Experimental Stress Analysis

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Lecture No. # 25

Overview of Digital Photoelasticity

We had looked at elaborately the basics of two-dimensional photoelasticity, and the last class we also looked at how one can go and analyze a three-dimensional model, and I also mention photoelasticity is one of the unique techniques, which provides you a convenient means to find out the stresses interior to the model with developments and computers. And also in image processing techniques, photo elasticity has not lag behind and people have started employing image processing techniques, and we have already looked at how intensity can be recorded conveniently with ccd cameras.

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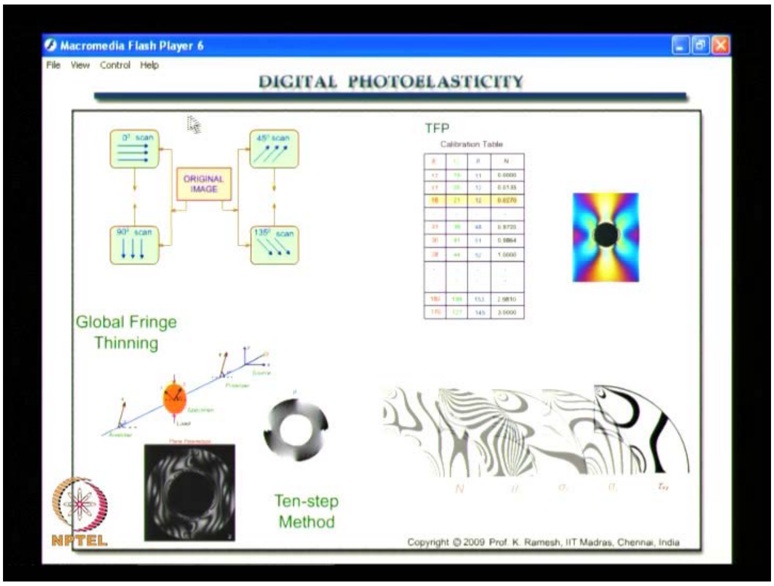

So, we will look at a flavor of what is digital photoelasticity in this class. We have already looked at one of the earliest methods, which mimicked what you do manually identifying the fringe skeletons how you can employ Image processing techniques?

How logical operators can help in finding out the fringe skeleton conveniently? And I mention you have color code, and this color code could be conveniently employed in digital photoelasticity to evaluate the fringe orders. We will have a look at certain aspects of this then finally, we will also look at what are known as intensity based processing methods, which are essentially phase shifting techniques and you have what is known as a ten step method.

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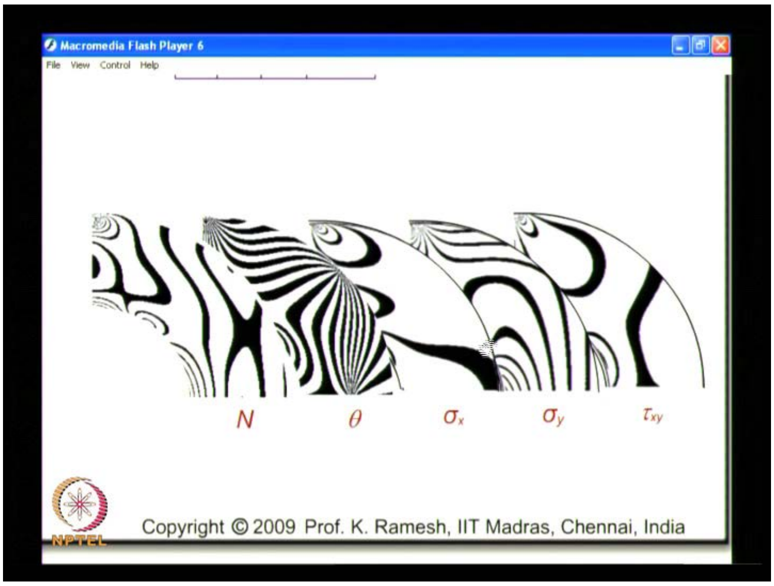

And what you have here is the method is? So, well developed that you get the fringe order n theta for every point in the domain using this you can find out sigma X, sigma Y and tau X Y stress contours, I can also do the separation of stresses. So, what I have here is with advancements in technology, you can find out the fringe order and theta at every point in the model domain. By processing the intensity, and also get the separated stress components though I have not spent time on how to find out these individual stress components with your background on fundamentals, you can actually do a self study to do that.

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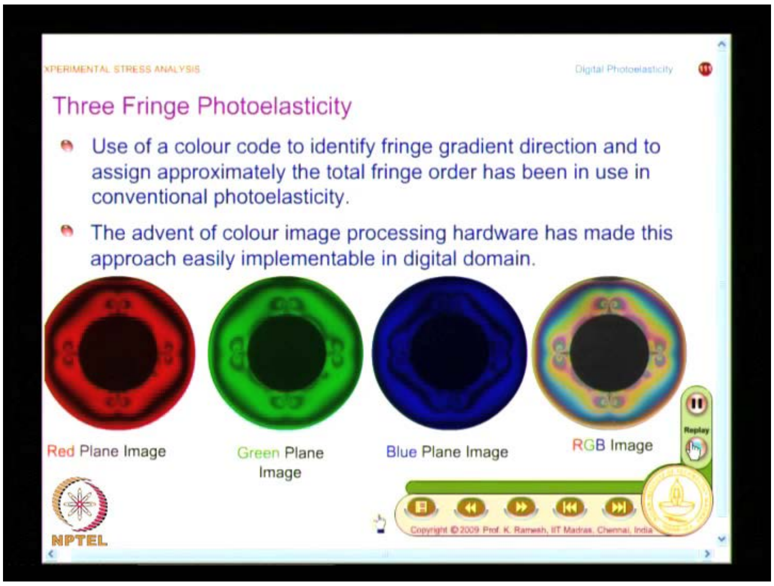

Now, we will take it up what is three fringe photoelasticity, and we have seen in conventional photo elasticity. The color code is use to identify the fringe gradient direction and also to assign the total fringe order approximately, this has been the focus in conventional photo elasticity with the advent of color image processing hardware this approach is easily implementable in digital domain.

Where icon get the fringe orders accurate, and what you have here is the problem of internal cracks from a pressurized cylinder. A color image can be thought of as assembly of a red plane image, green plane image and A Blue plane image. So, any color image can be thought of as assembly of red, green and blue and what you will also notice is here the problem is? So, selected that this is the crack and near the crack you have fringe order close to three, you do not have fringe orders beyond 3 in the entire field. What is the methodology?

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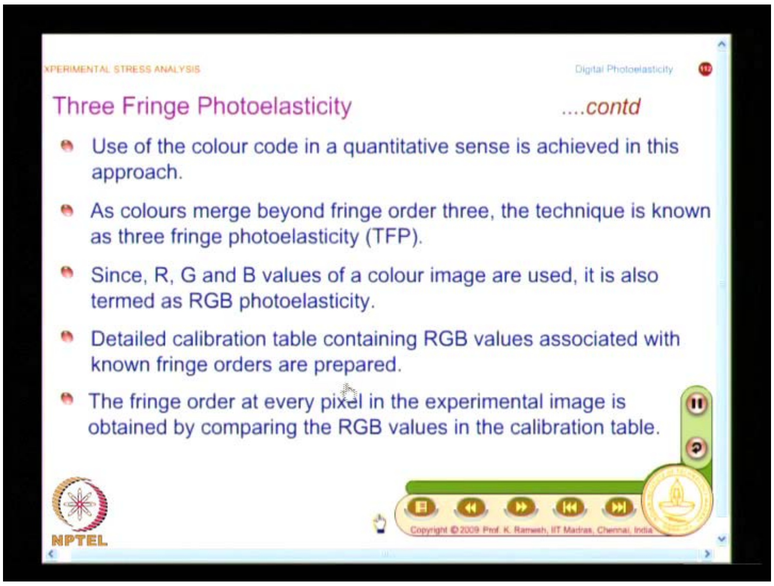

The methodology is as follows. So, you aim at use of the color code in a quantitative sense that is a focus. We have looked at color code more from identifying the fringe gradient direction with the digital hardware. It is possible to get the fringe orders in a quantitative manner with the color code.

