Introduction to Explosion and Explosions Safety
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Lecture - 12
Blast Waves: Damage from Blast Waves, Examples, Multiple Spikes in an Impulse, Iso-damage Curve on an Overpressure-Impulse Diagram,

Good morning, we will continue with the interaction of the blast wave with a structure which happens to be in the path of the blast. Like instance we have a body, the blast wave is propagating, we continue with this.

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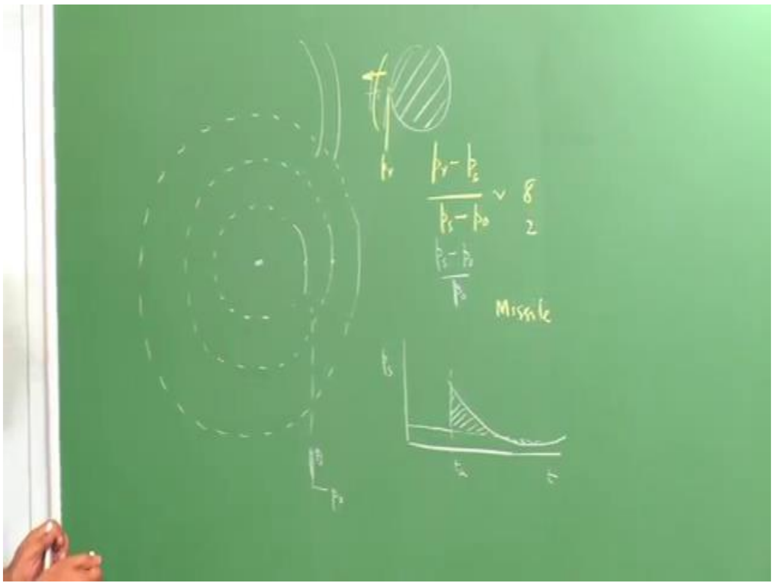

Today we will finish this portion, namely blast wave and its interaction with bodies. To be able to finish it let us first sort of review, what little we have done in this. We told our ourselves well a blast wave is generated when some energy is released at some source. The blast wave as it propagates further, we considered only a spherical blast wave because this is what really happens when the blast wave progresses away from the source. We have the spherical blast wave moving away from this

We told ourselves near the source or rather in the near filed of the explosion, well the over pressure that means if I take this particular point. The pressure rise from the ambient value p naught to the value p s behind the blast front or the shock front, which we call as over pressure p s minus p naught is rather very high. As it progresses further and goes away far from the source of the explosion, that is in the far field.

The value of the over pressure p s minus p naught is small and we non-dimensionalize it and expressed it as a value of the non-dimensional over pressure. We learned how to calculate this, we calculated it rigorously in the near field. We said well using some other theories it is possible to calculate it and we arrived at the expressions for this. This is 0.1, we also told ourselves in addition to this may be if I consider a point here or a point here or a point over here, what happens when I look at the pressure behind the front and sort of I say well this is the pressure behind the shock front or the blast front, or the lead blast.

I express it as a function of time, after the explosion starts that means at time t is equal to 0 I have an explosion taking place. It takes some time for the blast wave to come over here, that means the blast wave reaches this particular point after a certain time. We called it as the arrival time and what happens till then the pressure was the ambient pressure. Then the pressure rises and then the pressure fall off.

You know because of the momentum it could go to negative values. We said by got positive impulses we also got negative impulses, this is the second thing we learned. We told ourselves because of this impulse, well the thing could topple down or it could cause it is own damage because of the blast vent. Therefore, we talked of two types of damages from over pressure which was crushing or compression because you have rapid compression behind the lead shock, and also damage due to the impulse for a body which is hit by this.

But then mind you we also told ourselves or we were able to derive something that if the blast wave comes normal over here, you get something like you have the pressure now is p s in the side view. The wave reflects back let us see how it reflects back. Well it could reflect back like this, it reflects back over here. The reflected pressure behind it was such that, you had the reflected pressure minus the pressure behind the lead shock p s divided by the value of p s minus the ambient pressure, was of the order of 8.

It is not just multiplied by 2, it could be of the order of 8 for a very strong shock and for a weak shock well it was of the order of 2. Which means, when a blast wave hits it normally well I could have the pressure at the surface. As quite a high value that is 8 times the value of the value of the over pressure what I got from the instant field. This was something which we derive for strong shock and also looked at it for the case of the weak shock derived it for weak shock.

Then once it was over, we also talked of something else namely, we told ourselves well the damage is not only caused by the reflected shock which is very high and the impulses, but it could also be caused by the missile effects. Missile effects because fragments from the casing fragments from the neighboring could come and hit it with momentum and that could also damages, where the three types of damages which we talked off. Having said all this we got into the last part and what did we do in the last part we talked in terms of bodies having impedance.

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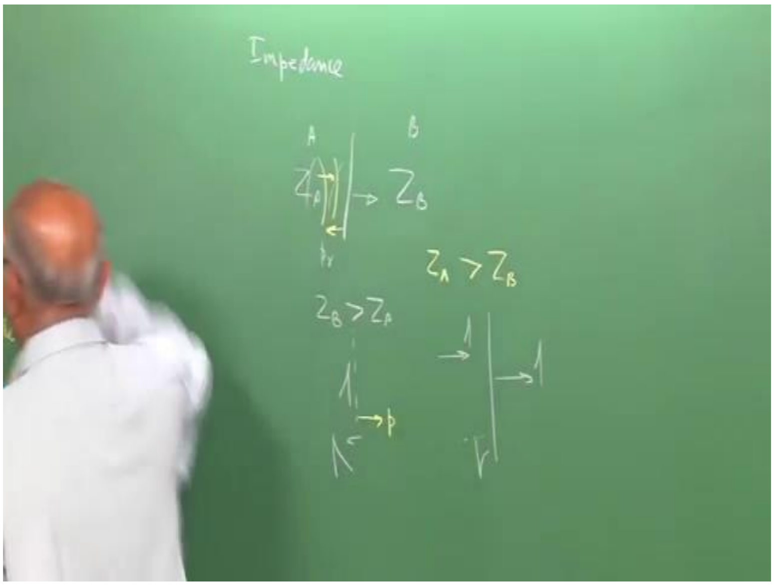

We told, well if I have a medium which has a certain impedance, let us say medium a having impedance Z a. We have medium b having impedance Z b and we have let us say the blast wave which propagates from medium a into medium b. Well something gets reflected. This is the incident wave, may be something gets reflected here, you have reflected and something gets transmitted into the second medium. We found, that if the impedance of the second medium was greater than the impedance of the first medium.

Well the transmitted shock goes away. You have reflected shock, in other words I have something like an over pressure coming and hitting this particular interface. This over pressure is reflected back as a shock again. We were able to relate the reflected wave with respect to the incident wave and we also found out the magnitude of the wave which transmits into the second medium, but for the case in which I had Z a, that is the impedance of the first medium being greater than the impedance of the second medium.

What happened, we found we were able to derive this expression again. We told ourselves well an incident shock comes over here. Let us say it comes over here. It gets transmitted with a higher amplitude into the higher pressure into the second medium. But what gets reflected is not a compression disturbance or a compression wave, but it is something like an expansion wave, that means if I have the ambient pressure here the pressure falls and I have an expansion fan which causes this.

This we found is the results in something like ((Refer Time: 06:57)) of the material a. Having seen all these 3 or 4 different aspects of the blast wave let us now go ahead and try to conjunct little bit more about the damages about the interaction. To be able to do so let us first put down on the board a few cases.

