Experimental Stress Analysis
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Lecture - 12
Plane Polariscope

In the last class, we had looked at what is stress optic law, and we also saw, what is the maximum stress information obtainable from a simple photoelastic experiment? We looked at that we need to find out fringe order N and theta at the point of interest. Then by invoking more circle, it is possible for us to find out normal stress difference, as well as in-plane shear stress. Now, we will have to look at what is the kind of optical equipment that we need to use to find out the fringe order N and theta at a point of interest and before we going into that.

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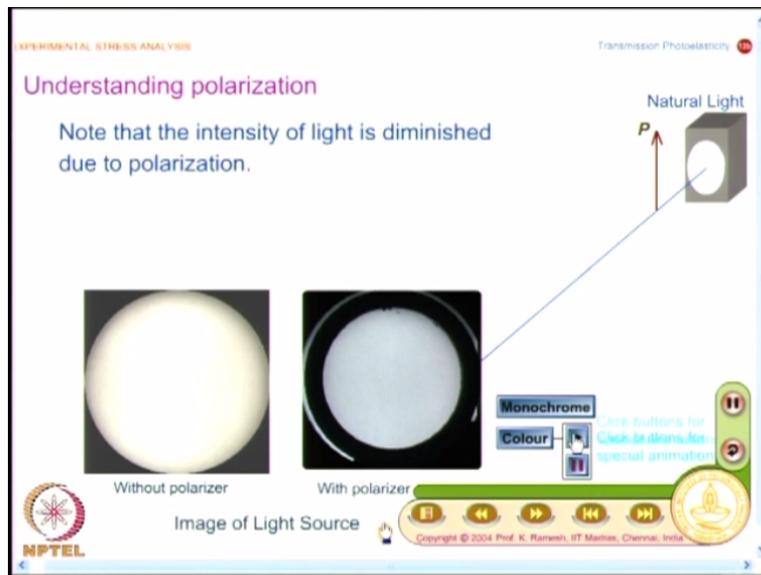
Let us have a look at what we have learnt in understanding polarization. So, here you have a natural light. Then I put a polarizer. It allows only one component of light and I want to investigate what is the status of polarization. I introduce another element which is physically the same and it is kept at different orientations to investigate and when I do this.

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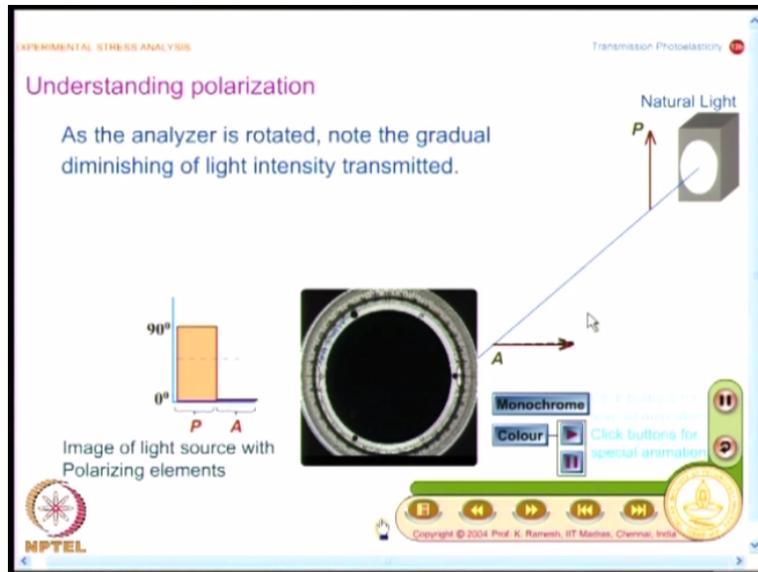
When I rotate this element you find progressively the intensity diminishes and when this axes becomes horizontal that is perpendicular to the polarizing axes whatever the light that comes out of the polarizer is completely cut off by the analyzer. So what we saw was you saw only a black background and another subtle point you need to note here is I am sending a white light. So this phenomenon is independent of wavelength.

We have looked at a model behaves like a full wave plate. When it behaves like a full wave plate it is a function of wave length. When it behaves like a full wave plate it is a function of wavelength, but on the other hand when I have a plane polarized light which is impinging on the model which comes out as plane polarized and this can be cut off by analyzer which is kept at perpendicular to it when the light vector is not a function of the phase retardation reduce.

There is also a possibility to look at the wave in that fashion. Now we will go and look at what happens when I keep a model loaded between the polarizer and analyzer because idea is we want to find out how the fringes get form in a birefringent model that is loaded. So what you find here?