And why we call it as three fringe photoelasticity? Colors beyond fringe order three merge the distinction becomes difficult, and hence the technique is known as three fringe photo elasticity. We abbreviate this as TFP, and you also have another name to it, because use the R, G, and B values of a color image; it is also termed as RGB photo elasticity. So, essentially use the R, G, B values to identify the fringe orders in a quantitative sense.

And how do you do this? You have a detailed calibration table containing RGB values associated with known fringe orders are prepared. Essentially, you take the case of beam under 4 point bending and we have seen. We had a neutral axis where the color is black and by increasing the bending moment icon increase in the fringe orders at the topper most end from 1 to 2 to 3. So, use that to prepare a calibration table and what you do is? You find out the fringe order in an unknown problem by comparing the RGB values in the calibration table.

So, in this methodology what happens is? You have to initially develop a calibration table and this calibration table has to be developed very carefully, and whatever the light source, whatever the polar scope and whatever the camera that you use all that influences your color code. So far a particular system you can have one calibration table and now what we are going to do is? We will find out a methodology and also minimize the error in identifying the fringe order.

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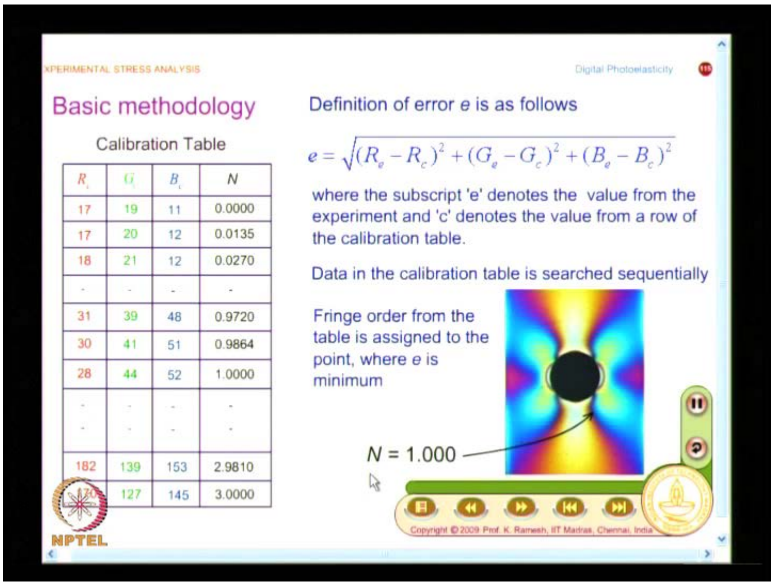

Let us see how it is done. The basic methodology has follows I said, that you have the color code develop from a beam under the 4 point bending, I have R, G and B values, and you have a fringe order, which varies from 0 to 3. For example, I have a problem of a plate with a whole, and if I have to find out the stress concentration factor. What is that you need? Because in many of the engineering applications, evaluation of stress concentration factor becomes important, because you have finite geometry. In a finite geometry problem, if you have to find out the stress concentration factor what you need is? You need the maximum fringe order, which is on the horizontal diameter and find out from the far field what is the average fringe order? You take the ratio you get the stress concentration factor.

It is as simple as that, because many engineering problems by processing the isochromatic data. The pertinent information can be easily obtained, I have now, said how to find out stress concentration factor? You also have methodologies to find out stress intensity factor, there again you need only is chromatic data and you also have contact stress problem where you want to measure the contact length, and also the maximum pressure develop, there again you need only the isochromatic fringe order.

So, there is a class of problems, where even if you know the isochromatic fringe order from the design point of view, you get the pertinent information. So, basically we are going to look at suppose I want to find out what is the fringe order in this, we all know from the color code it is about one, and how do I implemented in the methodology? Many researchers of contributed to this and what you do is? You write the basic equation, where in you define error as the difference of the R value of the experimental image at the point of interest, and R value of the calibration table that is why it is given as subscript c? So, I have the R value, I have the G value difference and I have the B value difference.

So, if the colors match, then I have found out the fringe order corresponding to the data point of the experiment. But in general you know, because of experimental difficulties it will not typically go to 0, it will have some finite value. Now, the question is we would like to minimize that error and how do I go about? And do it that is what we are going to look at, because computers faithfully do what you want? And without a murmur. So, I can do a sort of data searching, (( )) if have a 2000 data of fringe order and the corresponding RGB values for every data point in the actual experimental model, I can search all these rows available in the calibration table and find out the error and this is work and people also have identified what are the error sources? And to correct the error sources they have also come out with methodologies.

If you look at TFP taken almost 2 decades to mature to this level, whatever the issues in fact, I am skipping some of the mathematics the focus is to give a flavor. So, what you have here is the data in the calibration table is searched sequentially. So, that is what it illustrated here, I have a yellow bar, which moves row by row and every time you calculate the error e and I will wanting to find out what is the fringe order here. So, when I reach fringe order one the error is a minimum, and from that you find out what is the fringe order? So, you look at that row you match the RGB values of the calibration table with the experimental data point, and from that row find out what is the fringe order and label the fringe order? And you know this is easily said, but there are also error sources.

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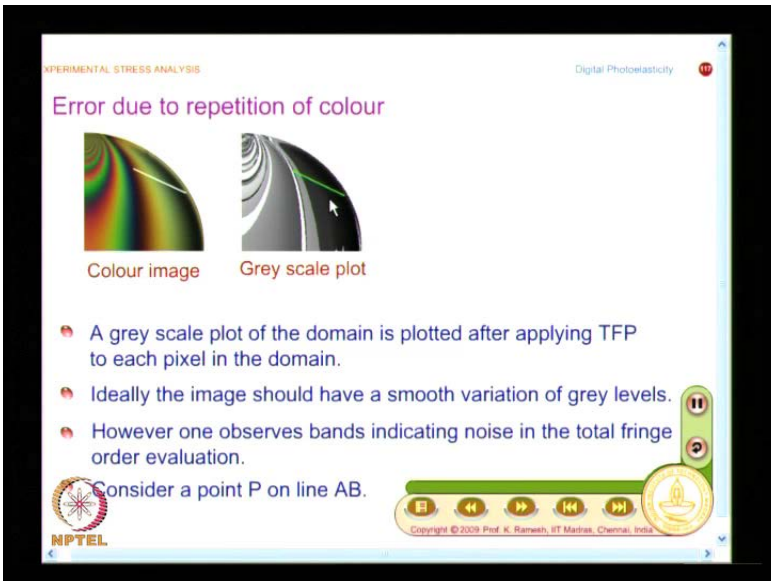

We look at what are the error sources? And how this can be corrected? See what you have here is I have the disc under diametric compression only one quarter of the disc is shown and this is the color image I have recorded and what is done is? Whatever the fringe order that I have obtained by searching the calibration table; they are plotted as a grey scale plot. Ideally, I should have from dark pitch to a pure white when it comes, because I want to have a gradual change in curve, but what I find is? I find this kind of distinct fringe and why do this come? Because I am only matching the color information there could be erroneous identification of the color, because of experimental difficulties. If you have a fringe order varies from 0, 1, 2, 3 you will essentially see the RGB colors are oscillating, it will be like a sinusoidal curve. So, there could be repetition with slight changes that may not be detected correctly by your experimental approach. So, we need to identify what is the source and also develop a methodology? What way it can be corrected?

