Introduction to Explosion and Explosion Safety
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Lecture - 11
1) Blast Waves: Amplification of Reflected Blast Waves
2) Role of Impedance, Spalling, Damage to Organs containing Air, Mushroom Cloud in an Explosion, Examples

Good morning, you will recall in the last class we were interested in determining if a blast wave hits an object, how much of the wave gets transmitted into the object and how much gets reflected. Therefore let us continue on that.

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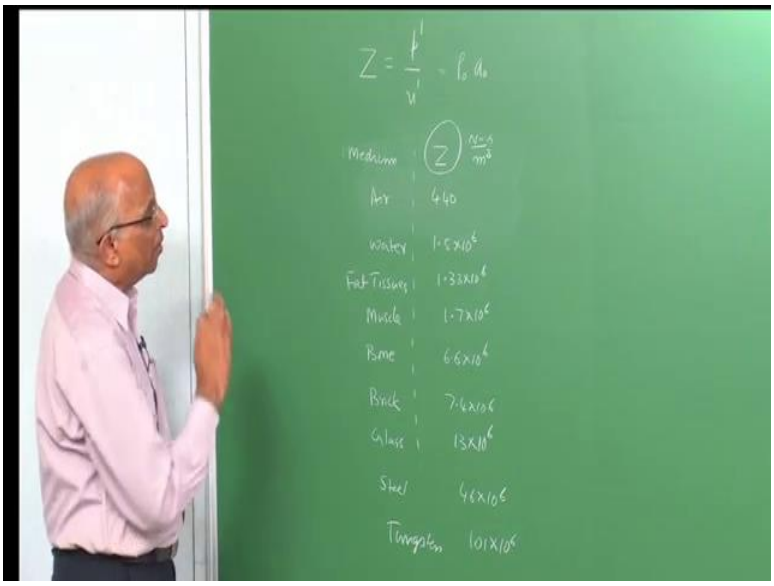

You know we will recall, we defined something known as an impedance e z, which we said is equal to the change in pressure divided by the change in velocity. We call velocity as u prime, the change in pressure as p prime, change in velocity this and in the limit that the wave is an acoustic wave we defined. We determined an expression for this impedance, which we called as mechanical impedance as equal to the density of the medium into the sound speed in the particular medium.

You will tell me that well it is for in the limit of round waves, that means a very weak shockwave, it is really applicable for strong shock waves, we will take a look at that, but we will keep the assumption. It so happens that it can still be used and that I will justify it a little later, but let us proceeds with this impedance and the problem which we are considering. Suppose, I have like say a medium some medium and into this medium, let us say a wave is propagating and at the end of it meet some other medium. Let us say over here how much of this wave gets transmitted into the second medium and how much gets reflected into the back into the first medium.

Therefore, before we do that, I think we should have some feed for this impedance value which we called as mechanical impedance or impedance. Let us put the value for some particular time or some particular medium or some particular materials of construction. Let us say I have some medium, if the medium is let us say air, we found that the value of the impedance or we called as mechanical impedance unit. You will recall it was Newton second by meter cube and the value for air was we determined to be something like 380.

Well, the actual value something like 44 Newton second by meter cube, let us put down a few of this things, it will acts as a guide line to develop further on this. Let me give a few values, for water the value is around 1.5 into 10 to the power 6 Newton second by meter cube for something like this tissue in our body that is the fat tissue in the body. The value is 1.33 into 10 to the power 6, something like a muscle in the body, that means we are talking of human beings, we are talking of tissues and muscles. The values are around 1.7 into 10 to the power 6 Newton second by meter cube, when I consider a bone in the body, bone is something harder the value is around 6.6 into 10 to the power 6.

If I consider a brick, which is used for a building, well the value is 7.4 into 10 to the power 6, let us take one or two more materials, the glass is somewhat higher like say pyrex glass the value is around 13 into 10 to the power 6. Well, if I consider steel, which is very much harder, then brick the value is around 46 into 10 to the power 6 and the last material like tungsten. The value changes from a 200 to several million and it is this values which really decided, whether the wave gets transmitted, whether the how much of the waves gets reflected.

We will keep this we will keep this as a reference with which we can understand something more about the reflection and transmission of waves. To be more clear about what this impedance clearly represented, we can tell ourselves in the limit of let us say weak shock waves nearing an a acoustic wave. What is happen well u prime is something like maybe I call it as p square, p prime square divided by u prime square.

We are talking of molecular velocity of fluctuation how much the molecular velocity of fluctuation represent as pressure fluctuation or pressure changes is associated with molecular velocity changes is what is in the limit what we derived the other day. Therefore, let us keep this as standby, let us now put the problem together, let us do how much of it gets reflected.