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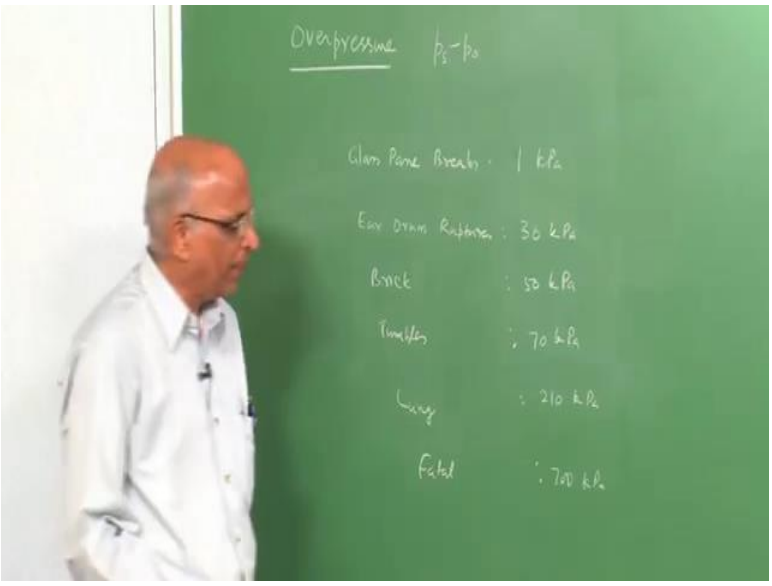

Like for instance we say, well over pressure could cause an interaction and damage may be impulse could cause, may be the missile effects could cause and the variation of the impedance change could cause some particular expansion which could call ((Refer Time: 07:34)).

Therefore let us first put down the effects of over pressure, that means p s by p naught. Mind you, we are still looking at the end view that means we are looking at a shock being formed, we are standing away from the shock and looking at the shock and we find that the pressure rise across the lead blast wave is p s or the lead shock wave is p s. Therefore, we did we take a few damages, we say well a glass pane breaks, when the over pressure is of the order of 1 k p a.

The next type of damage which we can say is supposing a blast wave hits our ear, the ear drum ruptures when the value of p s minus p naught is equal to 30 k p a. The next one I consider is brick a brick wall. Brick wall fails when the over pressure is 50 k p a. Next a man who is may be standing in the path of the blast wave, he sort of tumbles sort of a man tumbles or he is knocked out when the pressure is something like 70 k p a. So, on we can keep tab letting.

I just put 1 more or 1 or 2 more, I say the lung human lung gets damaged, when the over pressure is something like 210 k p a and if a human being is in the path like in the path of the blast wave. If the over pressure is of the order of 700 k p a that is 7 atmospheres, well it is fatal he just dies.

Therefore we say these are the things which we can put based on observations of over pressure. Let us take a look and why these things should happen and may be make some recommendations. This is what I do today, having said that let us take the example of glass pane breaking. We put this figure on the board again. We say well I have a glass pane glass pane is normally thin well I have a glass pane.

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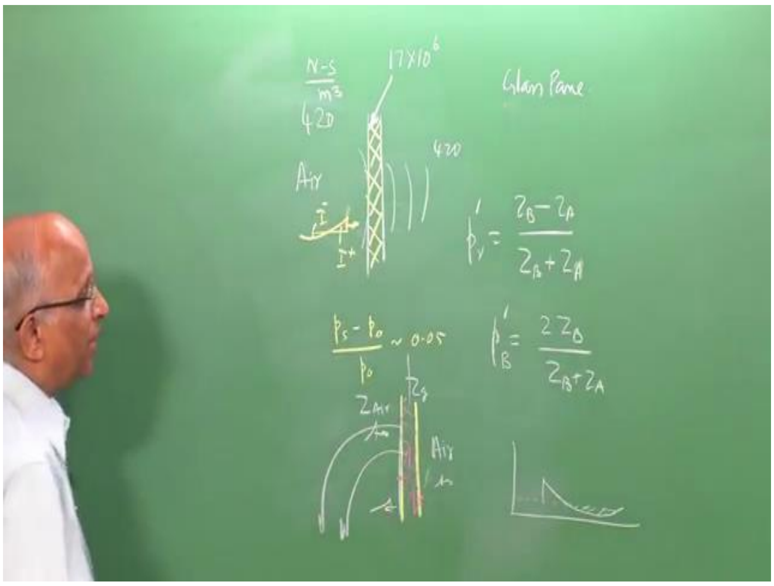

A thin glass pain over here, I have air through which may be the blast wave propagates hits the particular glass pane. Well the wave gets propagated out, let me put the thickness of the glass pane in yellow color. This is the glass pane over here. Well we tell ourselves if the value of the reflected shock behind the pane is about 1 k p a. Well it breaks therefore, I tell myself.

Well if I consider p s minus p naught divided by let us say p naught. Well p s minus p naught should be half because I am talking of reflected over here, I am considering the value of p s minus p naught is only 1 k p a or 100 of an atmosphere. Therefore, we say well it is 0.05 is sufficient to break my glass pane.

This is as per the values of the over pressure. Therefore, we tell ourselves well the type of magnitude of the over pressure. Well if this is the magnitude, let us say with respect to the height this is the pressure. Therefore, if I have a small value of over pressure of the order of 0.05. Well this is the type of shock wave I have the impulse being, I have the negative impulse here, I have I plus over here I have minus over here. This is the type which the blast wave is coming and hitting the particular glass pane.

Now, let us say for air, we looked at the values. The value of the impedance for air we said is around 400 to 420 or 440, let us say is 420 Newton second by meter cube. For the glass pane we had a value and the value was around 17 or so into 10 to the power 6 Newton second per meter cube. The value for air again was something like we say 420. Therefore, what do we expect to happen with the glass pane when it is hit by a very small pressure spike or the order of 0.05, that means the over pressure is only 0.05 kilo Pascal.

That is, it hits it I have reflected wave, I have 1 kilo Pascal which hits it. Therefore, that is going to happen on the left side of the boundary I have this, which hits it. Well the impedance over here is less than the impedance over here that means Z of the air is very much smaller than the impedance of the glass over here. Well it gets reflected then as a pressure wave and well if I calculate the magnitude.

Well the magnitude is will be about the same because I find that the magnitude of the Z b is very much higher. Therefore, this does not play a role and with the result the some pressure wave gets transmitted into the glass. Well the amplitude is now twice because you will recall, we had the expression p reflected is equal to Z b in the second medium minus in the first medium divided by impedance in the second medium plus the impedance in the first medium is the reflected.

What was transmitted was equal to p in b which is transmitted is equal this is the magnitude of the pulse, what is coming this is h magnitude of the pulse which is going through, was equal to 2 times Z b into Z b plus Z a over here. Therefore, with the result the amplitude is higher and we also told ourselves. Well, the glass pane is something which is not very thick it is quite thin therefore, the thickness of the glass pane being small.

Well this wave does not decay in the small length and when it reflects back over here the ambiance over here is again a f. I have from a higher impedance it goes to a lower impedance value. Therefore, this wave gets reflected as a reflected wave. Therefore, you have particles behind the incident wave being in a state of expansion and therefore, it is pulled over here. Here, the particles are pulled in this particular direction and therefore, the glass material is pulled under tension it fails.

Therefore, it disintegrates or breaks and therefore, you find well the glass sort of develops cracks and it breaks, but what happens it takes some time for the glass to break and mind you, what is transmitted out of the glass is only a very small portion. Because what gets transmitted out of the glass, in this case this becomes the first medium a this becomes the second medium is b and what gets transmitted is a very small portion is Z b, being very much smaller than Z a.

What is going to happen, the amount transmitted is very small because this is a high value, this is a small value very small magnitude of pressure spike gets transmitted into the medium. Here I have ((Refer Time: 15:17)) or the glass which disintegrates and breaks, but then what is going to happen. It takes some time for the crack to develop fully and break, by then you have the impulse. We told ourselves the over pressure is small and what is going to happen let us plot it out the over pressure.

You have this is the ambient pressure here, pressure rise it comes like this well it goes like this. You know since the over pressures are small may be the breaking can happen in the far field. In the far field these things have long impulses and by the time it breaks well, the negative could come and if the negative comes the broken glass will sort of fall back over here. That means the broken glass falls towards the explosion, rather than it falls away from the explosion. Well this is the type of failure we express, we expect in the case for glass pane.