So, only color code matching alone will not be sufficient, we need to bring in additional parameter let us first understand the error. Now, take a line that passes through the fringe field. So, we will have a line AB consider a point p on line AB.

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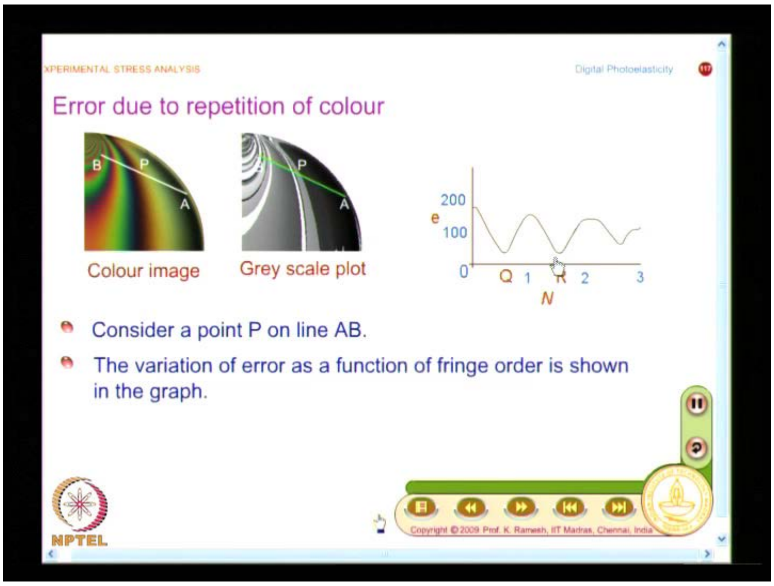

So, I am taking a line that passes the color Image as well as passes through this and let us also looks at the color code and find out what has really happen. So, what I have here is, if I look at the error which I do it for all the data points in the calibration table and the error is like this. So, I have minima here and this is will not be confusing, but there could be confusion between R and Q. So, we (( )) find out whether to choose Q or R, because the way we want we want to find out the minimum minimum error and these 2 errors are comparable and this is where the problem comes, if I depend only on the color, then I will have to be careful.

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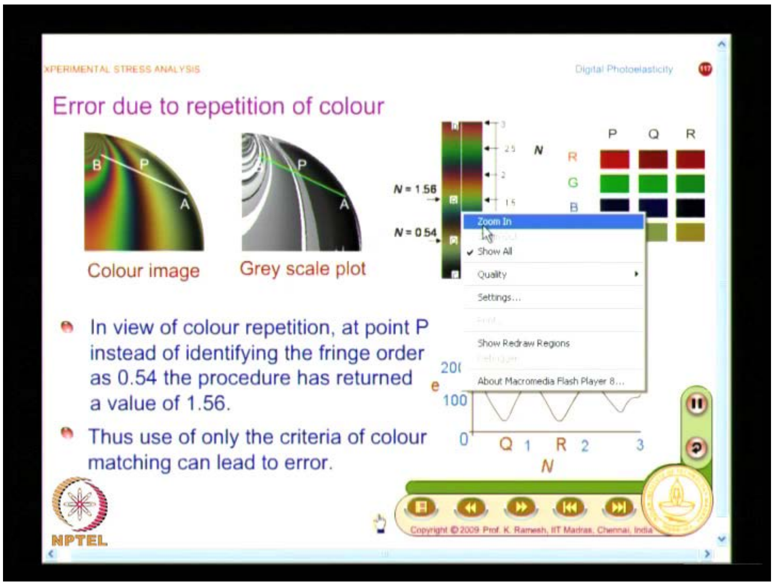
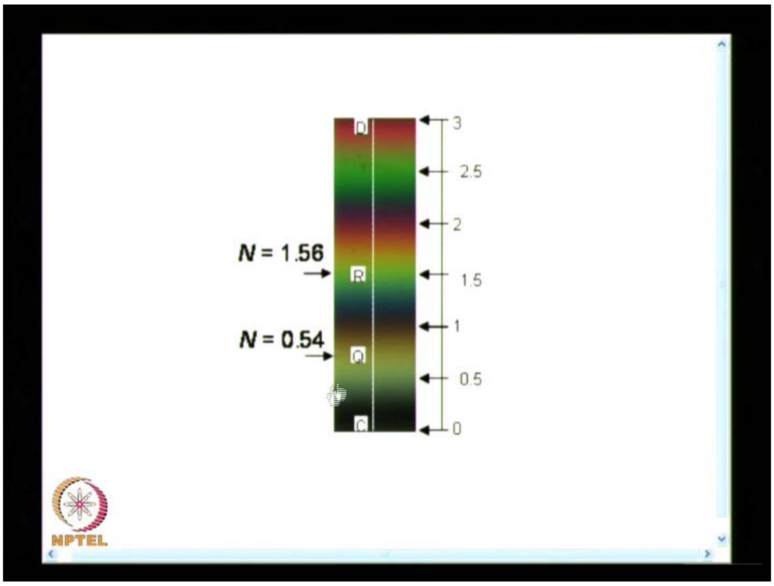


So, what you find here is I have the color code from 0 to 3 and what has happened is? (Refer Slide Time: 15:43)



The fringe order at the point Q is 0.54 instead; it has identified a repetition in color and identified the fringe order as 1.56. So, there is a sudden jump, because I have difficulty in the color code matching. Because you find in this zone there could be a repetition of color at certain locations. So, this is a source of error and these needs to be corrected. The procedure has returned a value of 1.56, because it only finds out the minimum error.

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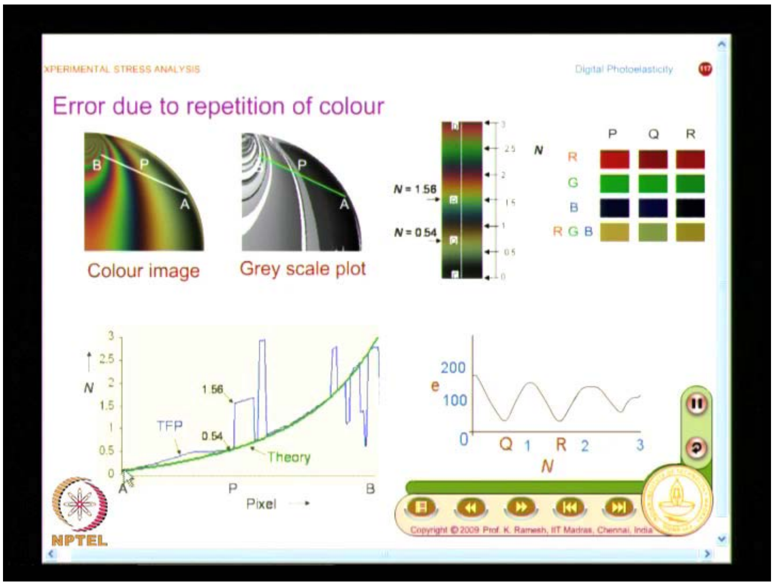

So, I need to have additional criteria to correct this and if you see the graph, it will be more clear that I have a variation of fringe order from theory like this and from TFP I find there is a sudden jump 0.54, 1.56 and you have it like this. So, these kind of variation cause formation of this kind of bands and this needs to be corrected and you here you have the Q. I have a fringe order variation, which has to be smooth I cannot have sudden kings in this. So, the best way is bring in fringe order continuity as the basics that are what we are going to look at? We will bring in fringe order continuity as criteria to identify in addition to color matching.