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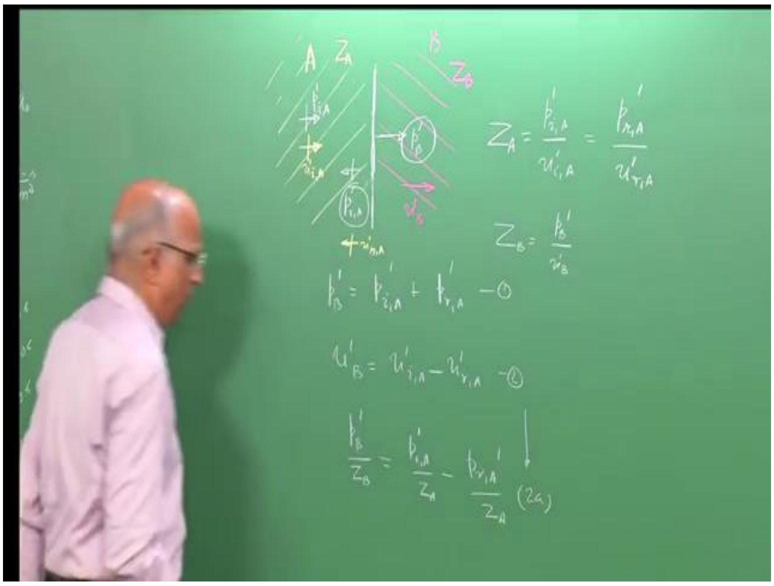

Therefore, I say let me say I have a medium two medium separated by a say an interface over here let us say on the left of this interface I have a medium, which I say is medium a and right of this particular one, let us say this medium a over here. Let me hatch the whole for you this is in yellow colour the right of this medium is let us say b medium b, which I show like this interface separates the two medium over here. Well, one could be air, could be solid one, water one could be solid, it could be different phases or may b different gases one could be hydrogen which is very light gas.

The other could be air, which is a little denser or could be air which is a little denser or could be still denser gas and so on. This is the difference between this two medium, well I am interested if a wave is travelling, let us say pressure wave is travelling in this medium a over here. It is incidence on this surface, how much of this pressure wave gets reflected and how much of this pressure wave gets transmitted to this particular medium into the second medium. Well, let us put some numbers to it, let us say the pressure wave has let us say an over pressure p prime over here is say well it is p prime, this is incident on this surface, I say incident on this surface in medium A.

Therefore, a h over pressure p a travels towards this particular interface, that is towards this medium, what happens at the surface, let us presume what gets reflected is p r in the medium. This is what is getting reflected and what is get transmitted into the medium b is equal to let us say p b prime over here. Therefore, we are considering this problem in medium a wave of amplitude or let us say a pressure wave of over p prime a comes over here get reflected over here and in medium b because of this wave something gets transmitted. I want to determine this value, let that mean I am interested in determining reflected value.

Therefore to do this problem immediately, I tell myself well I well I can do this problem because there is increase in pressure over here because I have p prime over here i further increase over here. Therefore, the net pressure at the interface is equal to the sum because at this interface, I have some increase further some increase over here is equal to p i a over here prime plus what is reflected over here p r of a prime over here. This is my equation 1, well associated with this pressure changes or pressure fluctuations or let us say over pressure, there is also a velocity component and let us now presume that the medium a has an impedance e z a and the medium b have an impedance, let us say e z b.

Now, that is what going to happen because of this p prime over here you know because of this pressure fluctuation. Let us say the velocity fluctuation associated with this incident wav is equal to u prime into i incident of a along with this that means I have a velocity perturbation shown in l. Similarly, the velocity perturbation associated with this reflected wave is going to be u prime incident, now this is reflected, therefore r of a over here. Similarly, I also have a velocity perturbation associated with p b here, p prime b here and that is equal to I have velocity perturbation u prime associated with b, this is an equal to u b prime.

Now, at the interface what is happening some velocity comes here some velocity removed from here and therefore, the velocity perturbation for b. I can write as let us write it out u prime b is equal to the value of u prime incident at a minus u prime reflected. That is what is pulling it back into a over here, these are the two equation which I get, now I want to solve this equation to determine the value of p a and p b, but then I note something.

I note there are two medium and this is the interface between this two media over here, therefore I can write the value of e z a is equal to the impedance of a is equal to in terms of pressure and the associated velocity is equal as to p prime. I have incident of a divided by u prime incident of and a, similarly I can also write the value for this for this reflected pressure this is also equal to the value of reflected pressure at a divided by u prime reflected of a over here. In this impedance, p prime divided by u prime for the incident wave is equal to impedance, I have this equation, similarly, I have the value of e z b that is the impedance of b is equal to I have p b prime divided y the value of u prime of b.