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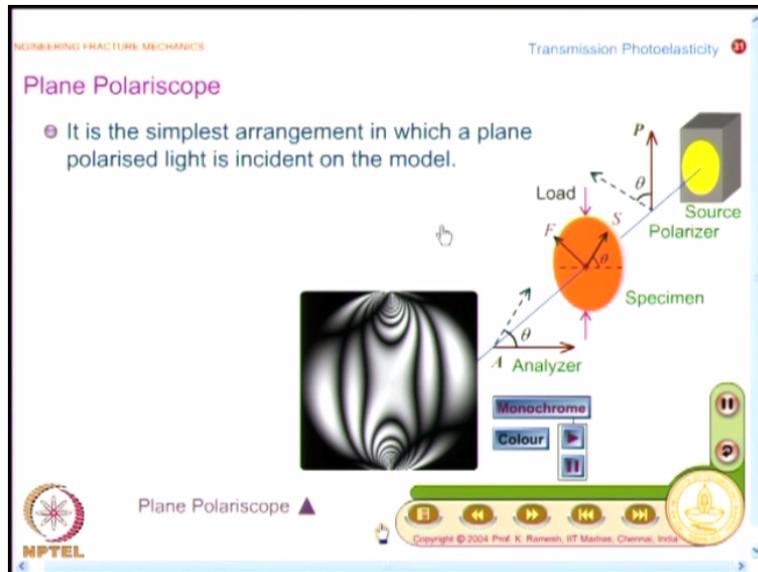
I have a polarizer, I have an analyzer and I am sending a monochromatic light source and I have a model which is birefringent which is loaded, and what you find here you have the background is still dark and within the region of the model you find fringe contours and you need to make a neat sketch of it. You first worry about light source put the polarizer, put the model, and put the analyzer.

And what you find here is this is the simplest arrangement in which a plane polarized light is incident on the model. so what you find here, when the ray hits the model we label that axes as fast and slow axes and we have no knowledge whether this is a fast or slow axes, this is only a representation and I said this matters when I go to digital photoelasticity for the kind of optical arrangements you have in conventional photoelasticity whether it is fast or slow it does not make much of a difference. Then what you find here.

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Once can use a monochromatic light source or white light for illumination. So what I can do is in some monochromal light source I can also put a white light source.

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So what I find here is when a put a white light which is nothing but light source of multiple wave lengths. Now I find one set of contours are coloured the other 2 contour that we saw they still remain black. We will spend some time on looking at this again. We will go to monochrome. Now what you have to understand I have a polarizer and I analyze the light that comes out of the model only by using a simple analyzer with this nothing but a polarizer.

But it is axis is kept differently. So this will only detect whether the light that comes out of the model is plane polarized. If it is plane polarized, in the same direction as the input light then this will completely cut off the light because that will be perpendicular to it, it will completely cut off and when the model can allow plane polarized light as polarized light we have looked at in the wave plate. If the wave plate behaves as a full wave plate, then whatever the light that impinges on the model it goes out unaltered.

So a plane polarized light incident on the model we will come out as plane polarized light which is a function of wavelength. The moment you say because it behaves like a wave plate you will also have to bring in function of wavelength that is the reason why we first look at only monochromatic light source impinging on the model and you also have a very nice picture here see this shows that you have stress is continuous that is the reason why you have a nice continuous contour.

So what I find here is I could have the regions which are black are really those regions where the exit light from the model is plane polarized in the same direction as the input polarized light because the analyzer is kept horizontal perpendicular to the polarizer that light is cut off. So you see this as dark and now the question is I see a 2 dark bands here are the same as these other dark bands or not? So what we will do is we will now rotate the polarizer and analyzer combination keeping then crossed and let us see what happens. So now I rotate them.

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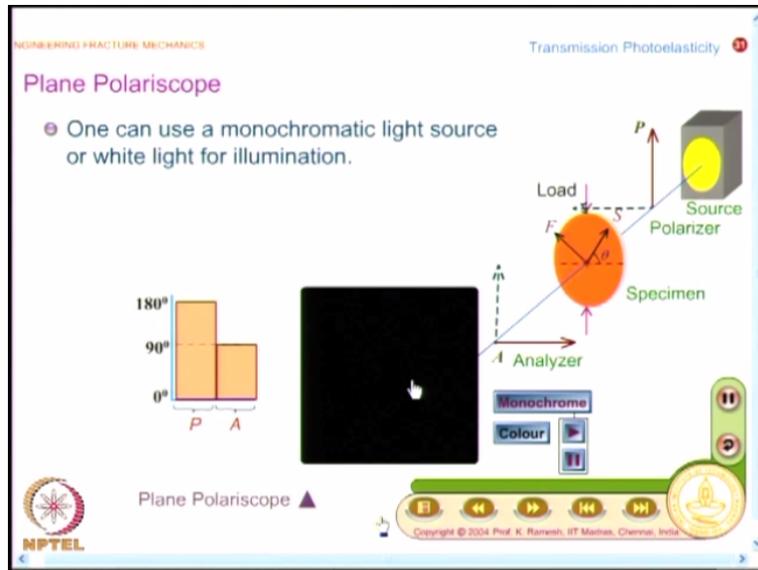
So when I rotate them what is find is one set of contour remains stationary. These contour keep changing and this feed the entire model and what you have here is the dotted line show that you have the polarizer analyzer are rotated they are kept crossed. What can you guess from this? When I was discussing about wave plates I also mentioned if the fast and slow axes coincide with the incident plane polarized light what comes out of the model is simply the same as what is sent inside.

There is no modification and because it is aligning with the fast axes it is not wave length dependent. So even if when I send a multi-wavelength light that will also be cut. We have to verify that statement but you can conjecture this is what happens so what you can now appreciate is when I keep a model in a plane polariscope I see 2 sets of contours. One set of contours where the model behaves like a wave plate.

Why I say multiple contours the model cannot distinguish phase difference is 0, phase difference is 2 pi, phase difference if 4 pi, 6 pi, 8 pi. It cannot differentiate that. That is why I get multiple contours. So one possibility of fringe formation is the model behaves like a wave plate. So the input plane polarized light comes out as plane polarized light unaltered. The second possibility is when I rotate the polarizer analyzer crossed at different points you have principal stress direction.

