Dynamic Behaviour of Materials
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Lecture - 24
Shock Wave Attenuation, Interaction and Reflection - I

So we talked about the shock waves complex problems. Now we will talk about the shock wave attenuation, interaction and reflection. This is the chapter number 7 from the Marc Meyer's book.

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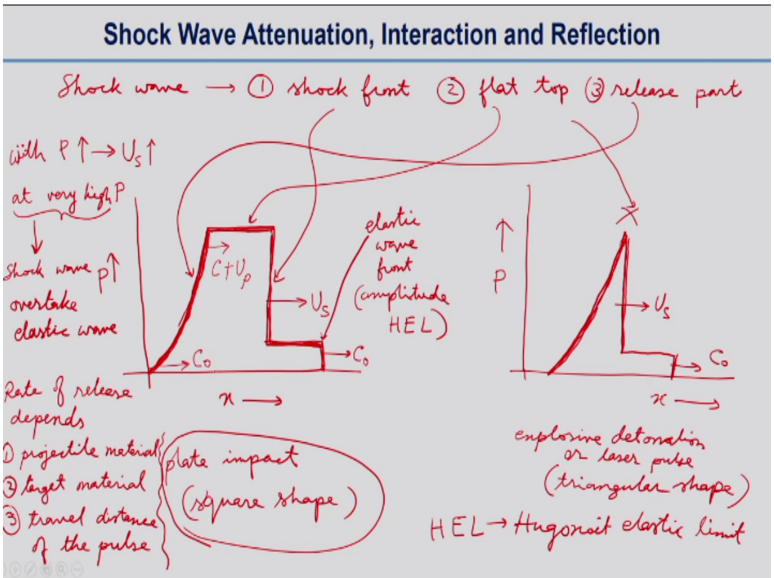

So shock wave ideally have three parts. One is shock front, that you already know, the front part of the shock wave. And then we have a flat top, I will show you what is that flat top or you can call that a plateau and then third part is release part. So these are three parts. If we draw this that is the pressure versus distance; P pressure, x distance. So it looks something like this, something like this.

So this is called shock front and then there will be the flat top. This one is the flat top and the release part which will be this part from shock state to the initial state. It will pressure drop downs return back to zero. And there is one more part here, this is the elastic wave. So elastic wave is traveling at a distance of C naught and the plastic wave that means the shock front will travel at the speed of U s.

We can tell that this is elastic wave front. So this looks little bit messy, but I think hope you have this diagram clear. So this is now, this as you know that we are assuming here elastic wave will travel faster than the shock wave, so U s. And this is for a planar impact, this is for a plate impact. For a explosive impact that will be a little different, that I will show you.

So plate impact, we call this as square shaped pulse. Why it is a square, that you can see that it has flat top and that is called square shape. Amplitude of this elastic wave, amplitude is equal to HEL, Hugoniot elastic limit that HEL is Hugoniot elastic limit. That you can, Hugoniot elastic limit, after that limit the material will behave plastically. So with pressure, with pressure, I will write it here with pressure increase that shock wave speed also will increase.

So at very high pressure, at very high pressure P, at very high pressure P, shock wave may overtake the elastic wave. So elastic wave speed is constant in a material. Shock wave speed, it increases with pressure and that is why at very high pressure this shock wave velocity can be higher than the elastic wave velocity. This is called release part right.

This part from the shock state to the initial state that returns back to the zero pressure. So that state, the rate of that release depends on, so how fast it will decrease to zero pressure that depends on the properties of the projectile material and target material and also the travel distance of the pulse of the shock pulse.

So because that means when it travels more distance, so with increase in x that release rate can be changed. So what we discussed is is for a square shape pulse for a plate impact, but just I want to show you the other one which is for explosive detonation or laser pulse. So the same plot pressure versus distance with distance how the shock wave will move.

So this is for explosive detonation or laser pulse. So we can have shock wave produced by laser pulse and in this case the pulse is of triangular shape. So it looks something like this and it will come down and it will have a elastic front. So if you see that there will be no flat top. So here there is no flat top. So this flat top is not there. But you can see the release part.