This is what is observed, the glass pane falls back well the over pressures are small in the far field we could have the breakage of window panes taking place. You know we talked of window panes breaking, we said in the Texas City disaster, something over a distance of something like a few 100 kilometers the glass panes of the buildings got shattered and therefore, this is one type of failure we can talk off. Let us some to the next time of failure where we will get back to this. May be we take a look at the ear drum rupture. Well, we told ourselves, well you know when we look at our ear drum. You know the ear drum you know we hear all frequencies.

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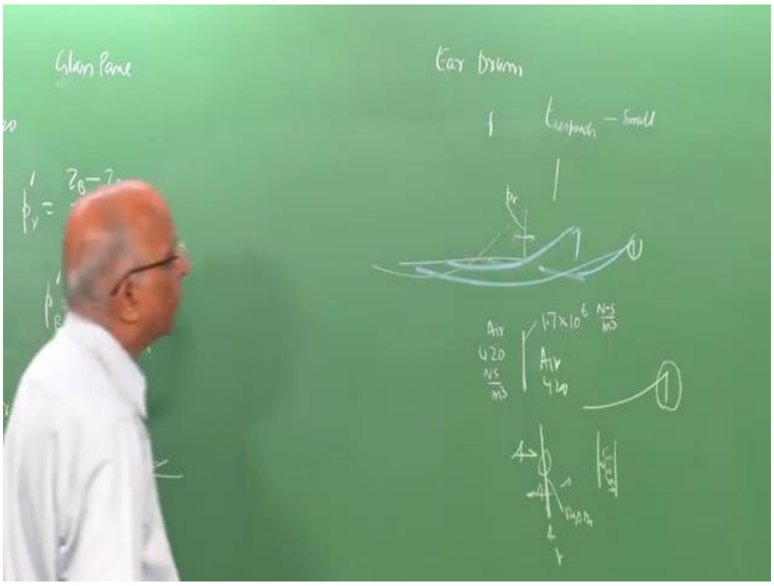

That means we are talking of the frequency response being quite high for the ear drum. If you talk in terms of the frequency response. We say well ear drum has a very high frequency response or the time over which is response to any sound is very small. Now, if you consider a wave that means we consider an over pressure. It is coming over here behind the over pressure there is an expansion it goes over here. This is the way the wave travels as it moves forward, the next signature of this would be may be at the next instant of time it comes over here. The amplitude p s minus p naught has decreased well it would go like this and so on it comes like this it goes like this. Well the time keeps increasing maybe I should have drawn the second 1 to be an increasing line because as distance increases the equivalent time increases.

This was the Grand Hawkinson scaling law and in this case well it increases still further it comes like this. Therefore, what is going to happen. If this magnitude of the over pressure is of the order of 15 because we told ourselves p minus p naught over pressure, that is behind a reflected wave that is the total pressure is thirty, behind this p s minus p naught it is about 15 the ear ruptures. Why does the ear rupture? Let us again look at the mechanism and then look at the time response.

The ear drum is a very thin diaphragm. The properties of the ear drum are something like a muscle. We can take the value to be 1.6 into 10 to the power of 6 Newton second by meter cube. Well for air, we said it is around 420 or 430, let us say 420 Newton second by meter cube over here. We also find that the value from air, the blast wave comes into the ear drum, it gets back into the air subsequently. The air over here the value is again 420.

What is going to happen, well the blast wave comes over here it meets a higher impedance, it gets reflected. This is the incident wave, this is the reflected wave what gets transmitted is from the ear drum it gets transmitted into the air, may be a small amount gets transmitted, but what really happens. Here, within the fabric of the drum you have a wave and behind the blast wave you have expansion.

It gets reflected over here as an expansion and the ear drum ruptures because of the tensile loading. That means if I were to plot, if I were to thicken this I have to just take a small part here I say it is the thickness. Well I have expansion wave behind the shockwave, I have expansion wave traveling in this. Therefore, I have this the particles pull each other and therefore, the ear drum rupture and this is how an ear drum ruptures, but then we tell ourselves that, we also know that the ear drum is a high response system.

Therefore, the moment I have a p s by p naught of the order of let us say 15 kilo Pascal that is the total value required is 30 kilo Pascal. That means even before the entire impulse is there, just the moment the over pressure is there the because of the high frequency response of the fabric of the ear drum, well the ear drum breaks. We will take a look at the response times, a little later in this class, but we tell ourselves well an ear drum ruptures from the tensile failure because of the air and the drum between the types of over pressures required is 15.

From the value of the value of p s minus p naught behind the blast wave because the total value of reflected value is twice because the value of 30 k p a corresponds to the far field which is not very very strong. Well we looked at the ear drum ruptures well if the pressure spike is much larger, the reflected shock wave could be not be twice, but it could be 3 times 4 times up to a value of 8. Well these are the two cases let us look at the third example. The third example we take is maybe a failure of a brick wall.

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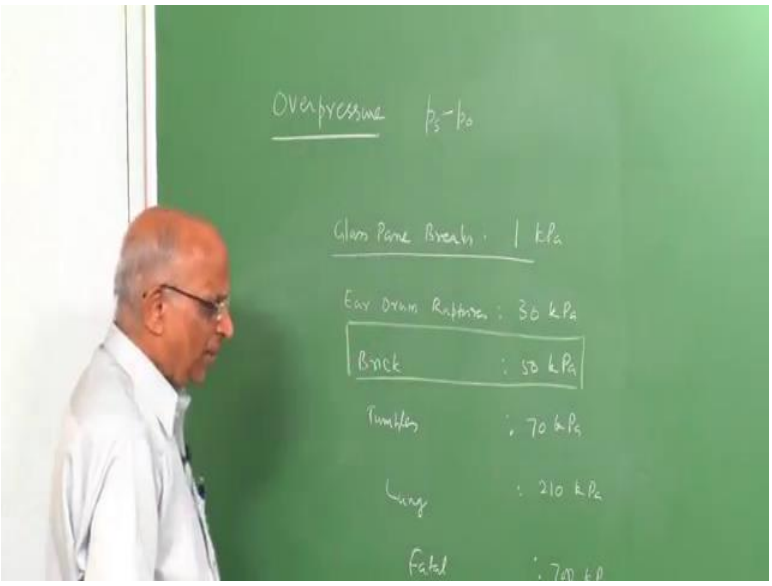

Let us consider this because you know we do use brick walls for protecting structures we have houses in which we have bricks and all that. Let us take a look at the failure mechanism of let us say a brick wall.

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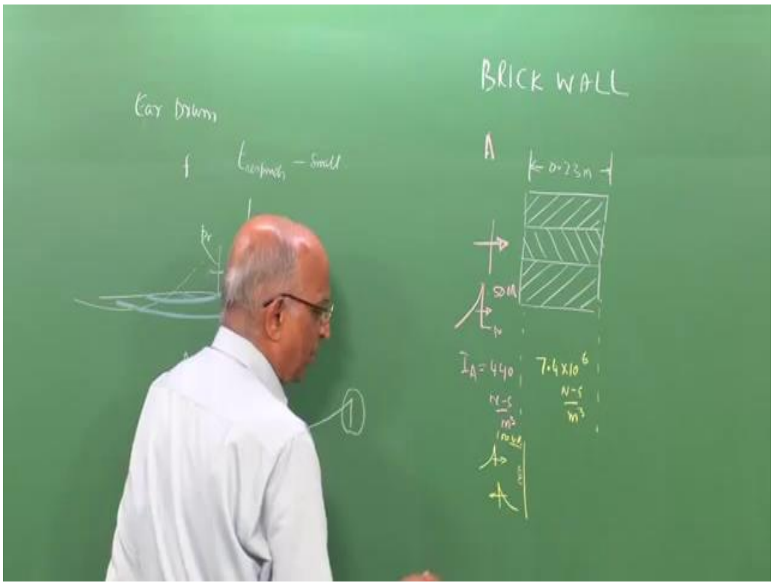

Well, it could be similar to this except there may be a brick, if it is placed horizontally maybe I have several of these bricks being placed. Well the length of the brick is around 9 inches therefore, it could be something like 0.23 meters and this is the brick wall over here. We place the second brick over here, mind you let us assume that the joint between the 2 bricks is same as the brick wall, maybe it is cemented together which same properties.