When it coincides with the principal stress direction at the point of interest whatever the light that is sent that is also cut off. I will also provide further explanation then it will become clear. First make the look at the animation and find out how they are. Now what we will do is we will change the wave length. We will change from monochromatic light source to polychromatic light source. So now I go for a polychromatic light source.

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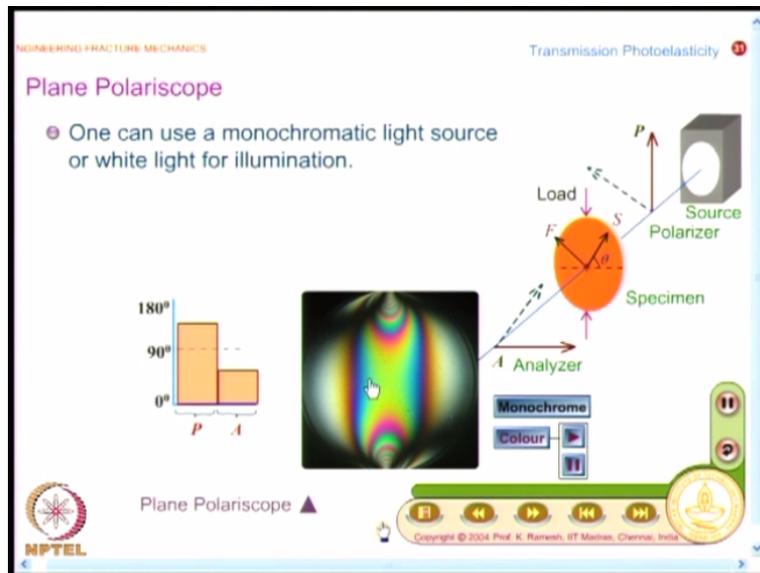
And as I said these are coloured this I have not provided that reason but this I have already provided when I rotate the polarizer analyzer you have this as a black contour. It is independent of wave length because those contours come because your polarizer and analyzer coincides with the principal stress direction at the point of interest. So whatever the wavelength of light you send it comes out as plane polarized.

Because the model need not behave like a wave plate the polarization change is not because of model behave like a wave plate it is because the input polarized light passes through the fast axes. There is no component perpendicular it. So whatever the wave length you send, whatever the light that you send it is cut off by the analyzer because it is perpendicular to the polarizer.

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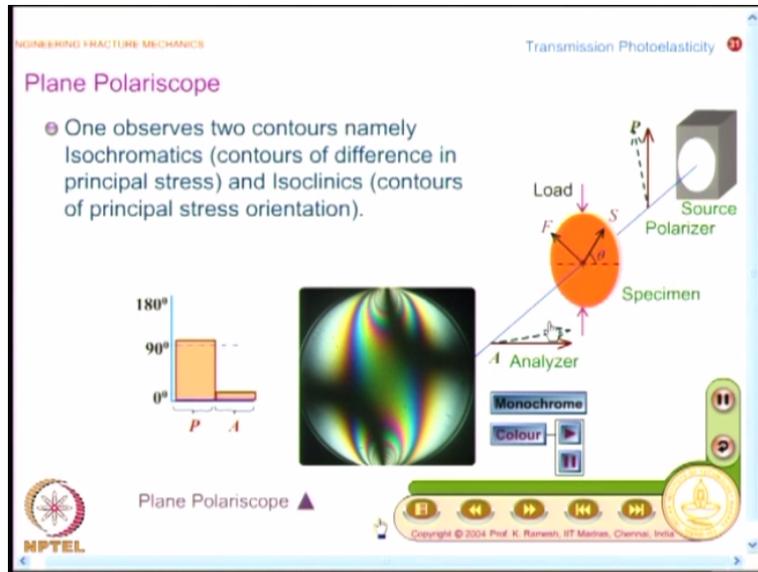
So what you have here is in a plane polariscope it is very clear now one observes 2 contours namely isochromatics, which show contours of difference in principal stress and isoclinics they are nothing by contours of principal stress direction and what happens here when I send when I want to analyze what are isochromatics in a white light source I see them as richly coloured so what happens is you know when I keep the polarizer, when I keep the analyzer crossed.

When the model behaves like a wave plate, full wave plate the input polarized light comes out as polarized light which is the function of wave length so what you see when I send a white light is out of the several colours of white light one colour is cut off because it will behave differently at different points depending on the stresses developed. It may be a full wave plate for red wavelength. It may be a full wave plate for blue wavelength for different values of stress.

So one of the colours is cut off you see the rest of the colours that is why in a polychromatic light source you see the isochromatics as coloured. So you see white minus extension of another colours and isochromatics the model behaves like a full wave plate. When model behaves like a full wave plate wave length of the light also is to be looked at. When the wave length changes it will not behave like a full wave plate.

What behave like a full wave plate for red wavelength will allow some retardation more than 2 pi or less than 2 pi it will not be exactly 2 pi. So what you find here is in a plane polariscope, you

find beautifully 2 sets of contours and now we will also go and develop a logical explanation. Suppose I want to develop the intensity equation you can anticipate that it should be a function of difference in principal stress as well as function of theta.

So you will anticipate if I develop the intensity equation it should be a function of delta as well as theta all that we will look at. No we will again develop this argument in the subsequent slides. We will see systematically.

