Dynamic Behaviour of Materials
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Lecture - 26
Shock Wave Interaction and Reflection

Hello everyone. So in the last lecture we have discussed about attenuation of shock wave. This lecture we will focus on interaction and reflection of shock waves. So we will discuss about how, what happens when a shock wave enters from one medium to the other medium and also what happens when it reflects from a free surface or what happens when two shock waves interact with each other.

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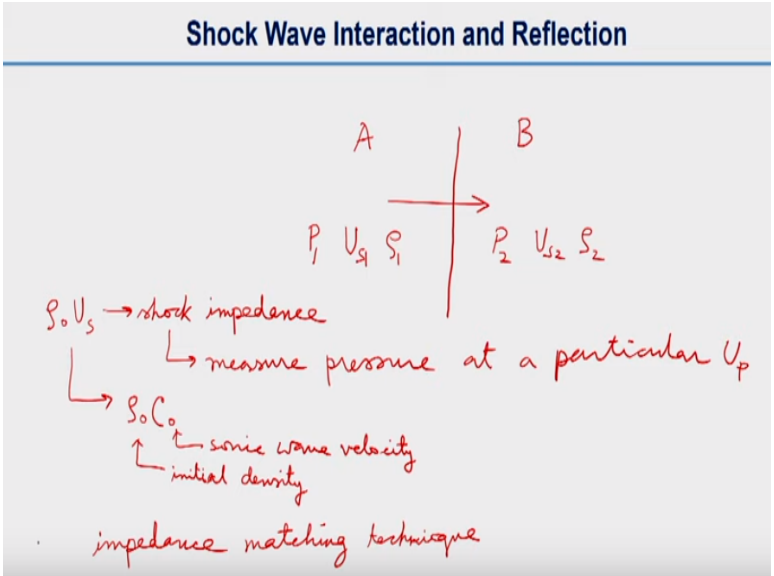

So first we will see when a shock wave enters from one medium to the other medium. Let us say we have a medium A and this is the interface and this is the medium B. So what will happen when the shock wave enters from one medium to the other medium the pressure shock wave velocity, density. So these parameter will change in the other medium. So if we write P 1, U s 1, rho 1 in this medium.

So here it will be P 2, U s 2, rho 2. The shock impedance concept we will here introduce. Shock impedance is rho naught U s like our sonic impedance. So this is shock impedance of a medium. So this shock impedance gives a measure of pressure at a particular particle velocity, at a particular U p value. And this can be approximated as rho naught C naught, with an approximated rho naught C naught.

C naught is the as we know sonic wave velocity, sonic wave velocity and then rho naught is the initial density. So this is we know that initial density of the medium. So in these problems from transmission of shock waves from one medium to the other medium, so we will be using shock impedance matching method. So impedance matching technique will be useful to calculate the shock transfer from one medium to the other medium.

So this is the method, the graphical method we will be working on. So now we will discuss two cases.

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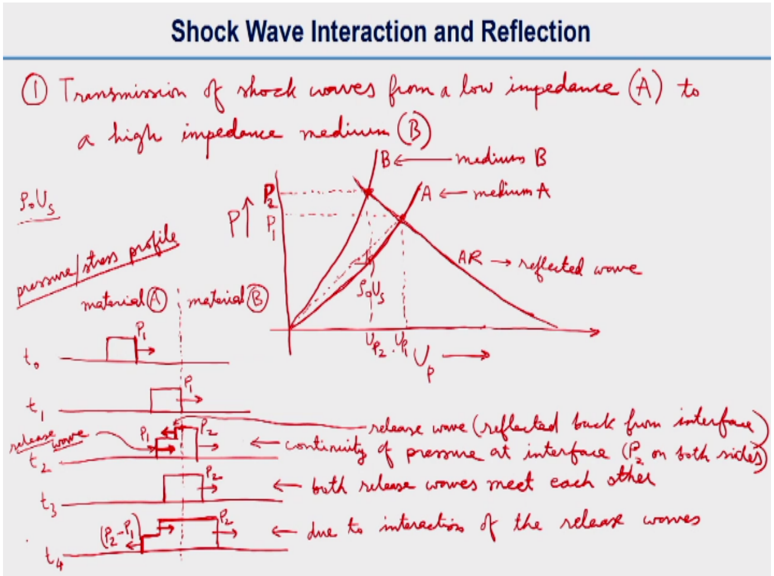