The release part, this one similar to the one we saw for the plate impact and we have this shock front, shock front our shock wave velocity U s and elastic wave velocity which is C naught which is elastic wave front. This is elastic wave front and this is shock wave front. We will discuss about this release wave part in a short while.

So this release wave, I did not mention it here that this wave has a different velocities at the start of the release part it is the velocity C + U p and on the back the velocity is C naught.

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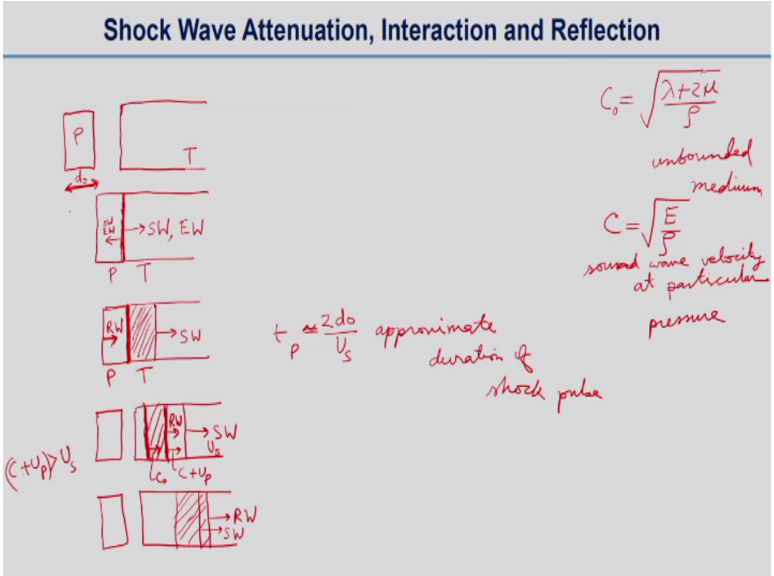

So what is C naught and C is as we know the C naught is we found earlier this is lambda plus twice mu by rho that is the elastic wave velocity for unbounded media, unbounded medium and for C is sound wave velocity at particular pressure P, so this is we will write here sound wave velocity. We discussed all those things earlier I think. So we know that this is now little different than this.

So C naught will be little higher than C that we already discussed. So now we will see what is that release wave. So how these release part of that shock wave produced. So for example, like we have a planar impact. So this is the projectile and we have a semi infinite target body. This is target. So what will happen is if the projectile hits the target, let us say this is our target and semi infinite target.

The projectile is hitting the, projectile is hitting the target. So this is projectile, this is target. We will write below so that we can write clearly some other things inside. So during this point of contact we should know that there will be shock waves, shock wave and even elastic wave and there will be even shock wave and elastic wave this side as well, shock wave and elastic wave.

So it goes to the projectile and goes to the target as well. So what will happen is during this contact, so some of this wave will be reflect back as a release wave. So release wave and then at the same time the shock wave will start moving this way. So this is our impact interface, impact plane. This is our impact plane. We know this is our target, this is our projectile and we have the shock waves and even we have elastic waves ahead of it, but we are not showing the shock wave.

So this is a very high pressure zone. This is a high pressure zone. What will happen when this now after some time this projectile will lose contact with this target. So now these shock waves will travel and after that, that release will travel. So release wave which reflects back from the back surface of the projectile. Now this is the end of this release wave and this is the start of this release wave.

And after some time what happens this release wave will interact, actually this release wave go faster. So if we see in the earliest slide, so we know that this is C + U p the release wave, the start of the release wave and this is C naught which is the end of the release wave. So end part of the release wave goes slower. C naught is less than C + U p. And in this case, this is U s is the shock wave velocity.

So we should know that C U p this is the velocity of this potion. This is C + U p and velocity of shock wave is U s and then velocity of the end portion of this wave is just C naught. So here you should know that C + U p would be higher than U s, shock wave velocity. So that is why this the release wave will overtake. So this is the release wave. It will overtake the shock wave at some point of time.