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Why do fringes get formed? We will try to provide a logical explanation. We have already seen the logical explanation. And this is another verification of whatever we have discussed. to simplify our effort, we will have the light source to be a monochromatic one and what I do is I have a model which is loaded which is kept in the field of view and what do you anticipate because the model is loaded the state of polarization of the incident light changes from point to point depending on the principal stress direction and the magnitude of principal stress difference.

Because when you take a disc and then load it near the load application point you will have very high stresses regions away from it, it will be stressed low and because it is a stress is a continuum what you have is you have an elastic continuum so when you apply the load the variations are smooth that is why you see beautifully smooth fringe contours. Stresses vary gradually from

point to point and you also see smooth fringe contours and what we do is by keeping analyzer we find out when the light is cut.

We find out when the light is cut. The analyzer will cut the light when the plane of polarization is perpendicular to it for the plane of polarization to be perpendicular to it the input polarized light should come out unaltered and in a plane polariscope inconventional photoelasticity we always keep polarizer analyzer crossed. If you go to digital photoelasticity people also tried keeping them parallel keeping that about arbitrary orientation, but in conventional photoelasticty polarizer and analyzer are always crossed.

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So what I have here is the first possibility is light extinction happens when the principal stress difference sigma 1 - sigma 2 is such as to cause a relative phase difference of 2 m pi. where m is 0, 1, 2, etc and this I have taken from a different optical arrangement which is called a circular polariscope for clarity so I see one set of fringe contours and when I send a monochromic beam of light I see this as black and white contours.

Whereas we have defined isochromatics as iso means constant and chroma means colour. Colored isochromatics are seen only when the illuminated source is a white light. So suppose I change the source of light as white, I see them as coloured contours. So you get a fairly good

idea that this how isochromatic contours appear in the case of a disc under diametral compression.

Because stress is varying gradually from point to point and you are having an elastic continuum I see this as beautiful contours and the regions where you have shades of light that is coming in where the retardation is not 2m pi, it will be either less or more than this so it will allow some amount of retardation you will have an elliptically polarized light all of that light will not be cut by the analyzer some light will come and hit the screen.

And we have also seen why a fringe appears as a band only those points where sigma 1 - sigma 2 is 2 m pi exactly you will have this is as plane polarized light coming out and this is cut off completely by analyzer which is kept perpendicular it. In other cases, state of polarization will be different you will also have a component along the horizontal direction that is why you see fringe as a band. There will be some small amount of light which you eye is not sensitive to distinguish and what is the other possibility.

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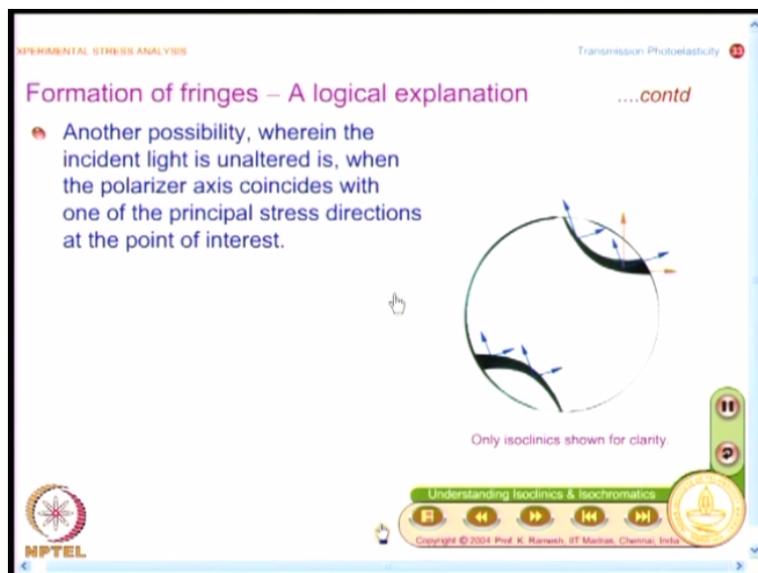
We have seen one possibility we have to look at other possibility. For clarity what is done is I have shown one representative isoclinic and what you need to understand here is I can have multiple branches, I can have one isoclinic here another isoclinic here, I may also have in some

situations a small curve here so what is important here is when the polarizer axes coincide with one of the principal stress directions at the point of interest and what is try to be shown here is.

I have the reference axes shown in brown and these are the principal stresses at the point of interest. Their magnitude may be different, but if you look at the orientation the orientation is same and here again only isoclinics are shown for clarity and in fact there is no unique optical arrangement which should provide only isoclinics. You have an optical arrangement which will filter out isoclinics and show isochromatics which is possible.

We will also see in a circular polariscope and I have always been mentioning in most of the experimental techniques it is desirable to get fringe information separately in some cases you cannot separate them out, in some cases you can separate them out. In a circular polariscope I can filter out isoclinics I can see only isochromatics but in a plane polariscope I will always see isochromatics and isoclinics together.

For clarity of understanding isoclinics are shown here, but there is no optical arrangement that is available to get you this. What you could possibly do is take a photoelastic material which has a very high value of sigma so for the given load applied you may not have significant formation of isochromatics that is the only way which you can see only isoclinics with some level of clarity and.