Let us assume that a blast wave comes and hits it. That means I have the incident blast wave and let us presume that we are hitting it. We know that maybe the total reflected pressure here, if it is of the order of 50 we say it fails. Let us assume that I have an incident wave whose over pressure that means p 0 over here p s over here, p s by naught p s minus p naught is equal to 50 k p a which comes and hits the particular brick wall.

Well the impedance of air ahead of it, we take a value which is around 420. We take impedance of air which is let us say medium a before the brick wall is equal to, let us say it is 440 let the unit be Newton second by meter cube.

The brick wall has an impedance and the impedance of the brick wall is 7.4 into 10 to the power 6 Newton second by meter cube. Then what is going to happen since the impedance here is very much higher than this, what is happening. The initial over pressure of 50 k p a gets reflected as an over pressure of 50 k p a. That means this is incident this is reflected. Depending on the magnitude of this, well it is not very weak it is not may be it gets the reflected pressure could be 2 times or slightly higher than 2 times over here.

Then what is going to happen, well if I work out this using impedances since I use acoustic impedances and we said impedances is equal to the density of the medium into the speed of sound in the medium. Well I considered the case of weak shock waves, well it is just reflected with twice the value. That means I have the pressure over here reflected pressure is equal to 50 into 2 that is equal to 100 k p a.

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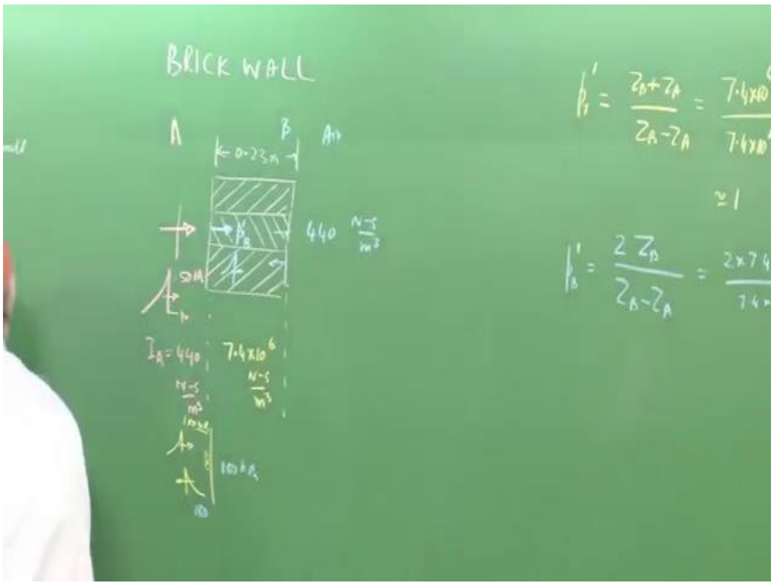

This comes out from the expression what we wrote earlier, we said well the value of the respected pressure is equal to Z b plus Z a into Z b minus Z a. If you put down the values, we have Z b is equal to we had 7.4 into 10 to the power 6 minus you have something like 440 that is 0.44 into 10 to the power 3 divided by you had Z b 7.4 into 10 to the power 6 plus 0.44 into 10 to the power 3, well this is very much lower than this and therefore, this comes out to be equal to 1. The reflected wave has the same magnitude as the incident wave or around the same magnitude. Now, we want to find out how much is transmitted into the medium.

Well this is transmitted into this medium, this is p into the brick wall b. Therefore, what is b reflected let us put it down p b prime is equal to, we derived this expression 2 times Z b divided by Z b minus Z a. Well the same thing the value is 7.2 into 7.4 into 10 to the power 6 divided by 7.4 into 10 to the power 6 minus 0.44 into 10 to the power 6 is almost like Z b which is equal to 7.4 around 7.399 into 10 to the power 6, which is of the order of 2.

That means I have a pressure amplitude that means let us plot it in blue. Well this is the amplitude and higher place, this value that means 100 k p a gets you have 50 k p a coming over here therefore, the value of the reflected 1 behind it is equal to 100 k p a and what gets transmitted is equal to 100 k p a gets transmitted into the brick wall. Well this goes down let us presume for the present.

That distance of over the distance of 2 3 meters the amplitude does not get decayed. It starts with this in practice over this distance the p b will keep decreasing because as distance moves, what did we say as r s by r naught increases the over pressure decreases, but in this case, let us assume which has small value. Therefore, what comes at this interface between the brick wall b and the air over here.

What happens I you have the same value of p b coming over here. When the same value of p b comes over here what is going to happen. Well it meets a lower density lower impedance air over here which is 440 into Newton second by meter curve. Therefore, what is going to happen you know the magnitude which gets reflected now has a value you have the value. I think there is a sign mistake over here. We said reflected over here it should have been Z b minus Z a is the reflected value divided by Z b plus Z a over here and here also it should have been z b plus Z a.

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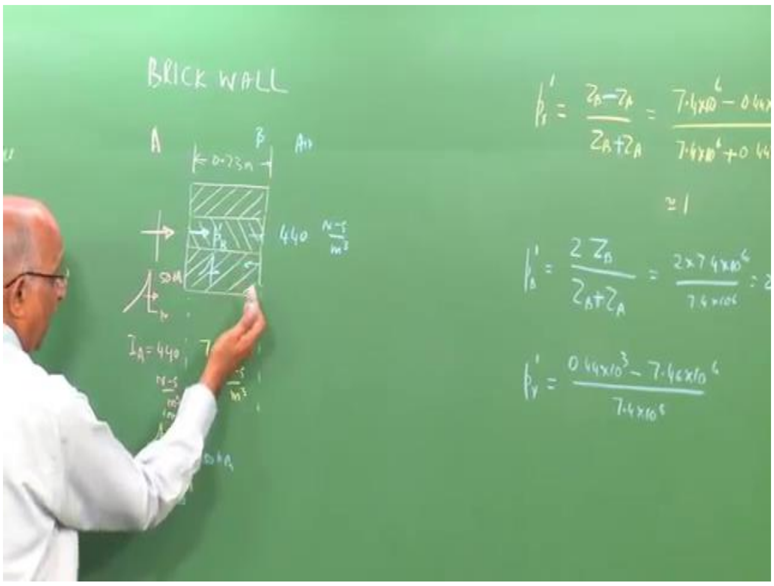

Therefore, what is going to happen. Now, you have the value of b which corresponds to air being very much smaller than the value corresponding to this. Therefore, the reflected wave p r prime is equal to if I take the value there is going to be 0.44 into 10 to the power 3 minus I have 7.46 into 10 to the power 6 divided by, I have Z b plus Z a which was same as the value of around 7.4 into 10 to the power 6.

Therefore, I find that the similar magnitude gets reflected over here, but as a rarefaction or an expansion wave, rather what comes over here is a strong wave over here. It comes over here with an amplitude of 100 and what gets reflected is as an expansion. That means instead of compressing it expands over here. Since, this behind this expansion wave particles move like this, here the particles move well the brick collapses over here because brick cannot take tension, but more importantly what is getting transmitted.

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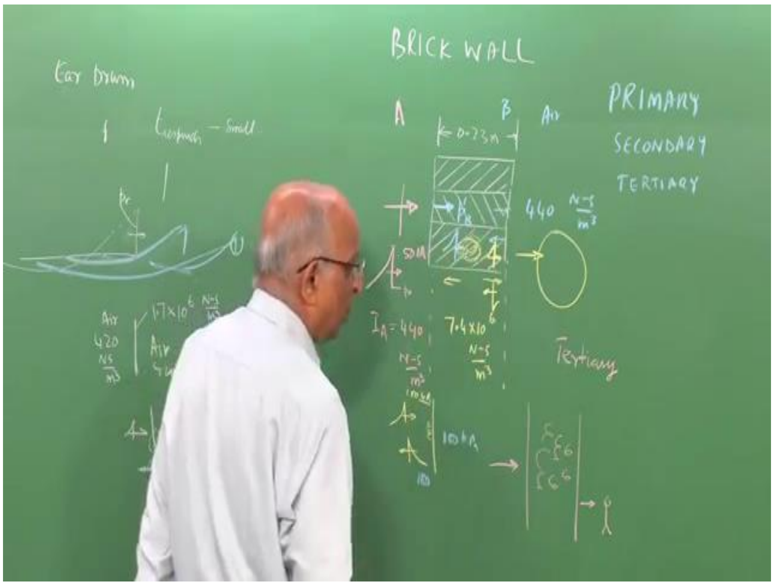

What gets transmitted into the air over here. If I were to take a look at what gets transmitted let us write it in pink color chalk over here, what gets transmitted is equal to what gets transmitted is 2 times into Z b divided by Z b plus Z a. In this case b is the second medium which is 440, that is 2 into 440 divided by this value is around 7.4 into 10 to the power 6.