Case number 1 is transmission of shock waves from low impedance medium to high impedance medium. Transmission of shock waves from low impedance let us say we assume that we name them that is A to from A to a high impedance medium, high impedance sorry high impedance medium. Or you can call high impedance material. So for this case, what we can do is for this problem we can first draw a pressure particle velocity plot.

So this is y axis is pressure and x axis is particle velocity. So we have two mediums as we have written here. The low impedance medium the P U p plot from the experimental data. So this is let us say medium 1 and that we know that the shock impedance rho naught U s will be the slope of the line at a particular pressure. So what we will we told that, that the shock impedance is a measure of the pressure at a particular velocity U p.

So if you have this pressure P 1, if you have a pressure P 1, so the shock impedance of this material A will this slope of this dotted line. So this will be the slope will be rho naught U s. That is the shock impedance of the material A. So if you draw the curve for the high impedance medium, high impedance medium. So this will look like this, this is high impedance medium with a higher slope shock impedance. So now we will draw the reflected wave.

That should be a mirror image of the curve A because the reflected wave will be exactly opposite, it will follow the opposite path. That means the variation of pressure and particular velocity will be kind of mirror image to what we got for the curve A. So how we can draw is we will draw the curve like this, although it is not perfect, I hope you can understand this.

So this curve the curve A and curve this one, we will name them that as AR. So that should be kind of mirror image, approximately a mirror image and it will cross the curve B and that point will be corresponding to P 2. That is the pressure of that medium B. AR is as you know, the curve for reflected wave, reflected at the interface of medium A and B.

This is for medium A this curve and this curve is for medium B or we can write material B. So if we draw the pressure profile or stress profile so we will not draw the pressure or stress profile of this transformational way. So what we can do is at time t naught, let us see, we have I am writing this vertical dotted line, which is the impact interface. At time t naught pressure pulse is this is the shock pulse.

It has a steep shock front and the pressure will be P 1. So this is the shock wave. This actually we should write that this is material 1 or medium A and other side of the interface this is material B or we can write medium B. So what will happen after some time at time equal to t 1, this shock pulse will hit the interface, will hit the interface and then at let us say time t 2.

So what will happen is the pressure will increase as we can see here it was still p 1 and here we have the pressure will little increase as you can see from our P U p plot the pressure will be P 2 now. So here if you can see from the above diagram, this pressure here is P 2. So here it is P 2 and the then the original pulse will still be at P 1. So this is at P 1.

And it is important to note that the release wave, we discussed in earlier lectures about the release wave. So this release wave will still travel towards the impact interface. So this is I will write it somewhere, this is the release wave I will write it somewhere here, release wave. This one is the release wave and so at time t 3 what will happen is this wave, so better we will again redraw this part little bit.

So why I have redrawn because I did not show the reflected wave from the interface here. So that I will show you. So this there will be a wave which will reflect back from the interface and that will also maintain a pressure P 2. So that reflected wave reflected back from the interface of the low and high impedance medium. So that will interact with the release wave which I have shown earlier.

So both of them are actually we can call them a release wave. But the first one is the release wave. This one is the release of the primary wave and the second one this which is traveling from right to left is a release wave I will just you know show with a arrow here. So this is the release wave that is reflected back from interface, from interface. Now what will happen, this two waves will interact.

The release wave from the primary wave and the release wave from this the reflected from the back surface, they will interfere and then this will now look like this with a pressure P 2. So now after some time that t 4 when this will meet, so in this case the both the release waves meet each other or both release waves both the release wave meet each other. That result is we can see at time t equal to t 4.

This will move forward in the medium B and so this the release waves will move from left to right and then part of the other wave. This is the result of the interaction between the both the release waves. So which is P 2 minus P 1. The P 2 – P 1 is the pressure of this part of the wave. And the other part is still at pressure P 2. So this is results from the pressure decrease, which is from P 2 to this P 2 – P 1.