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Formation of fringes – A logical explanation ....contd

- Another possibility, wherein the incident light is unaltered is, when the polarizer axis coincides with one of the principal stress directions at the point of interest.
- In this case, light extinction is not wavelength dependent and one observes a dark fringe even in white light.
- These are known as isoclinics meaning contours of constant inclination.
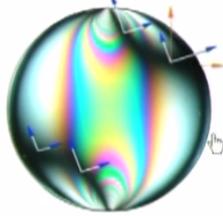
Isoclinics and isochromatics, recorded in a plane polariscope with white light as a source.

You have a picture of the actual fringe pattern seen in a plane polariscope and this is the isoclinic and this is the axes at the point of interest and the orientation of these axes remain constant and I again emphasize when the polarizer axes coincides with one of the principal stress directions light extinction is not wavelength dependent because I do not have another component.

I have only one component passes through so whatever the light that comes out of the model is completely cut and these are known as isoclinics meanings contours of constant inclination and it will take some time for you to appreciate what these contours are. I think the picture is reasonably clear. Do you want me to enlarge it?
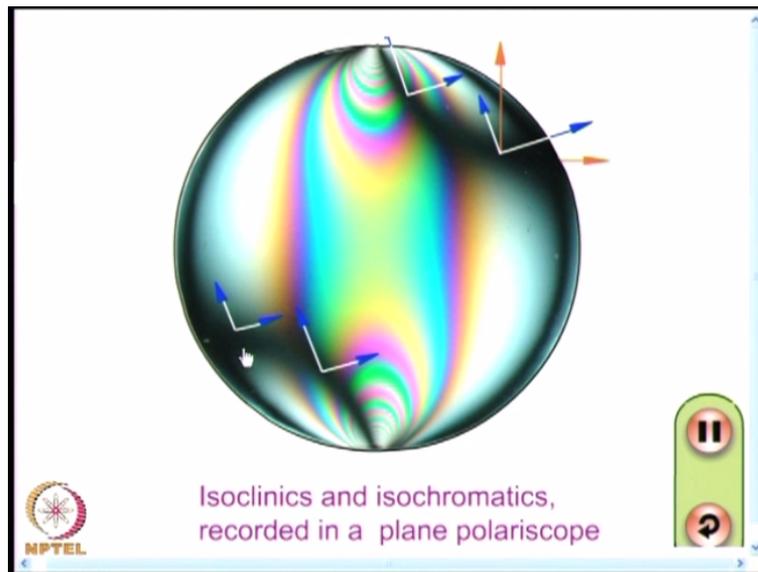
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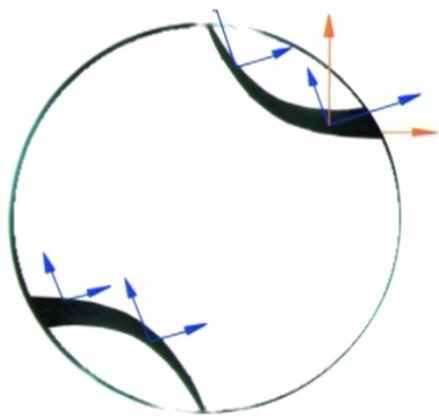
Only isoclinics shown for clarity.

So you can also replay. So what I have initially I have this only isoclinics drawn and you find this is the reference axes and this is the orientation of principal stresses at the point of interest, the length of the vector indirectly indicates its magnitude what is attempted to be shown here is sigma 1, sigma 2 can have different values. The orientation remains constant and if I

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Isoclinics and isochromatics, recorded in a plane polariscope

See what happens in a plane polariscope with white light as illumination I see the isochromatics superposed with isoclinic and this is what you see as isoclinic and we can also have another way of looking at it we will also have.

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Understanding Isoclinics and Isochromatics

- By rotating the polarizer–analyzer crossed combination in steps of 10^0 one can record isoclinics in steps of 10^0.
- For understanding isoclinic field information, it is desirable to plot only isoclinics in the model domain.
- On an isoclinic contour, principal stress direction is a constant.

What way we can represent. What I do is I rotate the polarizer analyzer crossed combination in steps of 10 degrees one can record isoclinics in steps of 10 degrees and plot them and what you have here is.

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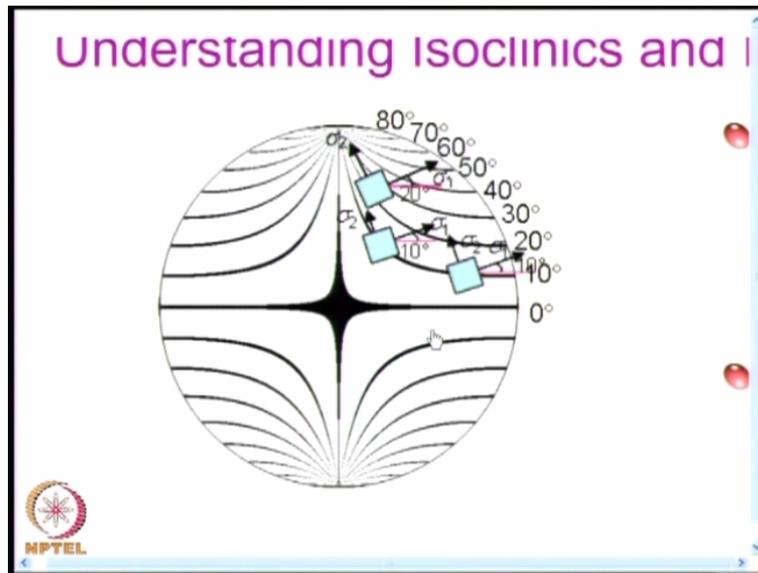
What is shown here is I have an isoclinic here which is labeled as 10 degree isoclinic and what you find here is sigma 1 and sigma 2 can have different magnitudes but the orientation remain constant in this isoclinic and if I got to a 20 degree isoclinic the angle becomes 20 degrees and this you have to extract data by several different positions of the polarizer analyzer combination. You do not see this information available in one experimental exposure.