And then we will have this portion. This is the end of the release wave. So it will look like this. So we will see some more plots to understand this. So this is just a rough idea about what is happening here. So let us draw another diagram, another plot which is we call time x-t plot, distance versus time plot.

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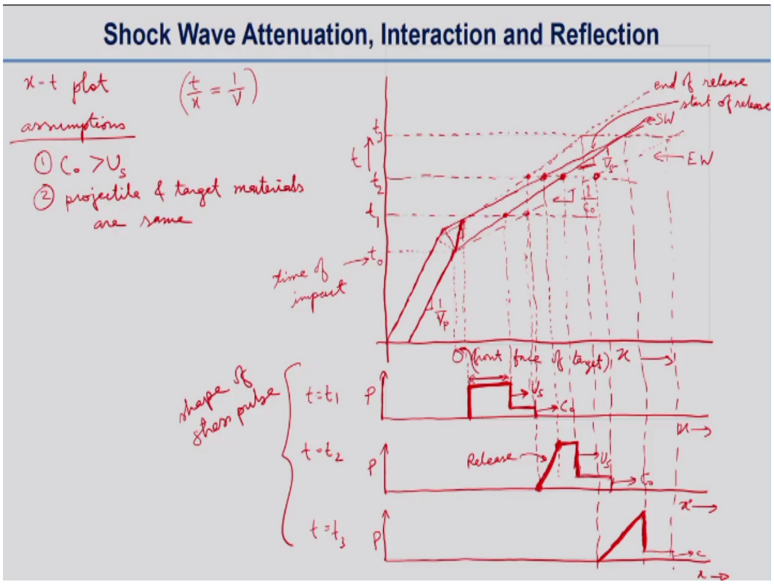

So what we will do is we will talk about the same problem what we described just in the last slide. So we have x in the x axis and t in the y axis, that is the time. And what we can tell that this projectile thickness is d naught and then our target is semi infinite. Let us assume we are starting from a time which is before the impact.

So and let us say at time equal to t naught, time equal to t naught, the projectile will hit the target and this is x equal to let us say zero is the plane of or we can say that the face of the target, front face of the target. So this point is or we would rather say here, front face of target is this point. So now what will happen is the projectile if we plot it here, the front part of the projectile front face and the back face of the projectile, with time it will travel towards the front face of the target.

So it will look something like this and when it hits the target, so what will happen? There will be two waves as we know and the first one is the elastic wave, elastic wave will this one is the elastic wave. And here we have some assumptions, we are taking some assumptions that first assumptions is elastic wave is faster than the shock or shock wave and then second assumption we are taking as like projectile and target material they are the same, materials are same.

So this is, this plot is t versus x. That means the slope of these curves whatever I have drawn this slope the dotted line, the slope is the inverse of the velocity. So this is 1 by C naught that is elastic wave velocity. So this is elastic wave. I will write EW for elastic wave. Then that I hope you understood it why it is inverse. So because t by x is 1 by velocity, so this is inverse, velocity inverse.

So there will be another wave that we know the shock wave which will travel like this. Okay, this is shock wave, this is shock wave and its slope is nothing but 1 by U s. The slope is 1 by U s, U subscript s. And then we know that the release wave will travel from the back surface of the projectile. That means and that will be reflected back from the back surface of the projectile.

So this will be two lines we will draw, one is the start of the release. So that you can see we showed here that there is one start and then one is at the end. So where it will end. End means the pressure will be zero at that time. So this one or even if you see earlier curves, so this point the pressure will be zero. That is our end point and this point is our start point.

So what will happen here is there will be one line for start of that release wave that comes from the back surface, back surface of this of the projectile. And then similarly there will be one this dotted line will be end of, these are our straight lines, end of release wave. So the dotted line is end of release wave. I will write RW and or you can write that the end of release only and then this line will be I will write it in arrow.

This will be start of release. We can just simply write start of release and end of release. That is the portion where the pressure will return back to zero. So now, we know this is the velocity of impact, that inverse of the slope V p velocity of the projectile that the same is the velocity of impact. And then after that, this will be reduced. So it will be reduced like something and the slope will be higher.