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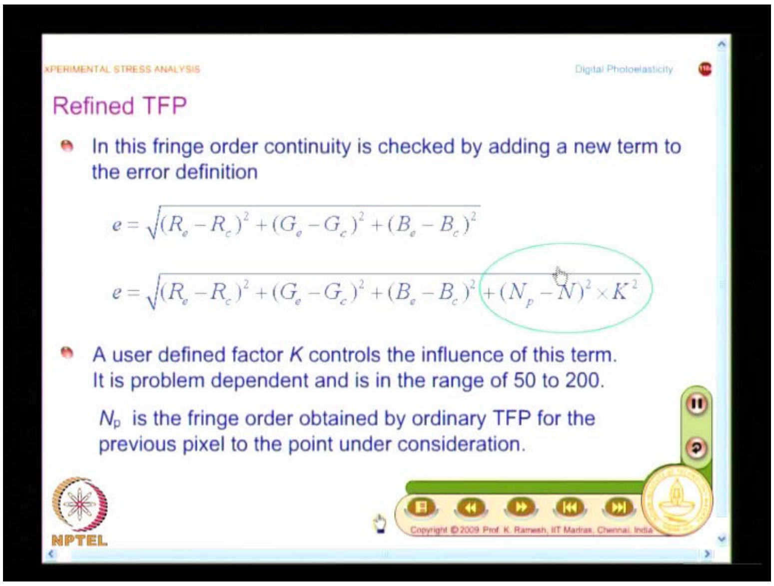

So, this is what... So, we have to reframe the basic equation and when we do that refinement, we call that as a refined TFP and the methodologies like this you know what you have here is? This is what you do it in a conventional approach. In the refined TFP I have an additional term, where p is the neighborhood fringe order and I bring in a fringe order continuity term in my error identification. Because we have seen only looking a color there could be error and we need to bring in fringe order continuity, and if I bring in fringe order continuity the whole procedure improves substantially and you have a parameter K, which needs to be determine based on the particular the problem on hand. So, there is a variation is reported and it is a problem dependant value. So, by using this and selecting it appropriately you can find out and that is what is illustrated next?

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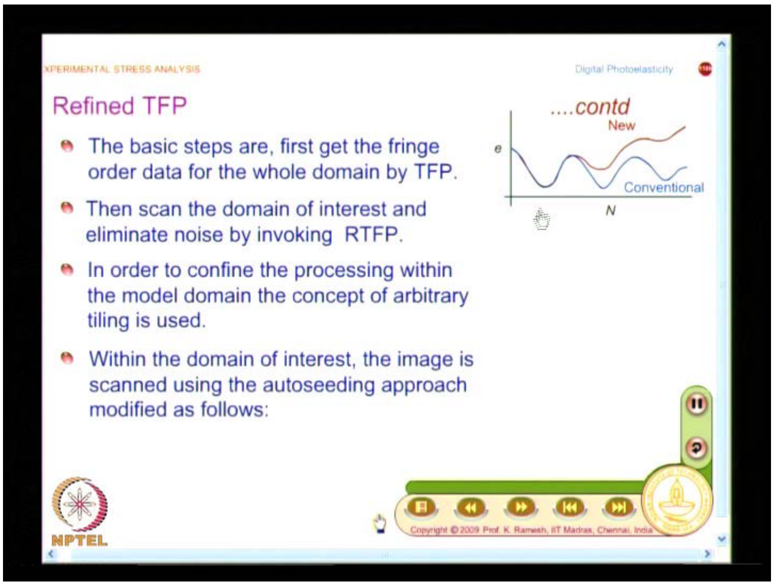

So, what I have here is conventional error will be like this, the repetition it was not finding out whether it is Q or R. Now, with the new criteria Q is a right value from fringe order continuity so, beyond that the error is more. So, the methodology will report only the minimum value corresponding to Q. It will not report this at all that problem is eliminated.

So, what are the basic steps first get the fringe order data for the whole domain by TFP, then scan the domain of interest and eliminate noise by invoking RTFP and you can also confine your attention within the model by using a tiling procedure I am not getting into those mathematical details. The graph is good the graph what you see here the graph varies like this, that illustrates how the additional term has helped in providing a minima corresponding to the first point and the second point where we had confusion, because of the fringe order continuity you see an error here the error increases. So, it is easy to identify the fringe order corresponding to the first minima, which happens to be the global minima.

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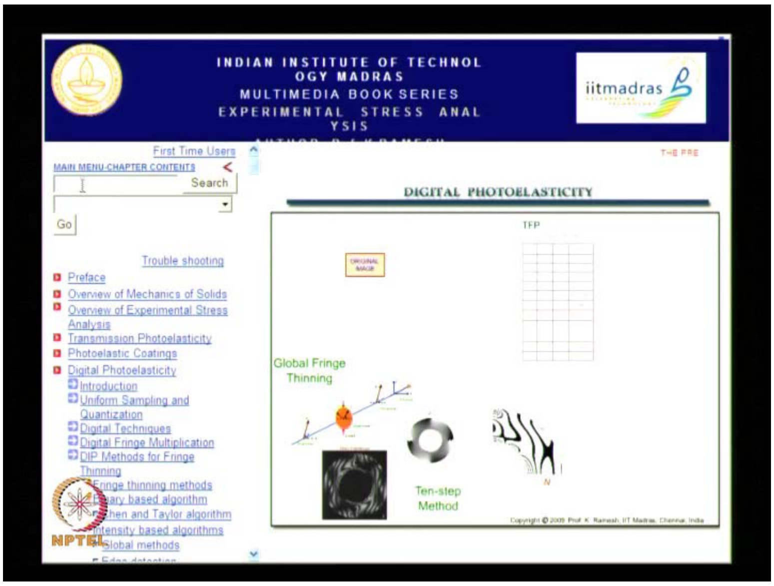

Now, what we look at is? We will look at a interesting application of this methodology and you know this also you have a provision in this book, where you can search what is the topic that you want that is…. what is illustrated here? And I take up a interesting application problem and this is becoming important in the case of electronic packaging

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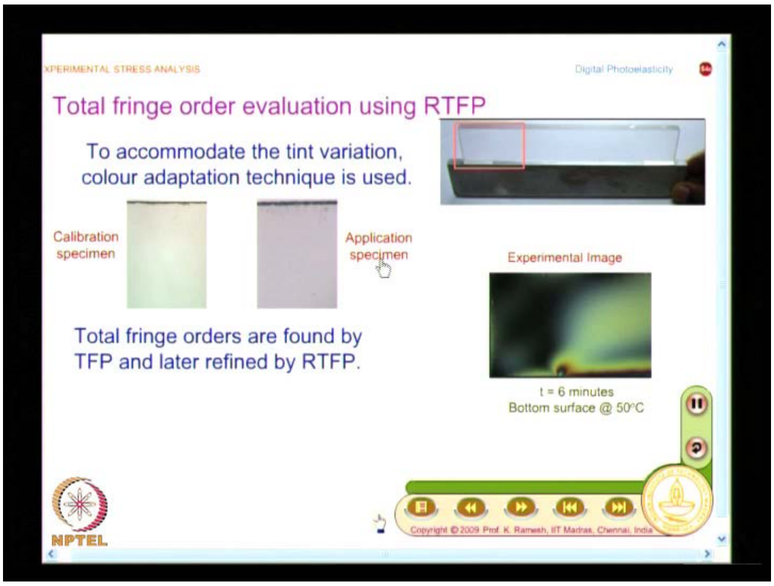

And what you have here is I have a aluminum bar and I have a poly carbonate and you have 2 edge cracks on this, and this aluminum is heated from the bottom, and at the tip of the crack. You see the fringe pattern like this and bottom surface of the aluminum is kept at 50 degrees, and this will vary as a function of time and at t equal to 6 minutes this image is recorded.