This is what you have in conventional photoelasticity that is why people said can I plot the isoclinic field for every point in the model domain and digital photoelasticity as now achieved you may have to take a few images and crosses the intensity and it is possible for you to generate plots of this nature by post processing the data acquired. In a conventional polariscope I have to keep it as 0 degrees, 10 degrees, 20 degree, 30 degrees.

And for each of them go and carefully draw the isoclinic sketch and there is also something very interesting I will not give you the answer see this is the circular disc for which you are given the stress field equation and you can find out what is the principal stress direction at every point of

interest and there is something very interesting this isoclinic meets at the point in the boundary. It will meet only at a specific point.

And this will also enhance your understanding of solid mechanics go back and look at what point it can meet go back and because this is the free surface. You know this is the free surface and this isoclinic has to come and cut at only at one particular point which you can look at from solid mechanics that will give a very interesting result. Take that as a home exercise. So what you have as isoclinic is little subtle and for me to get plots of this nature.

I need to conduct a series of experiments and from that you record them carefully in a conventional photoelastic analysis and we will look at what are isochromatics. We have looked at what are isoclinics we will look at what are isochromatics.
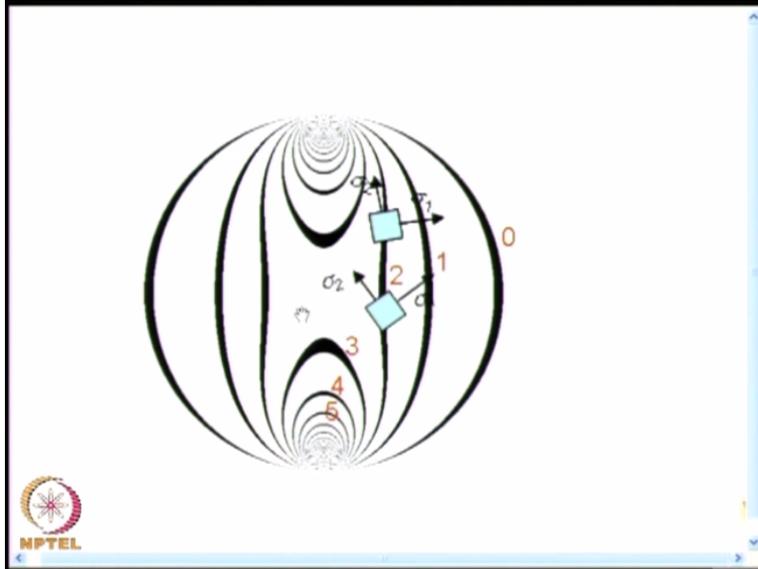
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These are the isochromatics and what you have here is the direction may be different, but the difference of sigma 1 - sigma 2 will remain same on an isochromatic contour.

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So that is the only difference. Direction will not remain same here. direction will keep changing from point to point, but the difference of sigma 1 - sigma 2 will remain the same and this you can actually put it one of your earlier contours you do not have to redraw this you have one of the isochromatics on that you can put this information.

So what you find here is on an isoclinic contour, principal stress direction is a constant on an isochromatic contour the magnitude of sigma 1 - sigma 2 remains a constant, but the individual values of sigma 1 and sigma 2 and their orientation theta can vary. So we have exhaustively looked at from a qualitative argument what are isochromtics and isoclinics.

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And now what we have to do is we have to go and look at can we establish mathematically that whatever we have looked at from a logical explanation and find out what is the equation of intensity of light. For that we need to go and develop the mathematics and the simplest way to do is doing a trigonometric resolution and what we will do is.

Let the linearly polarized light coming out of the polarizer in general is Ke to the power I omega t because I can have a cos omega t and sine omega t terms. For the purpose of this discussion, we will consider only the real part. When we go to Jones calculus we will retain as K e power I omega t and let us look at how we can label the axes when the light passes through the model and we will also have a larger picture of it.