Slope is higher and then that means velocity will be reduced. But anyways, we are not focusing on this part. So we will only focus now on how these successive progression of these the wave whatever we straight line we have drawn, first is elastic wave then shock wave and then start of release and end of release. So with that, we want to draw some pressure versus distance plot.

Pressure versus distance will show which will give you the pulse shape. So let us say we are drawing at three different times, three different times. Let us say this is for, first one is for time t = t 1, time t = t 2 and time t = t 3; all are pressure versus x, pressure versus x. So first one we will draw at t 1 which is this t 1 and I am just repeating it again that t naught is the time of time at with the impact happen.

So time of impact, so when the projectile touches the target. So now at time t = t 1, so what will happen is because the projectile head will be in this position, projectile front face in touch with the target is here. So what we will do, we will show the wave pulse here and then that will be the shock front will be in the time t 1, the shock front will be in this position.

And then the elastic wave front which is moving, traveling faster in this case, elastic wave front is like this. So this will look something like this, shape of the stress pulse. I will write here, stress pulse or we can write shape of stress pulse in these at these three times at time equal to t 1. We will see that there will not, we will not see some decrease of pressure, it is a sudden drop.

And then there will be a flat top which will be the high pressure and then this is the front, this is the front which is U s that is shock wave velocity and here we can write C naught that is elastic wave and if you see from the top figure, so this is the point where the elastic wave dotted line actually cross the time t 1. So that is why we are drawing it here.

And similarly, this is the point where stress sorry shock wave line crosses the time t 1. That is why we are drawing the shock front. This is the vertical line here. So similarly, if we take another line at time equal to t 2, so this is time equal to t 2. So now what will happen is we can first draw the elastic wave which is we will draw it here, elastic wave.

And then we will draw the shock wave, shock wave line will be here. So elastic wave will be here and the shock wave here. And there will be other two lines. So start of release and end of release. This is start of release and then this is end of release. So what will happen here is this will be different. See this. So it will look something like this, it will look something like this.

So this point is the start of release if you see in this figure, start of release and this point is the end of release. That means the release wave will end here and the pressure will be zero. So and similarly, where the shock wave crosses the time t 2, this point. So that is the point corresponding to this shock front and this point where the elastic wave crosses the time t 3 this is your elastic wave front.

This is our shock wave front and here the release part, I will write release here, that is the release wave and then again we will have one more time t 3, t equal to time t 3. So here again we will not we will see that elastic wave line is crossing at a very far distance. So what we will do is we can draw from here this is a velocity wave. Similarly, we will see that now the shock wave and the start of the release are almost coincides.

So we will draw a line here the end of release for time t 3. It comes like how it will look like now. This is the elastic wave. This is shock wave front and then as we know that the shock wave line and the start of release coincides almost at time t 3 or that now this the plateau will not be the flat top will not be there. That means the release wave almost overtaking in the shock wave.

So it will look like this. And also you can see that the slope of the release wave curve is lower than the earlier at time t equal to t 2. Why that is because we know that the end of release is traveling at a slower speed. You can see here also in the dotted line end of release is a higher slope. That means it is has a low velocity, lower velocity than the start of release.

And that is why it is has a less slope and that has a less slope. And also you can see that there is no flat top of plateau like our time t = t 2 because the release wave catches up with the shock wave. And then even we can see later that the pressure top the peak pressure will decrease after that. That we will see in subsequent slides.

So this is, also we wanted to tell you that the initial duration of the peak shock pulse which we did not discuss earlier, so it takes a time in this case it takes a time the t p is equal to twice d naught if the d naught is the thickness of the projectile. So it will be d naught, twice d naught by U s is the approximate time that is time taken from the release wave to come back to the impact plane.

So this is approximate time and approximate duration of shock pulse. So that is the time required to for the wave from travel from the impact plane impact the interface to go to the back surface of the projectile and come back from the back surface to again impact plane again. This is the part so that will be almost the distance will be twice d naught and that is the duration of shock pulse.

So that is all for this lecture. So we will discuss more about attenuation and interaction and reflection of waves, shock waves in the next lecture. Thank you.