It results due interaction of the two release waves. So as you know one is release wave of the primary wave and the other one is the release wave of the reflected wave back from the interface. So it is important to mention here that there is a continuity of pressure at the interface. So that we can see at time t equal to t 2. So if you see the interface in this point we can show that continuity or pressure at interface.

That means the pressure will be P 2 on both side, both sides of the interface so that continuity will be maintained.

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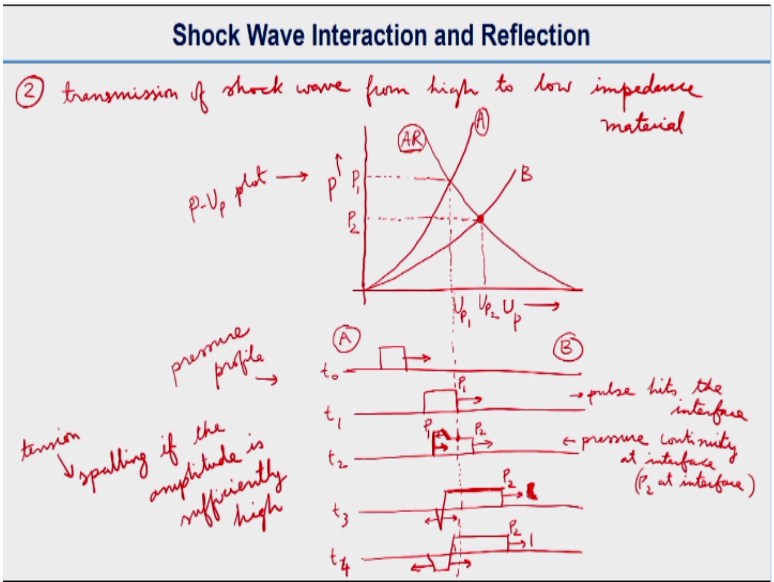

So now we will discuss about the case number 2 which is the opposite case that is transmission of shock wave from a lower impedance medium to a higher sorry from higher impedance medium to a low impedance medium. So we will see what happens in that case. Transmission of shock wave from high to low impedance material okay. So in that case, so if we want to draw a P U p diagram, pressure particle velocity diagram.

So let us draw the medium A which is at high impedance has a high impedance and then we have a medium B which has low impedance. So now if we have a reflected wave curve which will be a mirror image of the curve for the medium A. So this is let us say AR that reflected wave and then let us say this is at pressure P, P 1 in the medium A. And because the A curve will cut the B curve at a point this point.

So the pressure at the medium B will be P 2. I am repeating again. This curve AR is a is an mirror image of the curve A and it cuts the curve B at point which is corresponding to pressure P 2 and if we can have this particular velocities. This is we can say that this is U P 2 and this is U P 1. In the previous case, sorry I did not mention I think. These particular velocities are I forgot to mention here.

So this is U p 1 and U P 2 the two mediums the particle velocity values here. So now in this case, so if we want to draw the pressure stress or pressure profile, so what we have drawn now is P U p plot pressure U p plot, this one. And then if you want to have a pressure profile or stress profile, you can call that a stress profile as well. So what will happen is, we can take this as the interface that is the interface as you can see from P U p plot this is the interface. It will continue like this.

At time equal to t naught, so the pressure pulse as a shock wave pulse is moving towards the interface. So we have left side is medium A or material A and the right side is material B or medium B. And at time equal to t 1 this pulse will hit the interface. So we can write even here that pulse hits the interface and then t equal to t 2. So what will happen here is at pulse, at time t equal to t 2 what will happen is this pressure on side B or in material B will be less.

As you know this pressure will be P 2. Earlier it was P 1 which is higher than P 2 and in this side in this side it should be actually smaller here. In this side it will look like this. So what will happen here is this part of the pulse will come towards the left side and the release wave is traveling towards the right side. So you can see at the interface, this interface there is a pressure continuity at the interface, pressure continuity at the interface.