Again is what is and we already know that is 2 Z b, we have the value which comes here is something like we said 50 plus 50 is 100, 100 comes over here therefore, it is equal to

100 over here. Therefore, you find this is equal to 0.44 into 10 to the power 3 that means it is very small. Therefore, what is going to happen.

If I have brick structure housing brick structure and if a blast wave comes and hits it and people are inside the house. You know the transmitted blast wave into the house is a very very small part of what is getting into the brick. But however we find that the brick collapses when the over pressure which hits it is greater than around 50. Therefore, the brick crumbles and this brick can fall on the people and cause damage to them, but it is not the blast wave which is going to cause damage. Therefore, when a when a building falls on the subjects over here and still causes damage, we say that the damage is tertiary that means.

It is not a direct damage from the blast wave, but it is rather the collapsed building which causes the disaster. Therefore we tell well the type of damages which are caused could either be primary. Primary is from the blast wave directly hitting something which causes this, which causes the damage. It could be secondary, in the case of secondary it could be due to missile effects primary could be from over pressure and impulses.

Secondary would be from missiles and fragments which have the momentum and it is the momentum which goes and knocks down a person or causes injury to the person. The third is tertiary, which is due to the effect of a collapse building on the human being. Therefore, but how do we make a wall which is explosion proof or such that we save some people. Well the tensile strength of the brick or the concrete over here which is used instead of brick must be able to take tensile failure.

Therefore, we make better concrete systems may be instead of brick we use concrete and in concrete we put some slack such that the tensile property of the concrete is improved. We keep, we can now think in terms of a situation wherein we make the wall of the building little thicker. Let us put that figure down, in fact we have a thick concrete wall.

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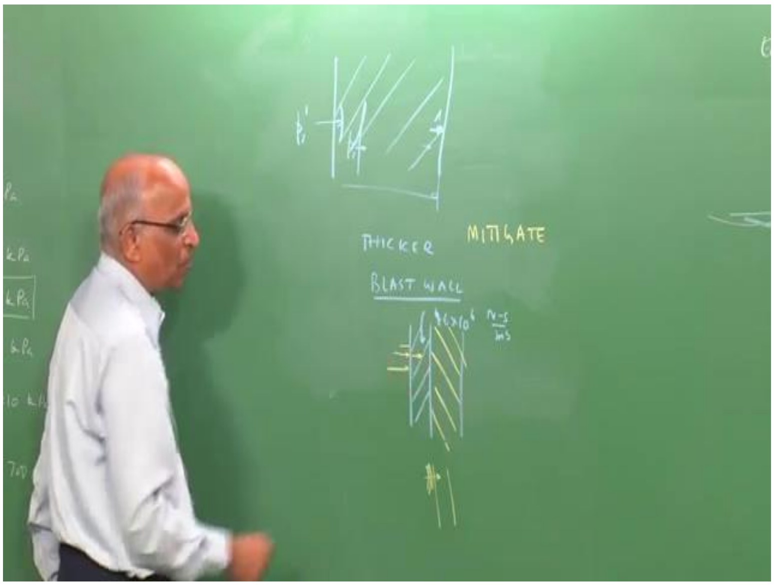

Then if a blast wave comes in let us say something gets transmitted into the blast wave. We have the incident value is p i prime, what is getting transmitted is let us say twice the value, but still it is quite high. If my thickness of the wall is something like very large, by the time this blast wave comes over here the reflected value depends on the value which strikes this interface between the wall and the air over here.

If this value is now decreases from the value of the large value over here because of the larger thickness. Well the expansion will be very weak and it will not be able to spoil or cause damage to the concrete over here. Therefore, whenever we use a concrete wall for protecting, we not only make the concrete to have higher strength and tension, but we also make the all to be thicker. Such type of construction when we use for protecting human beings or may be from blast is known as a blast wall.

We use blast walls not only for human being, but to protect some equipment, maybe we use it in places where we expect a blast wave and this is used as a protection structure. Well this I about protecting people and human beings and how to go about this. May be I could also think in terms of a different situation, may be I could have steel. We said steel has a higher value of the impedance, the value of impedance for steel was around 46 into 10 to the power 6 Newton second by meter cube.

You know if I can use steel, may be a smaller thickness because steel can take some amount of tension compared to concrete. I can also use dual structures wherein I use maybe steel with some other material over here, composite structure such that I just keep reducing the values of the over pressures. It is possible to use such structures to mitigate the influence of the blast wave.

Mind you, see in these things we presume that the structure of the brick wall or the structure of these composite things are, static over here. When the blast wave hits it they do not relax, but if the blast wave may be if the boundary conditions by which these structures are held allows the wall to relax may be I use something like a structure here which moves in this particular direction. Well in that case my reflections my transmitted wave will be much lower because I have some structure which is moving and when it moves, well it take, it relaxes the type of the it reduces the strength of the eave which hits the particular wall.

Therefore, the boundary conditions are important, but in this case when I have a wall which is rigid, well I can presume that maybe the blast wave comes to it. I have the reflected wave and I have the transmitted wave and this is what happens. In practice if you want to protect some vehicles, maybe I would like the ends if I want to relax it, well the ends the depending on the end condition the structure could move. If it moves well it absorbs some amount of shock over here and the transmitted shock will be even lower. Having said that let us go to some other examples.

Let us go to the last example we take and then we will generalize it. How about a human being who is struck by a blast wave and because what happens is may be at 70 k p a we said. Well a person who is maybe standing at some place gets knocked down what is this knocking down.

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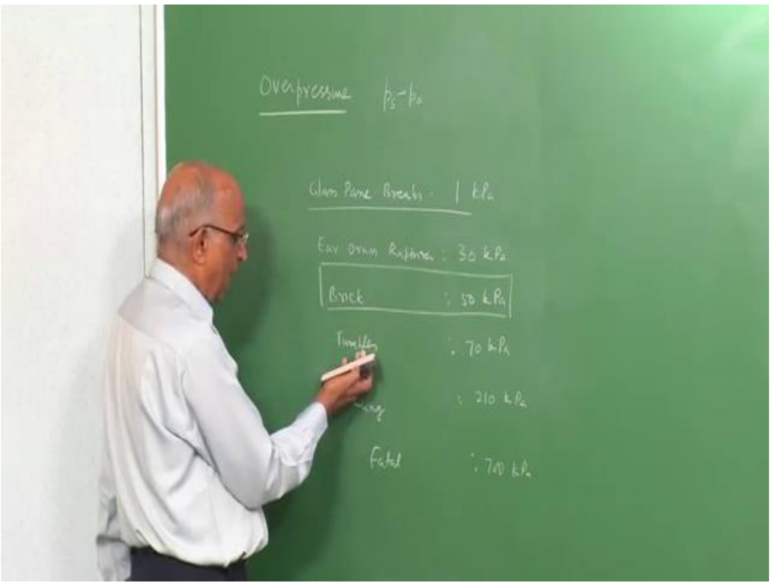

Let us take a look at this. We take the example, let us say there is somebody standing over here, well an over pressure followed by an impulse comes and hits him because of this what happens?