So, you have a time varying phenomena slow time varying phenomena. So, you record one image, you record only one image only a color image of the phenomena as a function of time, because it is slowly varying I have already said normal digital cameras can take 30 frames per second that speed is good enough to record this kind of phenomena.

So, we are looking at time varying phenomena with digital photo elastic approach and what you find here is? I have the crack and the fringes are very, very small and it is difficult to collect data for me to evaluate the stress intensity factor and what you will see now is? How you are in a position to extract pertinent data by employing 3 fringe photo elasticity and there are many, many developments that have taken place see what you have is? I said whatever the color code is a function of the light source function of the specimen material and the camera.

So, you will always find the application specimen by which you make the model may have a slight tint variation compare to the calibration specimen. Ideally, you should use the application specimen and then develop a calibration table, which will make your methodology very cumbersome. So, people also have developed, in fact me and my students have developed what are known as color adaptation techniques?

My students Madhu, and nether Simon have developed interesting methodologies and you can do a color adaptation technique.

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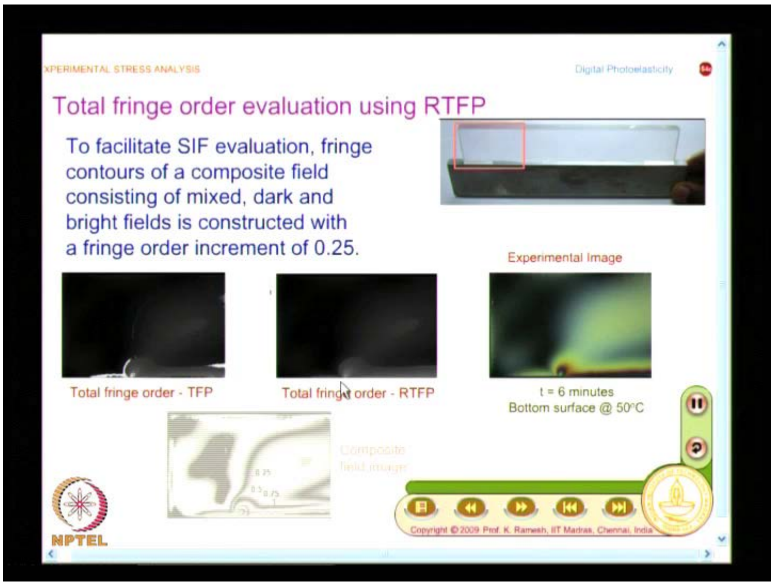

And the total fringe order from TFP is like this, which is improved by RTFP, and finally from this, you have the fringe patterns extracted from the whole field, and you find there is lot of data near the crack tip.

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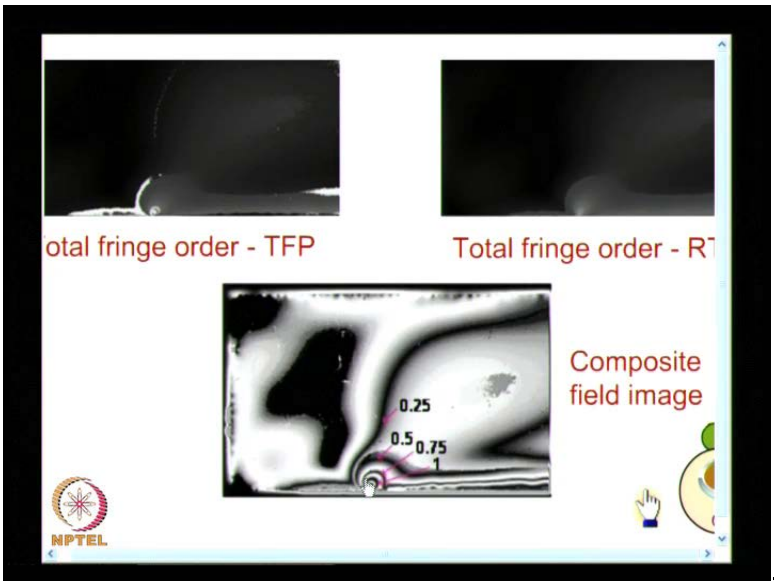

So, you have (( )) out fringe order 0.25, fringe order 0.5, fringe order 0.75, fringe order 1 and you see more details at what happens in the crack tip. So, what you find here is by employing the color code you saw only small information to start with whereas, when you determine the total fringe order at every point in the model. You are able to plot fractional fringe order contours and you have wealth of data for you to process and evaluate the stress intensity factor. So, we have seen for stress concentration factor or stress intensity factor you need only isochromatic data and this employs effectively the color image processing hardware. So, this is one philosophy.

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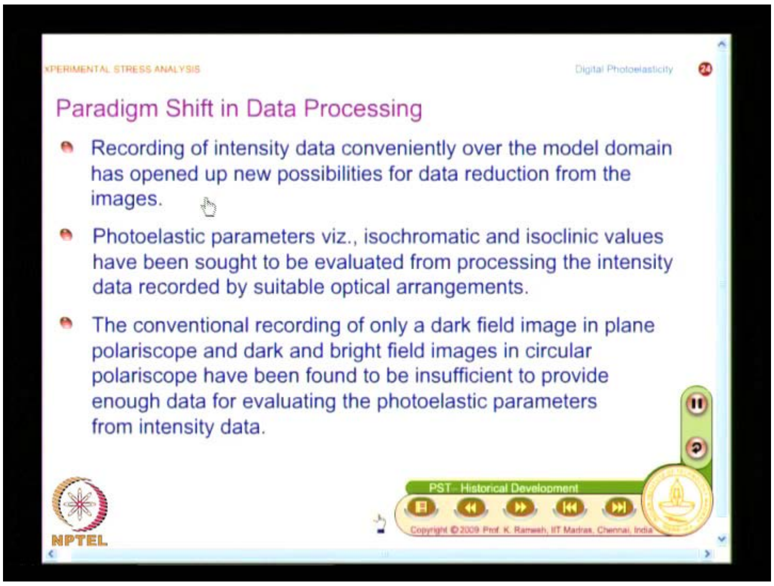

We will look at another philosophy; the other philosophy is brought in a paradigm shift in data processing. We have seen with the modern ccd cameras, you can record intensity data conveniently over the model domain, and this has opened up new possibilities for data reduction from the images. Our focus is to get isochromatic and isoclinic values and what we will now try to do is?

We will evaluate from processing the intensity data recorded by suitable optical arrangements and what you will have to look at is? The conventional recording of only a dark field in plane polarscope and dark, and bright field Images in circular polar scope, they have been found to be insufficient to provide enough data for evaluating the photoelastic parameters from intensity. So, people have to look at how to generate additional intensity data?

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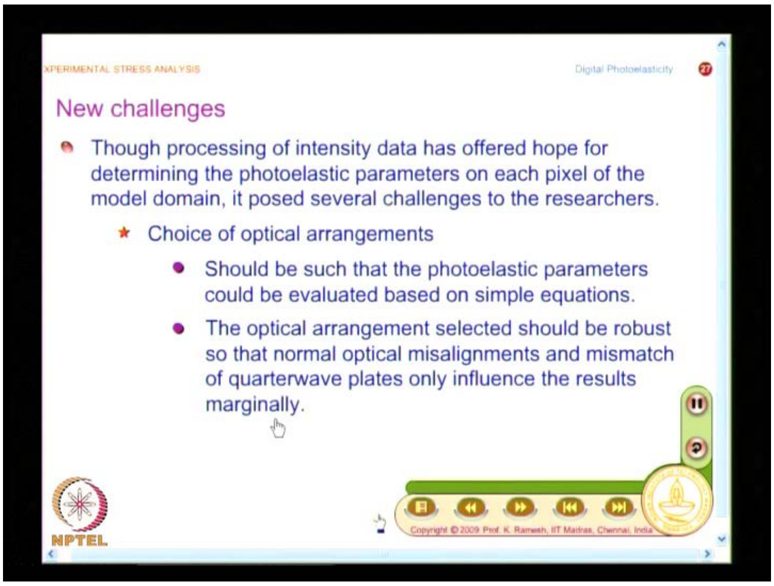

And this posed new challenges. So, what you have here is? Though processing of intensity data has offered hope for determining the photo elastic parameters on each pixel of the model domain that is a focus. We want to find out the whole field information the focus is not just point information, because with advancements in computer technology and also ability to record intensity data conveniently has opened up a very new approach, where in you process the intensity data and what are all the challenges.