That means pressure is P 2 on both the sides and this pressures is P 1 the higher pressure and this is at interface P 2, at interface on both side. So that is the pressure continuity and as you can see these two waves which is that means from this is the reflected wave from the interface that you can see it does not have a stiff front so that is actually not exactly a shock wave, it has a inclined front.

And the release wave of the primary wave which is traveling from left to right and these inclined front is traveling from right to left, so these will interact. So what will happen? This will when it will interact, it will form a tension. So it will form, when these waves will interact it will form a tensile wave. So at this point it will have a tensile wave. So that is why I am drawing below that reference line.

So this will be tensile wave and that tensile wave will be at time t 4 this will propagate. What will happen is so we have the pressure P 2. We should not have drawn the pressure P 2 in the front. It should be showing at the pressure level or we cannot I think we will cut this here. So that tensile pressure, tensile pulse will propagate at the material A. So that tensile pulse or that tension can lead to spalling if the amplitude is sufficient, sufficiently high.

So that we can see now. So what happened in this second case, the first case we did not see a tension behavior or spalling kind of behavior. In this case what happened transmission from shock wave from higher impedance material that is A to a lower impedance material that is Be. So it shows that when the release wave from the interface interacts with the release wave of the primary wave that can interact to form a tension.

And that tension, tensile wave if sufficiently high amplitude can cause spalling. That means it can lead to failure. So we will quickly see a problem involving this wave transmission from one medium to the other medium.

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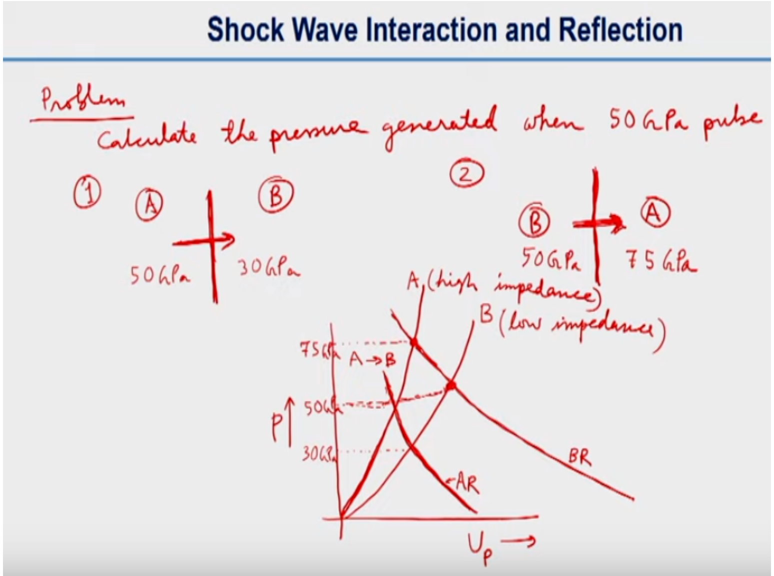

Let us assume this. We need to the problem is, let us say we need to calculate the pressure, the pressure generated when a let us say some 50 GPa pressure pulse is traveling from material A to material B. So what will happen here is we have a material B and material A. So we will consider both the case. First case is let us say from A to B. And in the second case we will assume the other case.

Let us say second case is from B to A and this is the interface, this is the interface. So we can draw the P U p diagram, that is pressure particular velocity diagram from experimental data U p diagram, P U p. So what we can do is we can have this curves let us say this is curve A and this is curve B. When the material travels in the case A from A to B. Let us say we will draw a curve which is mirror image of A, we will draw a curve mirror image of A. It is something like this, mirror image.

These two this one and the other one although my diagrams are not very perfect, but you can assume it to be mirror image. So that means that means these this is the first case which is from A to B transmission and this is the reflected wave. So in that case what happen the pressure which was 50 GPa now cuts the medium, this curve, reflected wave curve cuts the medium at this point.

Let us assume that this is 30 GPa. So what will happen is the pressure which is initially at 50 GPa here will be now in the medium, it will be 30 GPa. In the other case, what we can do is, we can draw the reflected curve as something like this. So it will be reflected curve will be mirror image of B. We will draw a mirror image of B. So the mirror image of B is this reflected curve.