Now, from this impedance equation for a, I can determine the value of u i a is equal to if I write it here it becomes p prime a divided by I also get u prime reflected at a is equal to p reflected a fluctuation divided by e z a or change here divided by e z a. Therefore, what do I get, u b u b prime is equal to p b prime by z b and therefore equation two, p b prime divided by e z b is equal. I write u prime a is equal p i prime a divided by e z a minus I have p r, which is equal to u prime u prime reflected a is equal to p r prime divided by e z a. Therefore, equation two now reduces to the form let us say equation 2 a over here, therefore let us put this two equation together and what is it I get?

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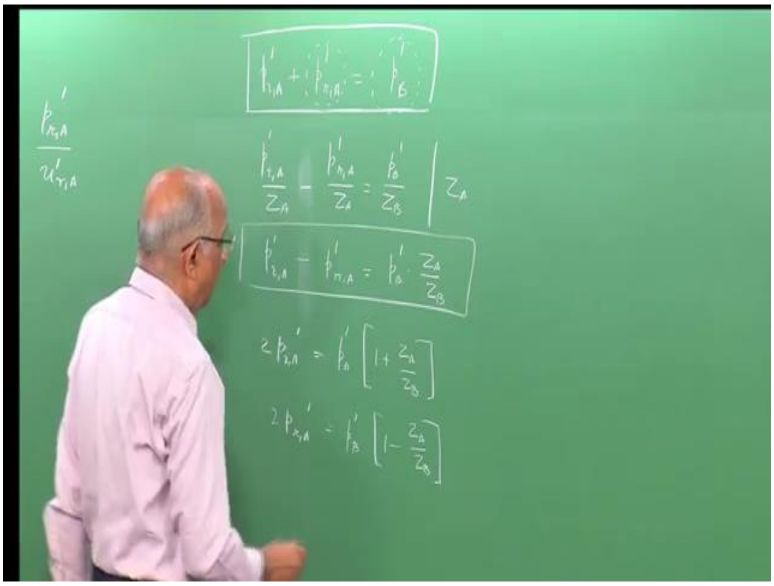

From the equation one, I get p i a p prime plus p prime reflected a is equal to that is this is equal to p prime band. From this particular equation, what does it say, well I get p prime a incident a divided y a plus, I get p prime reflected a divided by e z a over here. This will becomes this, this is my first equation this is my second equation which I called as 2 a, I want to solve this equations to determine the value of p r p prime r a that is the pressure over pressure of the reflected as function of the open pressure of the incident. I also want to determine what is transmitted over here, therefore, to be able to solve this, well I find this is p prime plus p prime for incident and reflected.

I have e z a, why not multiply the second equation by e z a in which case get p prime i a plus p. I think we have made a mistake over here, it is equal to p prime a by e z a minus p r a by e z a. Therefore, the value here is equal to minus over here, therefore the value is if I multiply by e z a, I get p b prime into I have multiplied by impedance of a medium b.

Therefore, this becomes my equation two this becomes my equation one this is my equation one, well I add that together, if I add that to the reflected component gets knocked down I get 2 p i a prime is equal to I get p b prime into one plus e z a by e z b d If I subtract this well it becomes minus p I plus is equal to minus, therefore I get 2 p reflected a prime is equal to p b prime.

Well I get 1 minus e z a by e z a over here, now I want to solve this t two equation for the reflected components. Therefore, lets us first get one value let us get the value of p b prime, now can I get the value of p b prime. Well, I used this equation and what does it tell me from this equation is say p b prime is equal to twice the incident value into e z b divided by e z b plus e z a.

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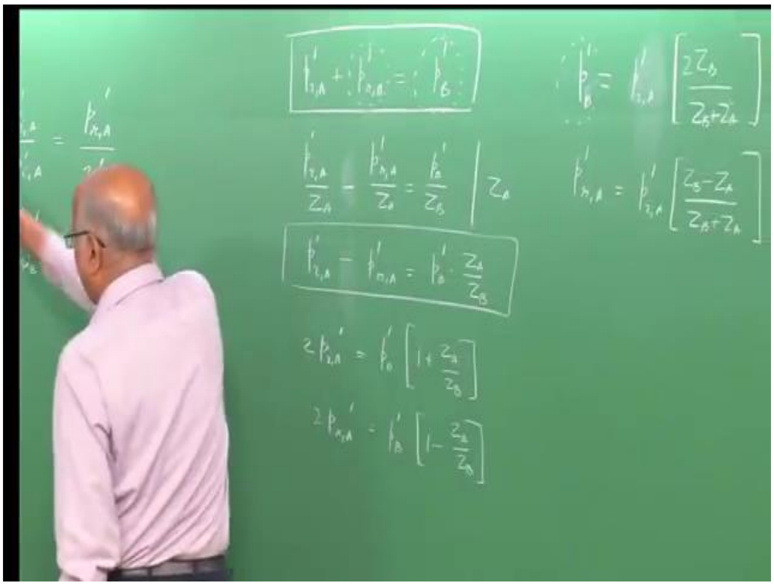