The first question is what is the choice of optical arrangements? Because you know you have only bright and dark field so, that is one aspect. The choice should be such that the photoelastic parameters could be evaluated based on simple equations. In fact, if you look at the digital photo elasticity literature (( )) people started coining new optical arrangements and the focus was to evaluate delta and theta and they got equations, which look very complex, because these are all inverse trigonometric functions they have multi valued and identifying the correct value was a challenge.

So, people had full freedom to develop different type of optical arrangements that is how the whole field started, but once you have unconventional optical arrangement you also have the problem of alignment. So, the optical arrangement selected should be robust so, that normal optical misalignments and mismatch of quarter wave plates only influence the results marginally. This is the requirement that you will have to put across. See there is one philosophy once you have digital photo elasticity people also develop sophisticated polar scope, we stepper motor control and also they had put achromatic quarter wave plates. This then the cost of the polar scope is very exorbitant and many institution that have conventional polar scope they cannot go into digital photo elasticity.

Now, the method what we are going to look at the conventional polar scope can be used you just put a digital camera and write an appropriate software. The technique has matured initially people looked at all directions find out what optical arrangements? That they have to choose and they were unconventional. So, they had to develop even new polar scopes, which employs the (( )).

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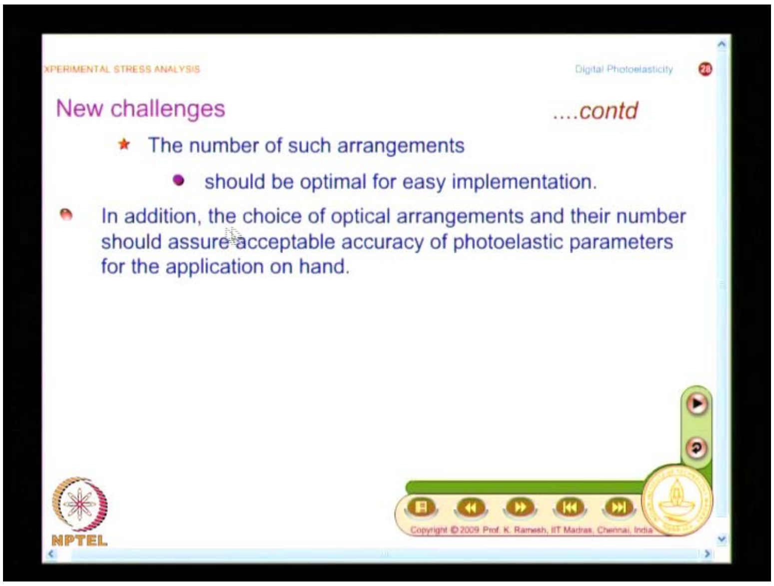

Now, what you have is methods, which uses conventional polar scope also and you also have when you looked at the optical arrangements how many number we have to use? How many parameters that you have? I have to find out the isochromatic parameter isoclinic parameter and the background light intensity. So, three should be good enough, then people found 4 is necessary from accuracy point of view you have to go for the more and more methods.

Now, you have a technique with, which is a 10 step method, which is very robust, which could be employed even in a conventional polar scope you put a ccd camera replace a human eye, and write your own code to evaluate the parameters. The focus is not only the choice of optical arrangements that should be minimal and so on.

The number and this combination has to be selected in such a manner the photo elastic parameters are evaluated with acceptable accuracy is a very key requirement. See you will have to find out… When you have to find out at a point accurately the fringe order you have been taught how to do tardy method of compensation, and by employing tardy method of compensation? You are in a position to find out the fringe order accurately at a point of interest.

Now, what we are saying is you must be able to develop that level of accuracy at every point in the model domain. This is really a big question to ask, we are really putting across a stringent requirement and how this has been achieved. We will have a look at it.

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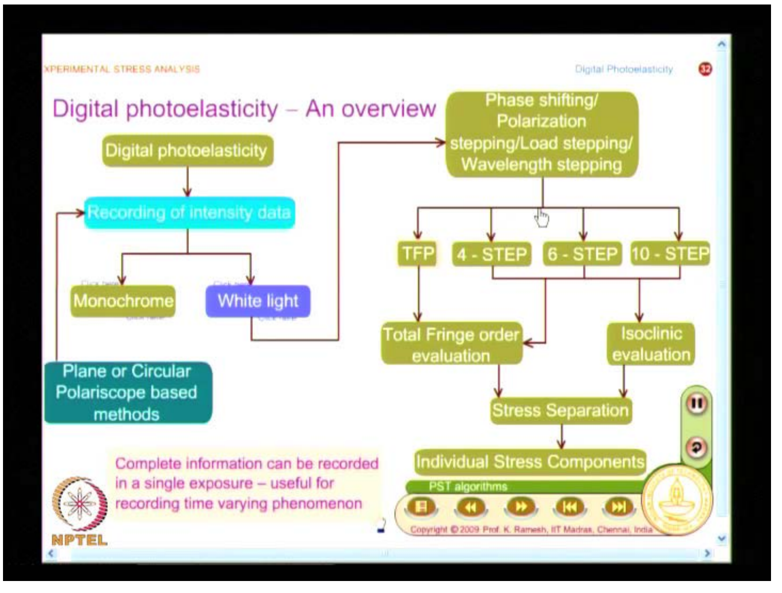

And we will have an overview of what is digital photo elasticity. Basically, you record intensity data and you use either a plane polar scope or a circular polar scope, and you have classification of methods as monochrome based methods and white light based methods and white light is what we have seen? We will also have a look at it what are the sub classification?

In the literature you will find there are phase shifting techniques, there are polarization stepping techniques, there are load stepping techniques and there are also wavelength stepping techniques, and these can be further classified as we have looked at already what is 3 fringe photo elasticity? And when I look at any of these phase shifting polarization stepping, they all will have, we have already noted each researcher came up with particular optical arrangement, and how many steps that he has to use.

So, you have 4 step methods, you have 6 step methods, and you also have 10 step methods, and if you look at the literature you know I said isochromatic evaluation is very, very important. So, initial focus was on methodologies to get isochromatics, only when people looked at we also need isoclinics people found out that, they need more optical arrangements to get this precisely.

So, if you look at TFP it gives you only total fringe order of the isochromatics, it does not give you Isoclinic, but if I go for stress separation I need isochromatics as well as isoclinic evaluation. So, these were possible from 4, 6 or 10 step, but as mention the accuracy depends on what is the optical arrangement? And what is the sequence that I use? And if you look at TFP, it provides you complete information on a single exposure.

So, that is what I showed, we had a problem of heating of aluminum poly carbonate combination and you have a temperature field develop, it is a function of time. So, you also need to look at am looking at static problem or am look at am looking at dynamic problem even in dynamic problems, you can look at slow varying phenomena and ultra fast phenomena. Ultra fast phenomena you have to go for really high speed cameras, and very sophisticated hardware, and those cameras also available, now they are available, if you pay a core of rupees you have those kind of cameras available.