Or we can even name both of them. What we can do is let us say we can reflect it first, but the first case we can give the reflect AR as name and this is it let us say we can give BR as the name. So now what will happen? This is a second case from B to A. So that pressure should be same 50 GPa, sorry this is a little bit higher and this would have been at 50 GPa.

So what will happen is this reflected curve will cut through this A curve at this point and this pressure let us say this pressure is something like 75 GPa. Now what happens? So this in this case, if you have a 50 GPa pressure from medium B which is entering medium A then pressure will increase, because it is the now 75 GPa at low impedance; this one is low impedance. And then medium A has high impedance.

So in the same figure we can show both the transmissions from medium A to B and B to A. So now I think it is clear from this problem. Then we will talk about superposition of two waves that is intersection of two waves.

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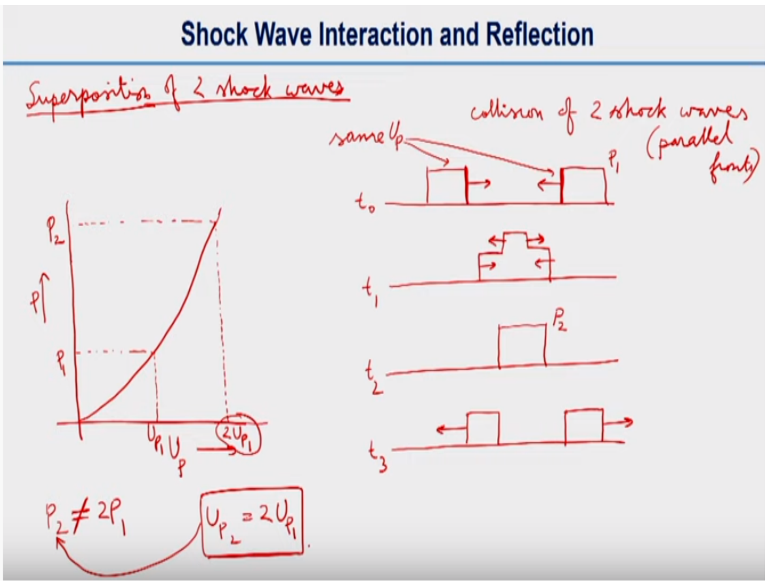

So what will happen two shock waves interact with each other? Let us assume at time t equal to t naught we have two shock waves approaching each other. And we can have let us the pressure is P 1. And when we will interact, encounter each other, this will be look like something like this. So these two are release wave and after interacting it will this will reflect back.

So at time t 2, time t 2 this wave will look like this and then at time t 3 this will be separated and this will both the waves will go back away from each other. This is at time t three. So what we can do in this case this is actually what we are talking about the collision of two shock waves and we can see they have shock waves they have parallel fronts. That you can see these fronts are parallel to each other.

So now what we can do is we need to find the pressure P 2. How we can find the pressure P 2? We need to add the particle velocity of both the waves. Let us assume both have same particle velocity. Then we will add the particle velocity of both the waves and then correspondingly we will obtain the equivalent pressure which is the corresponding to the addition of both the particle velocity. So let us make it clear from this P U p diagram.

So we have this P U p plot and let us assume this as U P 1 at pressure P 1. So pressure P 1 particle velocity U p 1 and we assume that the two waves have same velocity. So this wave and these wave have same particle velocity, same U p. So what will happen is then the U p of this the resultant wave, the superposition of two shock waves, superposition of two shock waves okay.

So when it superimpose, so what will happen if they have both same U p, so we can write the, that superposition we have a value twice U p 1 and correspondingly what is the pressure we will find it out. That is in this case let us say P 2 and that is what so then we can find that the pressure after superposition is P 2. So that is how we can calculate. But we should understand that P 2 is not equal to twice P 1.

But U p 2 which is this one U p 2 is equal to twice U p 1. So and we use this equivalent pressure P 2 from this plot. So again I am repeating we should not be confused that the P 2 is equal to 2 P 1. It is actually not equal to 2P 1. So it is from the particle velocity addition we **we** can find the equivalent pressure.

