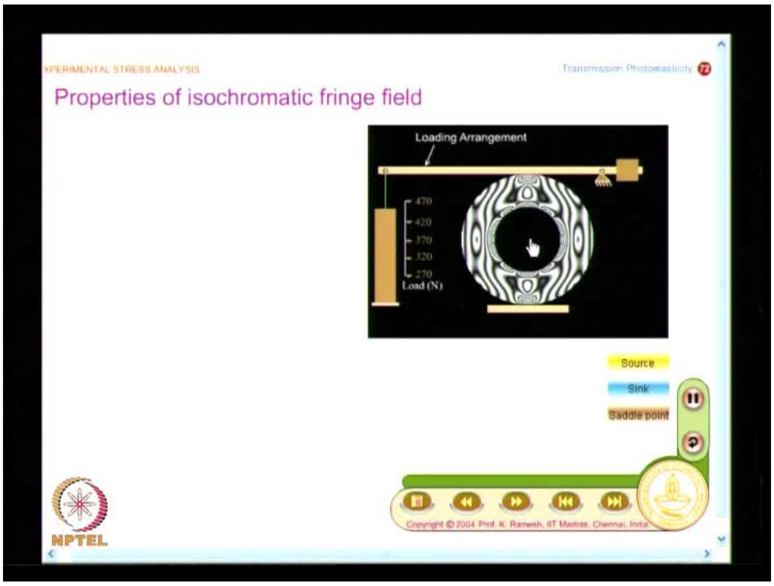

These are all guidelines, a guidelines you have to use it intelligently; guidelines are different from standard fixed step for identifying things, guidelines will help you how to, the path. And I am having a very nice illustration of fringe field in a ring under diametral compression, this I will magnify it, and what you need to look at is. I have this load being varied, this is a lever arm loading frame, and as the load is varied, you have fringes are developing and moving, and the idea is to just look at the fringe field.

See for few minutes, you need to see what all special features you look at, a very interesting things are happening, I want to take out this portion and then, see what is that you observe, what is that you observe in this zone, what is happening, as the load is increased a very interesting feature happens, do you see this. See, even if I take you to the laboratory to make you look at this feature, you would not be able to observe, because of the animation what I have I am able to repeatedly show this and you can see what is happening, what is happening at this point? The fringes go and vanish here, fringes go and vanish here, are you able to see, the fringe go and vanishes, so what is it called in fluid mechanics, suppose, the fluid flow, it is the sink.

So, you have a sink, you have a sink in the case of isochromatic fringe field, you see this beautifully. And let me show you one more feature, let me focus on this part of it, what is happening here, I have something special happening in this zone and I have something special happening here. As the load is increased in one case fringe go and vanish, in another case only the density increases only the density increases, fringe does not vanish. you should After me telling you this, you observe it, so in this zone what is happening is fringes come out of it and then, they become denser and denser and this remains as such. And we have seen, we have had enough clue earlier, we had said what is the zeroth fringe order, I said zeroth fringe order does not move even when the load is changed, isn't it, because one of the thing one of the aspects what I discussed was in a plane polariscope.

Suppose, you are given only monochromatic light source and then, you have to identify the difference between an isoclinic and isochromatic fringe field, I said if you have polarizer, analyzer crossed if I rotate them, isoclinics will move. On the other hand, if I change the load, isochroamtics will move exceptionally zeroth fringe order and that you see here, what I said you see here that, when the load is increased zeroth fringe order remains as such.

And you also say an interesting aspect, this is the high stress concentration zone, and in this case, the fringes emerge out as a load is increased and so that is what we have seen and keep looking at this fringe pattern for one more minute and there are also another interesting feature which I would take it up in the next class. So, you understand now, the fringe contours in the case of a ring is much more complex, we have reserved the discussion towards the later part of the course, so that if you learn how to order fringes here, you can order fringes in any problem that you come across with reasonable confidence. Because fringe ordering is a tricky issue even for experts, if there is very complex problem, phenomena is not understood, you may make a error in judgement and that is why you need to know these features.

So, if you know these features, you know, there will be a indirect check, I can approach the fringe ordering from one approach and label the fringes, I can verify by the other approach, if the ordering is correct by both the approaches you should get one unique value, so that is how you decide on the fringe ordering accuracy. If you have the luxury of color code, know nothing is equal to it, but some cases, you know, if you are doing a dynamic test and even recording fringe pattern at high speed itself is so complex, even if you get a monochromatic photo graph you are very happy. So, there are occasions where you need to live with monochromatic light source and you need to interpret the fringe -

order fringes. And fringe ordering is a most complex aspect and that is what we have looked at today's class, we have made a beginning in that direction.

We have looked at how to find out the data points that is required for f sigma calculation. We looked at fringe thinning methodologies and in the actual data collection, I have not shown how you go and collect, one simple way is to just click the button click the cursor and pick out data that so you do it conventionally, with modern techniques in digital photo elasticity, because I get fringe order at every point the domain, within that annular region of 0.3 to 0.5 r, you can even automatically collect the data by writing a code. So, with use of image processing techniques, the analysis could be made much more refined, where you use principles of statistical methods in processing experimental data; thank you.