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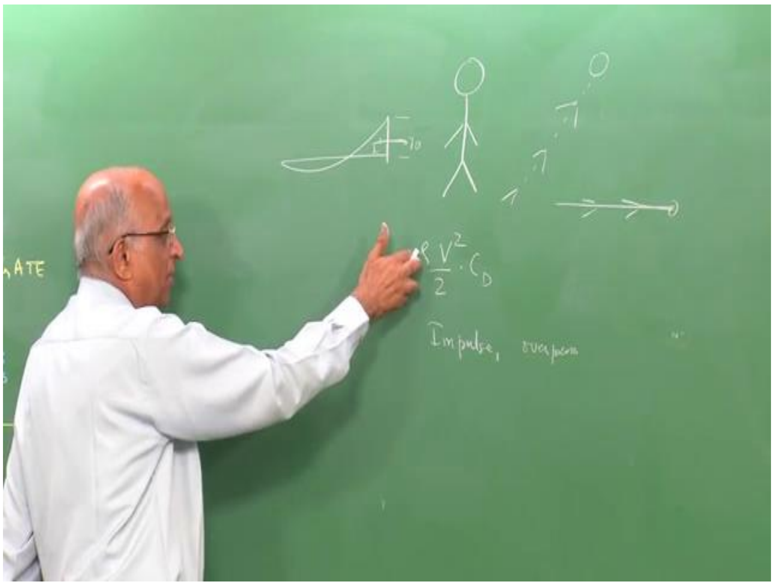

Well he is because of the over pressure he is just forced, he is displaced because of the impulse what is going to happen. I give him a momentum I give him a velocity that means he gets some velocity. Therefore, the when he moves slightly there is some drag force because of the wind effect, he is dragged behind and because of the drag force what is the drag force d, you have rho v squared divided by 2 the velocity with which he is dragged forward. The sides are he is pushed in this particular direction into the drag coefficient over here because of that may be he is displaced over here. Ultimately maybe he falls on the ground something like this.

That means he is toppled down and why does he get toppled down because of the impulse that is the positive impulse which provides him with the velocity. In addition what happens in the over pressure, sort of displaces him whereas, the impulse may be knocks him down. We said an over pressure of 70 k p a is something which knocks him down. Well it pushes him and the impulse behind it knocks him down. Therefore, may be in this case I should consider the failure or the or the type of destruction or the knocking down is more due to impulse than it is due to the over pressure.

The over pressure will only displace him like for instance. Let us consider a man who is stout who is heavy, who is hit by a wave. Well he can withstand the over pressure, but as he is dragged down by the velocity by the blast vent well he topples down. Therefore let us try to put this in a better scenario. I show it in a particular slide. You know I show here an object over here.

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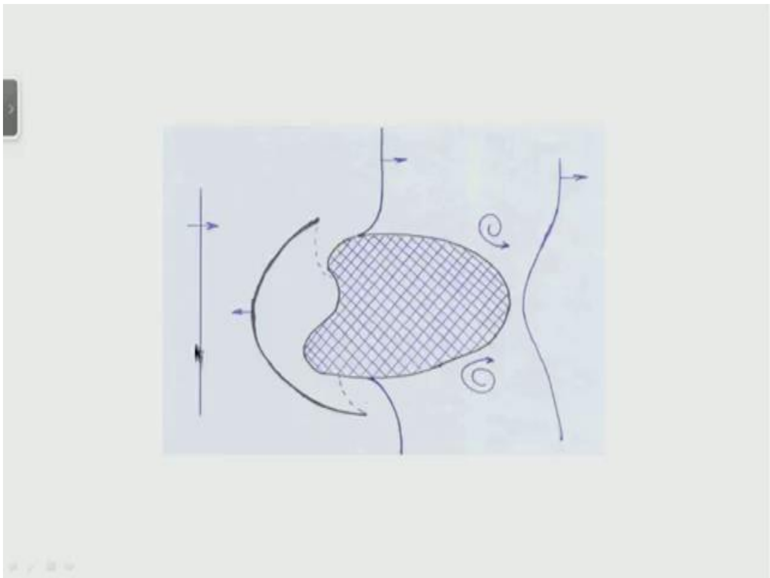

This object is being hit by a by a last wave over here, it comes inward it hits him over here. When it hits this particular irregular sized object over here, well it gets reflected. Well the reflected pressures are very much higher than the incident values depending on the strength of the initial blast wave what we get. Well the reflected blast moves outward in this particular direction because the object is not very very much like a straight line or something which I have assumed over here. May be I have the initial spherical blast wave coming over here, the characteristic length here is small. Therefore, I represent it by a straight line.

You know because of the reflection you have uneven pressure distribution on the surface. Therefore, you have the loading on the particular body over here is not very even. In addition to this, what is going to happen. The blast wave when it comes in these particular portions it gets expanded over here. The blast weakness and far away, well it could still be stronger, near the body it weakens and it progresses over here. Therefore, you have higher pressure here lower pressure here therefore, maybe there is some wind over here.

Therefore, what is happening, as the wave moves forward may be you have from the higher pressure region towards the lower pressure region, some wind blowing. Well it creates an a d or a vertex over here. I have a vertex over here and the blast wave ultimately which moves through the air gets here. There will be some element of transmission of the blast wave through this. We have not put this in this figure, but what I want to show is, well I have the velocities which are induced over the surfaces.

They cause the drag and because of the drag well the body gets knocked down. This is the thing, but what is more important is, well the blast they the over pressures whoever here need not really be even and the here the you find that the body is subjected to over pressures here, which are not of the same magnitude because of the distances here the incident wave is a little weaker than the weave over here.

Here, the incident wave is stronger because is nearer over here and therefore, we find the pressure distribution over the body is itself not uniform. Here you have expansion taking place and because of this you have a force over here, which is addition to the wind causes the body to be knocked down. Therefore, what is it we can now summarize the whole thing by telling the following. Well we looked at 3 or 4 examples and based on these examples we find.

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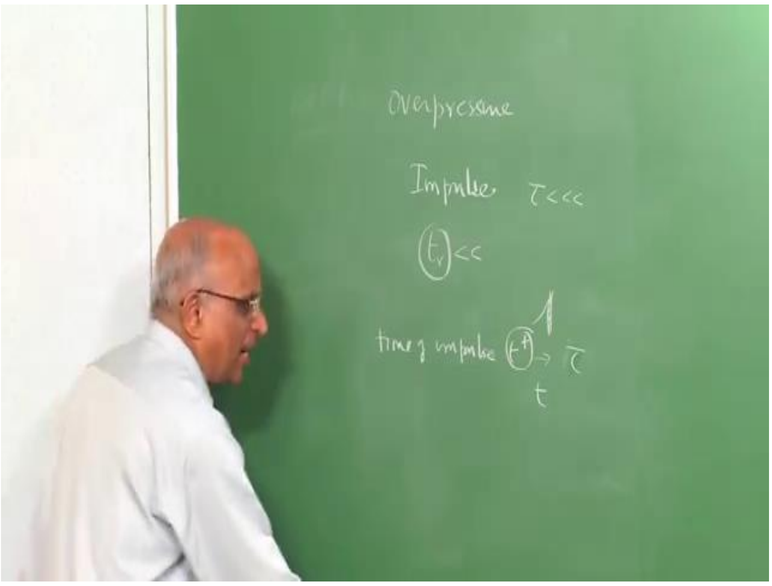

Well both the over pressure and the impulse, that is the wind effects are important, but can we say little bit more. We also talked in terms of the rear drum having a very high response that is the response of the human ear is so small that it is a very small number. Therefore, we said well, it could be due to the over pressure itself. Impulse will not play a role because even if I have a short impulse well it the impulse is over a period of time, much before this time. Well the ear ruptures because it is thin and the reflected expansion waves at the second interface causes the failure.

Therefore, we know we have to somehow relate the time of the impulse, that means we are talking of positive impulse t plus. We are also talking in impulse over here t plus with respect to the characteristic time, that is the frequency response of the body which I can say is tau. I can tell well the ear drum has a characteristic time tau which is a very small number. Whereas the impulse has a characteristic decision, let us say t plus or some value of t over here. How do I relate these two is the question? Therefore, to be able to understand this let us take one small example of let us say a structure or some particular body, which is resting somewhere and we all know well it is possible to represent a body.