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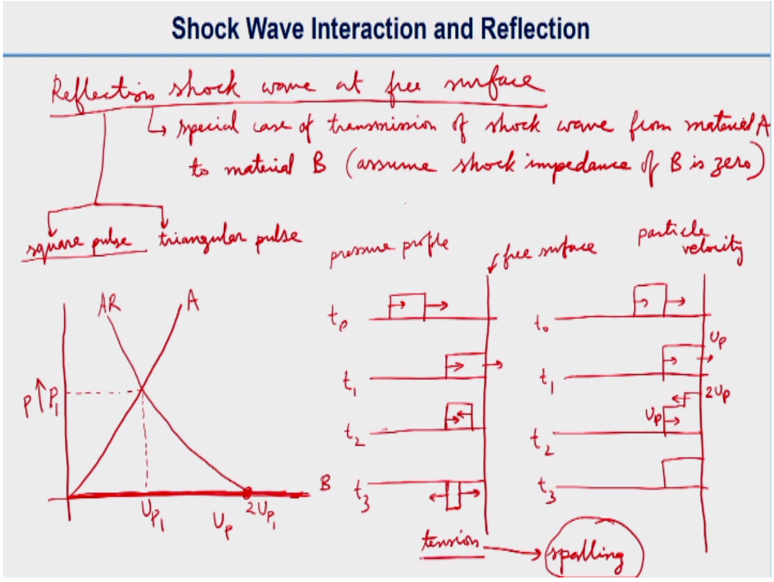

Now we will talk about reflection of shock wave at free surface. So this is as we can understand from the earlier elastic wave calculations as well. So this is a special case of, special case of transmission of shock wave from material A to B, material A to material B and we assume that the shock impedance of material B is zero, shock impedance of B is zero. So that is a special case.

Similarly, we did it for elastic wave propagation. So in this reflection of shock wave, we can consider two cases. First case is square pulse and second case is triangular pulse. So we will first talk about the square pulse. So to understand this so what we will do is to understand this reflection of shock wave at the free surface, what we can do is, we can draw a P U p diagram, and then we have this curve for material A is this one.

And then curve for material B is the horizontal line which is exactly at the x axis. So that line is our line curve for B, material B. And if you draw a mirror image of A which is the reflected wave. So that is a mirror image. So that we will write as AR that at medium A the pressure is P 1. And the corresponding particular velocity is U p 1. So as it is a mirror image, AR is a mirror image of A.

So this reflected curve will cut the curve B at U p 2 or we can write twice U p 1 because of the symmetry of the AR and R curve. So AR curve will cut through the curve B at twice P U p 1. So if you draw the pressure profile what will happen is you have the free surface, I will write a vertical line, free surface. This one is the free surface, free surface.

So at time t naught this pressure pulse will travel towards the free surface at time t 1. The pressure pulse will hit the free surface and you know that we have a release wave following the primary wave. And then this release wave will interact now with the reflected wave because at time t 2 the wave will reflect back. So what we can see is here the wave will reflect back.

That is also release wave from the free surface and then release wave of the primary wave is from left to right hand side and then this will come towards each other and at time t equal to t 3. So what will happen? It will generate a tensile wave because of the interaction of the both the release waves, it will have a tensile wave. So this is tension and these tension can lead to spalling. If the amplitude is quite, high sufficiently high then it can lead to spalling.

Or very quickly we can show the particle velocity if we draw the particle velocity profile here. So what we can show is at time, so if you have the free surface and at time t naught, time t naught this, the particle velocity profile will look like this. And then at time t equal to t 1, the particle velocity when it hits the free surface, hits the free surface, let us set this U p profile. And then particle velocity at t equal to t 2.

As you know this will be now it is a high velocity U p here and twice U p here. Because from this, we can see that this is from P U p plot, this is twice U p. And so this will, the reflected wave both the release wave will interact and at time t 3. So we will get the result of this interaction. So this is time t 3. So basically this will, reflection at the free surface can cause spalling if the tension has sufficiently high amplitude. Thank you.