So, we have looked at what are the classifications in white light? You can also look at what are the subdivisions in monochromatic light source? So, here again you have a phase shifting polarization stepping and load stepping you have the 4 step, 6 step and 10 step and these methods can provide you both isochromatic fringe order as well as isoclinic evaluation and what you find is a 10 step method ? Definitely assures high quality determination of parameters and recommended for stress separation studies. Because tress separation studies require high quality isochromatics, and isoclinic and let us look at what are all the features of the ten step method?

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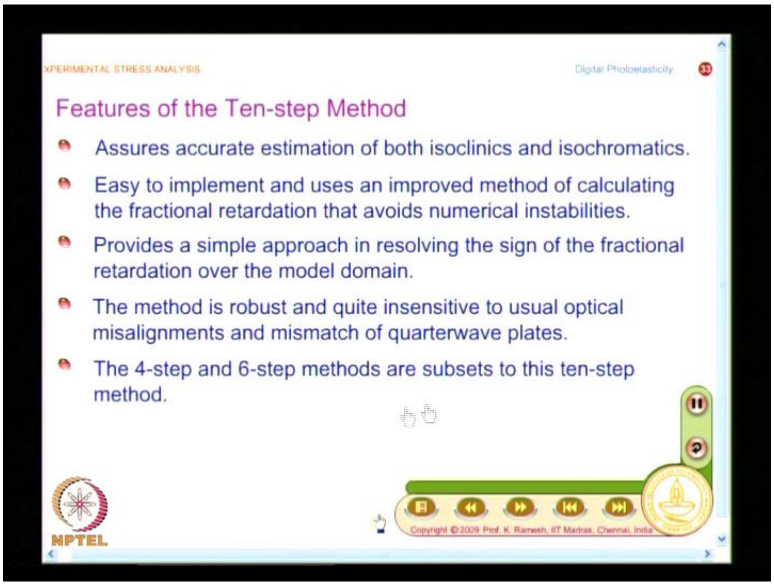

So, the first achievement is it assures accurate estimation of both isoclinics and isochromatics. The methodologies easy to implement and uses an improved method of calculating the fractional retardation that avoids numerical stabilities. In fact, this was a very difficult problem many researchers have looked at it and finally, we have a methodology, it is not? So, simple.

It every point that I mention has taken several years. I am only trying to give you an overview in a (( )) skipping lot of mathematics. I am trying to tell you a just of what is the philosophy behind digital photo elasticity, and it also provides a simple approach in resolving the sign of the fractional retardation over the model domain. Because I have said, that this was one of the burning problem, and in the case of tardy method of compensation. You are able to get the sign of the fractional retardation by looking at whether a higher fringe order has moved to the point of interest or a lower fringe order moved to the point of interest, you had that heuristic information. That heuristic information is no longer there in digital photo elasticity, and this has been solved in a 10 step method very comfortably.

The method is robust and quite insensitive to usual optical misalignments, and mismatch of quarter wave plates, this is also very important. If you say that method demands very high precision moment of optical elements, then you need to go for a sophisticated the stepper motor controlled polariscope, where you are able to precisely align the optical elements.

Where as we have seen compare to all other optical methods photo elasticity was robust all along that was one of it is strong points and we should not take away the strong point by putting lot of restriction on the very precise optical alignment, nevertheless you should try to align it as accurately as possible. But it should accommodate common variations that you come across, and if you look at the 4 step and 6 step methods, they are subsets to this ten-step method. They are not different, if I know the ten-step method, I can know what is the 4 step method as well as a 6 step method.

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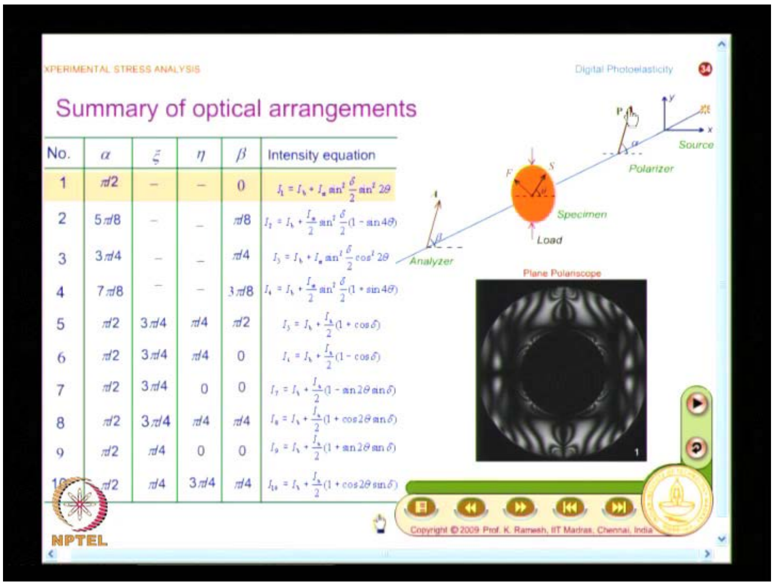

And let us look at the summary of optical arrangements, you know what you have here is I have a plane polar scope. The difference here is keep the polarizer, and analyzer at angles alpha and beta and you know we have found that, if you want to find out isoclinics, you need to use a plane polar scope to evaluate the isoclinic's. So, the first 4 steps of the ten-step method essentially, a plane polar scope, you keep the polarizer, analyzer combination crossed. So, when say phi by 2 0, when say 5 phi by 8 phi by 8 they are crossed positions. So, I take 4 of that.

And you know we will go one after another, you may not be in a position to write the intensity equation. Just observe the philosophy behind it, and what we will see is for each of this optical arrangement, you will have a fringe pattern different. So, we will go one after another. So, this is the nothing but thus I keep the analyzer 0, beta is 0 and alpha is phi by 2 that is polarizer is phi by 2 this is nothing but your 0 degree isoclinic's, that is what you see here.

Then I go to the next arrangement, I have 5phi by 8 phi by 8 isoclinic, and then then I go to phi by 4 isoclinic, then I go to 3 phi by 8 isoclinic. So, what people found is? If you have to find out isoclinic over the domain just record 4 isoclinic values, and you have the equations to find out what is the isoclinic value at every point in the domain very intelligent.

In fact, this was developed long time back, but people looked at it only later, that is simple plane polar scope gives you accurate values, but there are also difficulties you know isoclinics are not defined on isochromatic skeleton. This was the burning problem that is the reason why people went in for wave length stepping? Instead of doing it in a monochrome light source, if you do with a white light source you get isoclinic's with better accuracy. So, you have a ten-step method with the monochrome light source, you also have a ten-step method with white light light source that we have been looking at.

Then the next 6 arrangements are from a circular polar scope. The in intensity equation is appearing slightly differently, but if you look at this is nothing but your conventional bright field arrangement. If you look at this I will have the quarter wave plate introduced, and this slow axis of the first quarter wave plate is labeled as (( )), and the slow axis of the second quarter wave plate is labeled as eta. And if you look at (( )) and eta they are again crossed.

I had mentioned a crossed optical arrangement of the quarter wave plates minimizes the error due to mismatch. So, this knowledge of conventional photo elasticity is also useful in digital photoelasticity, and I also mention by changing the handedness of the input like ellipse they were able to minimize the quarter wave plate. All this is incorporated in the ten-step method. If you look at this the first 4 arrangements I have (( )) as 3 phi by 4, the last 2 arrangements I have this as phi by 4. So, the handedness of the input light ellipse changes it is a circular light (( )). The first 4 positions the handedness is 1, the last 2 position handedness is different. All this is done to minimize the mismatch of quarter wave plates.