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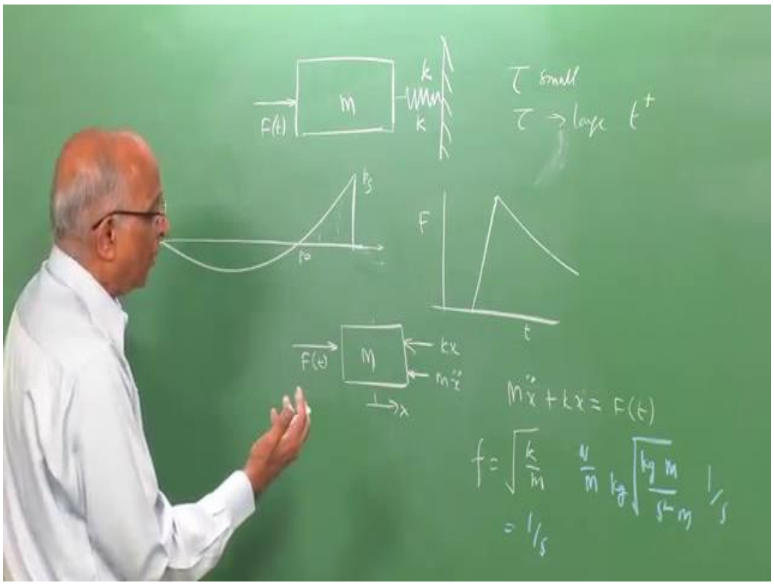

Let us say of mass M. You know there it is resting against someplace therefore, I can also modulate in terms of spring mass system well I say equivalently I have a spring of stiffness k and it is held may be over here. What is going to happen, well it is hit by a blast load. Therefore I have something like an over pressure and behind it I have the impulse coming over here and what is happening is, I have the pressure initially is p o rises to p s, then it comes to p 0 again and it reaches the value p 0 again. This is the positive impulse this is the negative impulse.

Therefore, because of this at different instance of time, I have different pressures which the body forces or rather I have a force as a function of time or rather I can tell myself the force which the body experiences is, when the lead shock may be at this particular time when the lead shock comes over here. Well the force reaches the maximum and there after the force decreases.

Therefore, this particular characteristic can come out as in terms of force being varying with respect to time. Therefore, I have a periodic or a time dependent force striking a body of mass m in it sort of a spring over here some value of holding the body is here. Therefore, I can represent this free body diagram of mass as m. I can say well if I consider spring of stiffness k, then I have k into x over here, which is the resisting force. I have the body force over here f t.

I have the force that is the force on the free body diagram it is m, into x dot over here this is the let us say the direction of x over here, this is the acceleration. Therefore, I can write my equation for the body as equal to m x 2 dot plus k x is equal to the time varying force over here. Now, if I look at the frequency response of this particular body. Well the frequency is equal to under root k by m, stiffness by the mass of the body. Well stiffness as units of let us say Newton per meter, body has units of so much kilo gram, m has units of kilo gram. Therefore, you have Newton per meter kilo gram over here.

This is equal to kilo gram meter per second square. This is therefore, equal to I have kilo gram meter per second square is Newton. I have meter over here therefore, this becomes therefore, the unit is 1 over second and this is the frequency. So, much one over second. If I look at this characteristic frequency, the frequency is very higher. Well the characteristic time of response of the body is small. Therefore, if I have a body which has a very small response. Well the over pressure is itself is sufficient to cause the damage, whereas, if the characteristic time t of the body is large.

What do we mean by large, large as compared to the or significant as compared to t plus. Well the impulse will cause a damage and may be what is going to happen is the average value of the pressure is going to, is going to cause the damage plus the impulse is going to cause the damage. Can I therefore, put these things together in some form of figure, such that I illustrate, where impulse is going to cause a damage where over pressure is going to cause a damage. Let us try to see whether I can do that.

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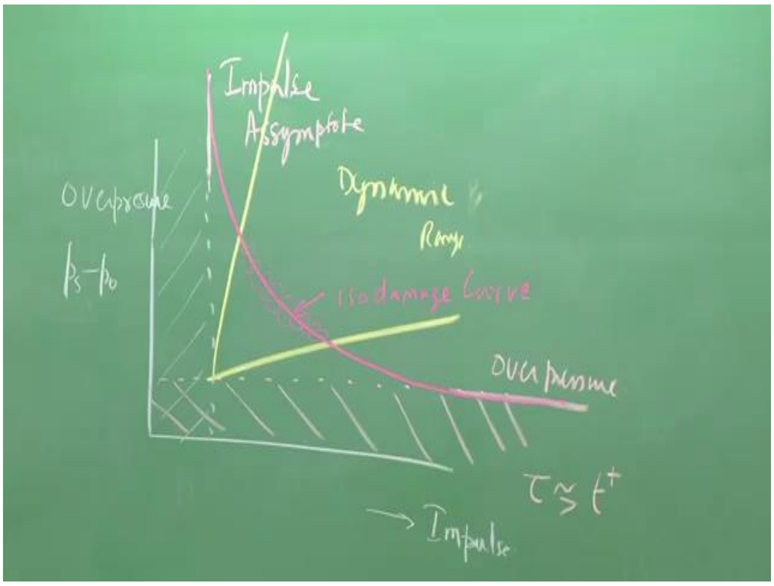

What I do is I have a figure in which I put over pressure. On the y axis that means I put p s minus p naught over here, I put impulse on the x axis. Well, you know for some bodies we find that well impulse is not really matter of concern, it is only the over pressure which causes the damage because the response is small. Therefore, I say well this could be one case over here and this particular region is the region, wherein only over pressure type of causes the damage.

I could also have the other condition, wherein I could have something like a large value of impulse which causes the damage. May be even at smaller over pressure I could have large values of impulse which causes this therefore, this becomes my second zone over here. Therefore what is it, you know we are talking in terms of a situation, wherein may be this is the limiting asymptote corresponding to impulse. Therefore, I say this is the impulse asymptote

Well here it corresponds to the minimum threshold value of where over pressure of over pressure type of an asymptote over here. What is going to happen, this happens in this region. We tell that the characteristic time of the body tau is of the order or very much greater than the impulse time. That is t plus or equivalently the impulse time. In this case t is very much smaller and in the region wherein, you have t of the order of magnitude that means the characteristic time of the impulse and the characteristic time of the responds of the body are same. Well it could be the dynamic region.

In which case I have to do the dynamic analysis that is the dynamic range over here. Therefore, if I were to put the value of let us say an iso-damaged line for a both over pressure and impulse, what is it I will get. I will get the value as something like this coming over here and coming over here and this becomes something like an iso damage curve. Therefore, we could talk in terms of may be impulse induced damages when the frequency is large or the characteristic time of the body is small, of response of the body is small.

We talk in terms of these damages here, when the time constant of the body is quite large compared to the impulse times. When both are of the same order maybe we should do some dynamic analysis or this is the dynamic range of this. To do this is quite involved may be we have to look at the frequency response of the bodies and put together the over pressure and impulse together. Well this is how we look at damages and let us continue with this.

Let us take a look at what are the type of impulses which we get on the body and the ambient and how they amplify each other. We will consider one small example now. Let us re visit the example of crater which we talked earlier. We talked the example of a crater.