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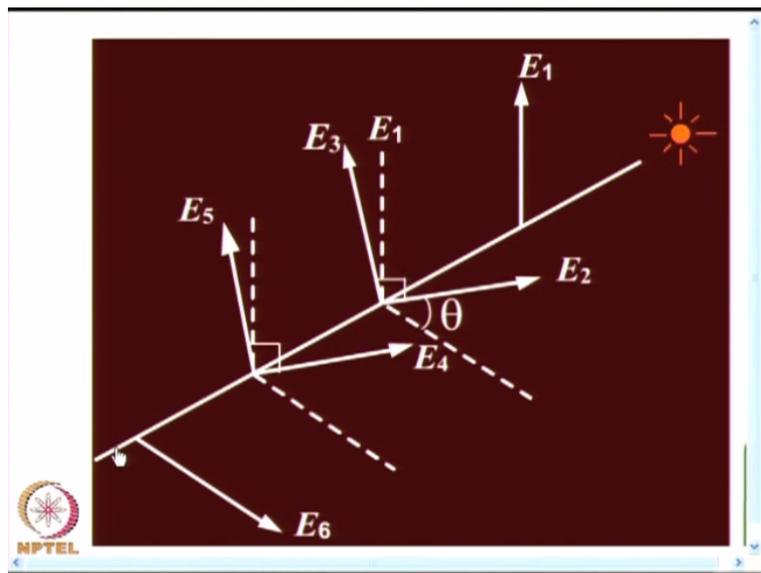
So what I have is I have light source and the first optical element I have is polarizer which is labeled as E1 then what happens you have the model which is shown with enlargement here that I have this is the point where light enters the model and this is the point via light exits the model for clarity these are shown distance apart and at the incident plane I will have 2 axes we will label them as E2 and E3.

They are essentially slow and fast access at the entry point and these axes will remain because I am looking at a 2 dimensional model essentially it is a plane for convenience we have some finite thickness for clarity this is shown as enlarged. So you will have 2 axes E4 and E5. Then I

represent the analyzer which is kept horizontal the polarizing axes of analyzer is horizontal and I put this axes as E6.

So what I need to do is I need to write the light vector for even find out how do I write the right vector as E2 and E3 then I have to find out how to E4 and E5 then finally I will have to look at only the component E6 that is filtered by the analyzer. So if I do all that I will know what is the exit light that is coming out which I could simply and then find out what is the intensity of light transmitted and we have already anticipated that it should be a function of delta and theta.

If you get that then all our qualitative argument fits nicely with the mathematical development and because it is a very simple optical arrangement trigonometric resolution is very comfortable and simple and also provide you a level of understanding which you will not get otherwise. So we will go by a trigonometric resolution. Later, we will also analyze the same problem by using Jones calculus and you will find Jones calculus is very comfortable when I have several optical elements in the optical bench.

Here I have only a polarizer model and analyzer it is very simple, so trigonometric resolution is quite alright and we will see how we do the trigonometric resolution and what will do we will simply say E1 as k cos omega t. So I have an amplitude, I have this as cos omega t and you have to recall when we discussed retardation plates. This is the input polarized light that hits the model as.

As soon as it hits the model you have the amplitudes split along directions E3 and E2 so you can write what is E2 and also what is E3 it is fairly simple. You make your own attempt then I will show you then what you have is when it hits the model, model is loaded so for one incident light you will have 2 refracted beams. Because of this orientation, this is 90 - theta here so I will have a component will pass through E2 and another component will pass through E3.

Essentially the amplitude will change. So I have this as k sine theta cos omega t and E3 as k cos theta cos omega t. it is fairly simple. If you recall the discussion that we had on retardation plates we spent sufficient time on looking at what happens to the incident light when it hits the model

and what happens within the thickness of the retardation plate a similar thing we will have to look at here.

So for directions E2 and E3 we are able to write the light vector comfortably and how do you write for E5 and E4, E4 and E5. These are the axes at the exit of the model. So within the model the light has acquired a relative retardation. Suppose I say retardation is delta I can say no retardation along direction 4 and full retardation is in direction 5. I can also put 0 and delta, I can also put delta by 2, - delta/2 and + delta/2.

This is for our convenience. Keeping in view that I am going to develop Jones calculus where the matrices will look nicely we will take the choice of - delta/2 in the slow axes and + delta/2 in the fast axes that is just for convenience. Mathematics is not going to change. So that is what we will do now.

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So what we say is the model introduces a phase difference delta and let E2 be the slow axes and E3 be the fast axes of the model and E2, E3 are the if it is slow and fast E4 is slow and E5 is fast and we want to do it for E4 which is considered as a slow axis so what I will do is the same amplitude of that will not change but the phase I subtract - delta/2 and on E5 I add + delta/2. So what I have here is E4 turns out to be k sin theta cos wt - delta/2 and E5 is k cos theta cos wt + delta/2.

So do you understand the way that we go about in writing the changes in the light vector as it passes through different elements of the polariscope. We start after polarizer when it hits the model we look at we do not look at it as one plane we look at hits the model at the front surface leaves the model at the other surface. Theoretically, when you are looking at a plane model it is as thin as a plane, but physically we use a finite thickness.

So we bring in some engineering approximation and we also say that the principal stress direction remains constant within that thickness and we do this as 2 operations first there is the intensity, the amplitude of the light vector changes. The second case we put appropriately the retardation then it comes out. When it comes out of the model this E6 what it will do this is nothing but your analyzer.

This will allow only component of light that is parallel to this. For any other component if it is perpendicular to the, if the light vector is perpendicular it will completely cut off so we want to write an expression for what is the light transmitted by E6. that is very simple I have E4, E4 you know this angle I can find out what is the contribution from E4 and what is the contribution from E5 can you write E6 can you write what is E6.

So what we do here is because the optical arrangement is very simple we are in a position to do trigonometric resolution and stage by stage we are able to incorporate what changes that happens to the incident light vector and we know E6 will pass only the light component parallel to this we write an expression for E6 in terms of E4 and E5 it is fairly simple E4 cos theta - E5 sin theta and which is also simplified if you go back I said for all this you need to have knowledge of trigonometric identities. It is a very simple step.