And let us look at the second arrangement in the circular polar scope; this is your conventional dark field. So, in a normal polar scope, in conventional method we will only record the dark field or a bright field. We will not record any other patterns, because we are tuned only to looking at fringe pattern. Here you are recording only intensity data and the focus here is I need to get this intensity equation in a form, which is convenient for me to evaluate theta and delta that is a focus.

So, if you look at the other arrangements, you will see unconventional patterns. The interpretation of these fringes has physical information is not possible. They are only representing intensity data. I have the eighth arrangement like this, ninth arrangement like this and tenth arrangement. So, what is important here is? I record 4 images in a plane polar scope, I record 6 images in a circular polar scope and essentially, record ten images and I get the intensity data, which I intelligently process to get the isochromatic and isoclinic.

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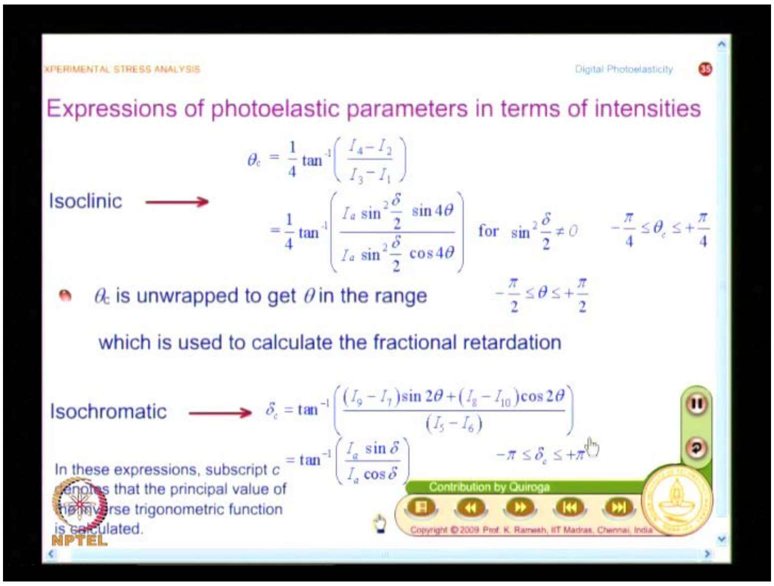

Let us look at the expression, the isoclinic is determined as theta c equal to 1 by 4 of tan inverse I 4 minus I 2 divided by I 3 minus I 1 and what you need to do is? As soon as I get this the recommendation is unwrapped this theta in the range minus phi by 2 to plus phi by 2. Because I had said that identifying the sign of the fractional fringe order was very important and that is very easily sorted out when you unwrap theta in the range minus phi by 2 to plus phi by 2, and use the theta to find out the fractional retardation.

We have seen when I go to compensation technique though my interest is to find out only the fractional retardation. I need to find out theta, then only go to delta the same approach exist in digital photo elasticity also. So, I have the expression for the delta is given and this is given as delta c equal to tan inverse I 9 minus I 7 sin 2 theta plus I 8 minus I 10 cos 2 theta divided by I 5 minus I 6, see to look at this expression looks very simple even this bringing sin 2 theta as well as cos 2 theta in numerical term. In the term at above the denominator was a challenge, you know people have looked at it that it should not the modulation should be high.

So, people coin this and this is the contribution from (( )) and others and that methodology we have popularized and this assures high modulation in the evaluation of delta. So, what you find is you learn the philosophy that I have isoclinic parameter as well as isochromatic parameter evaluated by processing the intensities mathematically, that is the strong point and the unique approach in phase shifting methodologies.

Now, the question is yes I get the fractional fringe order how do I get the total fringe order? I have to do a process called phase unwrapping. All these are very interesting developments; I will just show one more aspect.

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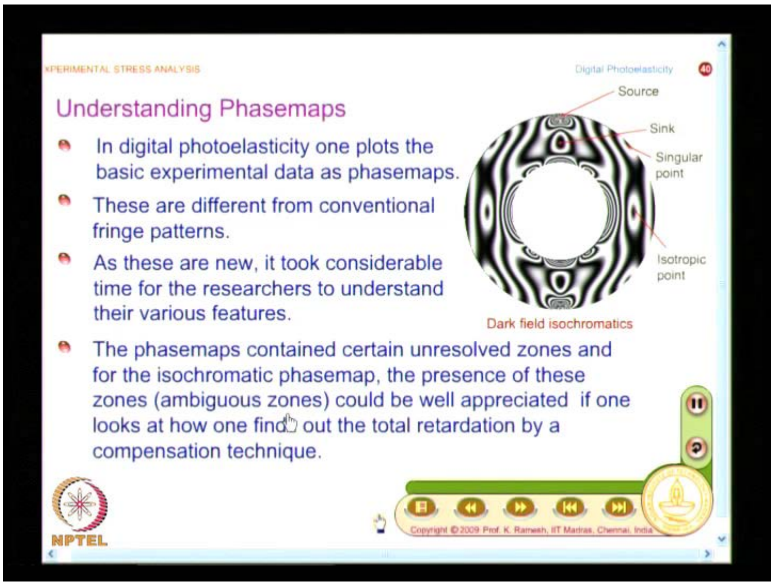

See you have what are known as phase maps? That is what is plotted in digital photo elasticity? And these are different from conventional fringe patterns; you know we have spent quite some time on looking at the fringe pattern of a ring under diametric compression.

This is not a fringe pattern, but it is the phase map and what you see here I have black white and then white goes to black and then it from white it goes to black, you do not have a fringe like situation. Now, I will super impose the fringe and see the difference, you see the fringe pattern. You see the fringe pattern here. Fringe pattern has a variation it has the maximum intensity, then comes down to lower intensity it goes in a oscillator cycle.

Whereas this phase map goes as a step change (( )) form, and we also know from our conventional photo elasticity I have isotropic point singular point sink source and so on. And what you find here is a very interesting aspect, you see in this zone and you see a border line here, and there is a sudden changes in the way the intensity changes. I can just show this this one of the important aspects, I have intensity variation in one fashion here, and I have intensity variation in another fashion here.

And this was a burning problem in digital photo elasticity, and this change comes, because the fractional fringe order sign changes, and this is also related to whether I find out sigma 1 direction uniquely on the domain or you have sigma 2 directions in some portions, sigma 1 direction in some portion whether this was contributing to it. In fact, our group has identified that if you find outs the principle stress direction of one of the principle stress consistently, you do not have the problem of these kinds of distinct zones.

And this is also labeled as ambiguity, and this was resolved by having determined the isoclinic value for a particular principle stress. It could be maximum or minimum that does not make a difference, but it should be consistent on the entire domain and that was achieved in the ten-step method.

And you know all these are new it took considerable time for researchers to understand the various features and what I have shown is? The phase maps contain unresolved zones, these were labeled as ambiguous zones, and for you to resolve this you need to find out theta for a particular principle stress consistently over the domain.

So, now you have the flavor in digital photo elasticity, you process intensity then you should not immediately think… I have a ccd camera I collect the intensity and process it and get the answer immediately. It is not as simple as that. In fact, there were several shuttle issues and researchers across the world have spent time, and try to evaluate it only now, the methodology has stabilized. Now, we can confidently find out isochromatic as well as isoclinic with sufficient accuracy for you to even do stress separation studies.

So, this has given you a flavor of what is digital photo elasticity? We have looked at a conventional method of global fringe thinning in one of the earlier classes. In this class we have looked at two aspects; one uses the color code in a quantitative sense, the other methodology is known as phase shifting technique, when I taught tardy method of compensation I said rotating the analyzer is equivalent to giving a phase step.

So, this was the concept that people exploited to arrive at different optical arrangements. Now, the methodology is well developed. So, that you have confidence on finding out both isochromatic and isoclinic with sufficient accuracy. Thank you.