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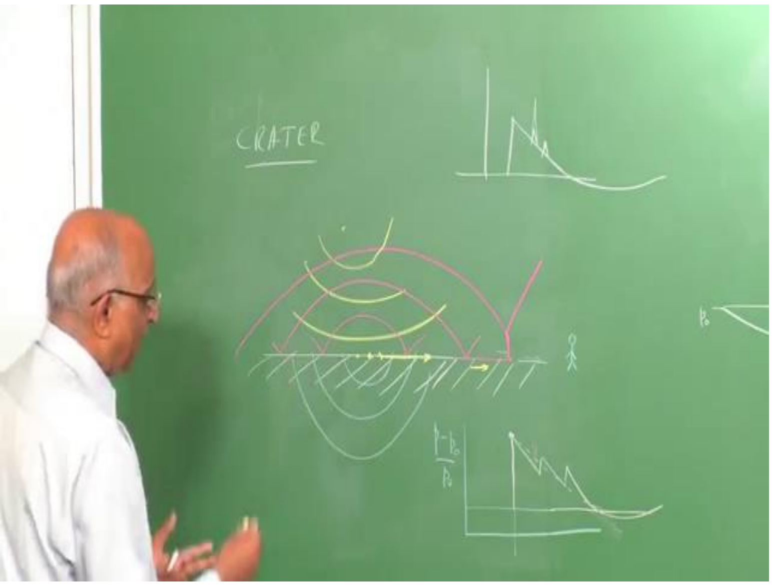

What happened in the case of a crater, let us put it together. You know in the case of a crater, we have a blast wave which comes towards the earth. Well the blast wave hits the earth gets reflected goes up and we also talked in terms of additional waves which are being formed let us take a look at it. Well this is the earth over here well a blast wave originates.

From let us say air over here blast wave comes over here. Strikes over here then what happens, something gets reflected let us take a let us plot the value of the reflected values well the reflected wave comes over here. Now, we told ourselves well the reflected pressures are higher.

Therefore, and the these reflected waves are traveling in a medium, which is already heated by the incident wave, plus if there is an explosion the other heat from the explosion is also going to heat the medium, with the result the reflected waves travel faster. They are even stronger and with the result when these reflected waves impedes on the earth over here, if the angle is quite small. Well I get the reflected waves over here, but as this angle becomes shallow what happens is, I am not able to maintain.

You will recall we did this in our class, we told well if the angle is such that it is not we are not able to meet the conditions, wherein the velocity on the round has to be parallel to the ground. Well the incident wave that is the reflected wave which strikes it gets spurted up from the surface and what is found is something like a mark stem shock. Then I have a shock like this. Therefore, I have a mark stem shock a reflected shock an incident shock and of course, as all of us know, we have the transmitted shock into the ground which forms the crater.

Now, we will not look at the crater formation we have looked enough of it. Therefore, we find yes I have these reflected shocks which are stronger. I also have a mark stem shock. I have a reflected shock over an incident shock over here. Therefore, if I a person is going to stand over here, what is it he is going to see, what is the type of shock pattern or the impulse patter he is going to see. Well let us sketch it out.

Well we tell ourselves I am looking at p minus p naught divided by p naught. This is the pressure to which he is going to be subjected to, well at this time after the blast wave hits the ground, after some time he sees only the ambient pressure. After a particular time what does he see, he sees well the wave is going and hit him, he sees this particular mark stem shock or the reflected hock which comes and reflected shock from the reflection which comes and hits him.

Then after sometime well the second shock comes and hits him and may be so on, the third shock goes and hits him. Therefore, the type of impulse what he sees, is not going to be a single spike, which came down like this, but as series of spikes. In general, the impulses because of the ground reflection the other shocks which are there cause series of spikes in the impulse pattern and we seldom get an impulse pattern, which is really something like this, but we do get spikes over here because of the additional shock which come.

Sometimes, these spikes could be even larger than the initial value. It all depends on the ground conditions on the type of reflections what you have, but we must also remember, when you have an incident a reflected pressure over here. At the surface you could have the seismic wave and this wave is also traveling along the surface, but what causes the damage is the impulse from this particular one.

Well theses are about the different ways of looking at it, just to wrap up the subject what I do is in the last 1. Let us take a look you know these multiple shocks in an impulse are not only due to let us say due to when the blast wave hits the earth. It could also be let us consider the last example, wherein I have a sphere.

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In the sphere let us say this is the, this sphere gets exploded. That means the initial volume of the sphere, let us say we put it back in terms of what we learnt we say that the radius of the sphere is r e. A sphere which explodes and when this sphere explodes what happens is a blast wave takes off over here. Now, this is the high pressure gases which explodes the cylinder. It could be hot it could be cold, but all the same it is high pressure. Then the interface of the high pressure will also follow it will also expand out like this.

The high pressure gases expand over here and when I create an explosion that is a blast wave in this particular direction. Well here the gases are at high pressure and what is going to happen, a wave is going to travel back that means an expansion wave is going to travel into the body, into the medium which has just exploded because of this interface over here this is the symmetry line. Well this reflection wave, this expansion wave which gets reflected is again coming over here.

I have a reflection wave going over here. Now, what is happening the dotted line red may be I will show it like this, in this region. Well this is a high pressure gas region which is gradually expanding out, this is the ambient pressure over here. I have an interface here well the impedance of this is lower than the impedance of this. Therefore, the rarefaction or the expansion wave you know when it comes here, well it gets reflected as a shock wave. For the same reason, you know when a shock wave comes, it gets reflected as an expansion when a rarefaction wave comes, it gets reflected as a shock wave, let us show it and yellow them.

That means it gets into the medium as a shock wave over here. Well it gets again reflected as a shock wave and therefore, what is going to happen it progresses into the medium over here. It goes into this medium well over here I get a rare faction wave or a wave which is an expansion wave. Therefore, when this comes as an expansion wave over here, well you know it gets reflected as a shock wave. Therefore, I have a wave like this and this wave comes forward.

Therefore, I have a series of shock wave 1 shock wave 2 shock wave 3. Therefore, if a person is sanding over here or may be at some particular time he is over here he sees the first wave then he sees the second wave and then he sees this third wave. At the nature of the impulse what we see is, this is the positive impulse and this is the negative impulse.

Therefore the impulse need not be something which is smooth like what we said, it could contain a series of shocks 1 after the other and this happens in all explosions. The interaction between a blast wave and a body placed on the path. We looked at the mechanism of failure and may be with this, we will stop our discussions on blast wave. We will revisit it again when we look at ideal and non ideal explosions. Also look at how to quantify damages, we will try to quantify damages in term of in statistically because we also recognize that, we told ourselves in this class, that may be the ear drum rupture at let us say a pressure of 30 k p a.

May be a small child who is more sensitive the ear drum of the child may rupture quite early because it still very tender, where as some an older person will be able to, strong person might be able to withstand a pressure of 50 k p a. Therefore, to some extent the damages are statistical in nature. Therefore, later on in the course we will look at damages through a statistical procedure. Well then, than you and in the next class we will try to take a look at energy released from the explosion, in explosions.

Thank you.

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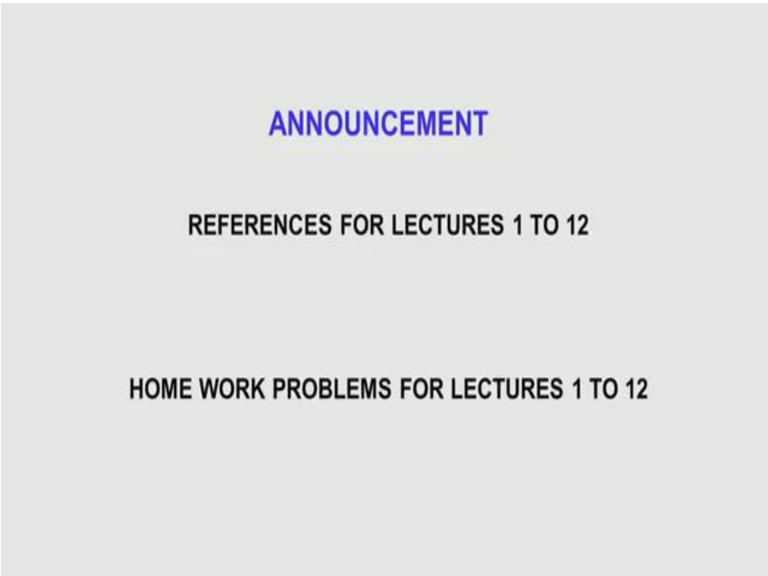

An announcement please, in the last 12 lectures we have covered the basic of what constitutes an explosion and the modeling of blast waves. I give in the downloads of this video course, additional reading material namely references relevant to these portions. A small set of homework problem is also given to help you work with the basics, which we covered in lectures 1 to 12.