It is not difficult at all. So you take this component E4 multiplied by cos theta, multiply this by sin theta and do a simplification. This is the component of light that is transmitted by the analyzer that turns out to be k sin 2 theta sin delta/2 * sin omega t. So what we have anticipated we have anticipated that this should be a function of delta which is related to sigma 1 - sigma 2 and theta. So I have k sin 2 theta sin delta/2 both are appearing, but what do you record. I do not

record the complete light characteristics all the sensing elements are sensitive only to the intensity not the complete light vector. So that we will have a look at it what happens.

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Human eye is also a light sensing instrument. Human eye and all other light sensing instruments respond to the intensity of light it is a very key concept why we always look at intensity of light is because we respond only to this and there is a relationship. The intensity is proportional to the square o the amplitude. The intensity is proportional to the square of the amplitude and this is a point to clarify you have rapid time variations which cannot be detected and for a sodium light we have the frequency as 5.1*10 power 14 Hertz.

So you do not perceive the time dependent component and you are sensitive only to the intensity of light transmitted and intensity of light transmitted is square of the amplitude. So what will have to look at is, we have got the E6, we will look at this E6 expression and we will square the amplitude and find out what that expression gives. So that will give you beautifully an explanation what we see as fringes in a plane polariscope and I am not going to do the complete derivation.

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Trigonometric resolution   *....contd*
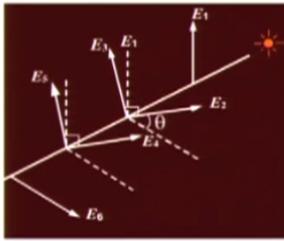
- The rapid time variations cannot be detected and for a sodium light, the frequency f is 5.1×10^{14} Hz. Hence the time dependent component is usually not considered.

- The intensity of light is obtained as

$$I_p = I_a \sin^2 2\theta \sin^2 \frac{\delta}{2}$$

I_a accounts for the proportionality constant and the amplitude of incident radiation.

I am going to give you the final result which you have look at it and you can actually go back and do this as your home work and I label this as IP, the P denotes this it is a plane polariscope and I get the final expression as Ia sin square 2 theta sin square delta/2. So, we have with very simple mathematics we have been able to find out what is the intensity of light transmitted in a plane polariscope when a model is kept loaded.

And we have said this intensity is proportional to square of the amplitude whatever you have put as Ia it accounts for the proportionality constant and the amplitude of incident radiation. So, now we have to investigate when does this intensity expression goes to 0 so it can happen for 2 cases. I can have a situation where sin square delta/2 goes to 0 so those contours correspond to sigma 1 - sigma 2 they are called as isochromatics.

You can have another possibility where theta goes to 0 when theta goes to 0 essentially means the polarizer axes coincides with the principal stress direction at the point of interest. When it coincides you have only one light beam travels through the thickness of the model that is completely cut off and this is independent of wavelength when the incident light coincides with the polarizing axes at the point of interest which is nothing.

But the principal stress direction it gets cut off and it is independent of the wavelength the light getting cut off is independent of the wave length. So that is why you see 2 contours and the

isoclinics appear black even in white light. The difference is when I rotate the polarizer analyzer combination these black contours also move and you know there could be questions like suppose you are given a plane polariscope how you will identify whether is an isochromatic or isoclinic.

What are the ways that you can think off, I have said one which you can easily derive? You keep the polarizer, analyzer combine and rotate it. When I rotate it one contour will move with it that is isoclinic. Can I make the other contour to move why do you say no? You have to say what is that I have to do. Suppose I change the load what will happen when I change the load does the principal stress direction change? Then you have to go back and brush up solid mechanics.

See in linear elasticity when I increase the load, stress magnitudes change, principal stress direction do not change so that is why always say when you learn experimental stress analysis your fundamentals of solid mechanics become clearer and clearer because certain things you assume you think you know when you are confronted with the question you do not know what is the answer.

So I can also make the other contour move if I change the load the contours that are functions of the load are isochromatics the contours are not functions of the load are isoclinics because isoclinic will not change, should not change in linear elasticity they will not change. So that is the way you distinguish between isochromatic and isoclinic even in a plane polariscope with simple monochromatic light source.

If you are given a white light source you have a luxury, I see coloured contours and then I have black and white contour but there is only caution I do not this is not very prominently seen in a circular disc the zeroth fringe order is always black. So, you have to distinguish even in a white line source what is zeroth fringe order and what is isoclinic. I have to make a distinction and though in general fringes move.

When I apply the load what will happen to the zeroth fringe order, think about it. See for every rule there will be an exception. There will be rule and there will be exception you should understand both you should know the rule as well as the exception and why it is so. So, this is

what you will have to understand. So in this class, we have started looking at what is an optical arrangement that we need to conduct a photoelastic experiment.

And we said that a simple incident of plane polarized light is good enough and I get 2 contours one contour corresponds to sigma 1 - sigma 2 for which I have to find out the fringe order right now we have not discussed how to find out n that we will keep it as a separate discussion. First time we have seen fringes and we have classified one set of fringes as isochromatics and another set of fringes as isoclinics how to find out n.

How to find out theta we will have separate discussion. Now what we will do is we will go and develop our mathematical skills better because we want to go for a circular polariscope where I will have more than one optical element in the path of light and for me to analyze trigonometric resolution is not convenient. I need to develop a special type of calculus called Jones calculus that we will take it up in the next class.