Form this equation, I can write the value, let me write it over here p b prime is equal to the value of 2 p i a 2 p incident value i into get the value, what comes over here e z b upon e z e z e z b divided by e z a or rather e z b plus e z a. Rather, I take the two inside and if I have to express it in terms of p i a, I can write this as equal to p i an incident in a into two e z a divided by e z b plus e z a. Now, I substitute it in the second equation to get the value of the reflected value, I get p prime reflected in medium a is equal to I get the same value here p prime of the incident value.

If I have to substitute it, well I have taken this is 2 divided by 2, that means p r a is equal to p b by 2 cancels of and in the denominator I have e z b by e z a, now it becomes e z b minus e z a divided by e z b plus e z a. Therefore, what is it we have done we have been able to get the pressure which propagates in medium b as a function of the pressure in medium a in terms of the impedance of b and the impedance of a.

Therefore, this is this is precious because now we are able to get the value of the of the pressure, which gets transmitted into the medium. Therefore, in this particular problem i tell myself well I can determine these values in terms of the incident value of the pressure over pressure. I also get the reflected values which is equal to e z b minus e z a divided y e z b minus e z a well this is all about the derivation. We are able to get the value of the reflected of the transmitted pressure in the medium b we are able to get reflected values in medium a. Let us try to discuss this result and see what it really represents let us consider this medium again let let me erase out some of the things over here such that i can use the portion below this to be able to represent some physical conditions.

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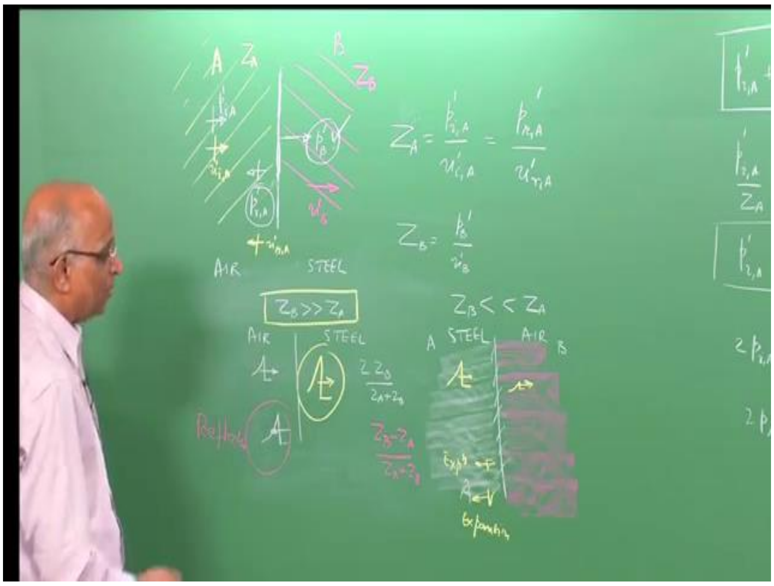

Supposing, I say well this medium is something like let us say air for as an example for which the e z a is around let us say 440 seconds by meter cube. This say is something like steel or some material for which the value is around very much higher almost of the order of 4 into 10 to the power of seven. Therefore, in this case what is we are talking of is e z b very much greater than e z a, what is going to happen lets taken a look at the expression what is going to happen. Let us say now in this case K, have the medium a over here which is let us say air the second medium is let us say steel over here for which the impedance is very much higher.

Now, let us say I have a shockwave, a shockwave is like this, I have over pressure and this is my magnitude of pressure which is going towards the wave. Now, what is going to be the wave which gets transmitted into this medium, if I have this which is incident let us say this is my p prime a over, what gets transmitted is the magnitude multiplied. If I were to take a look at this is going to be 2, which is we are talking 2 e z a plus e z b that means the magnitude of the pulse which gets transmitted into steel is going to be higher. This is what gets transmitted into my particular medium and is there something what is going to be reflected well what is reflected we saw is equal to e z b minus e z a.

Let me write it down w z b minus e z a divided by e z a plus e z b we told ourselves well b is very much greater than a. Therefore, this is a strongly positive number of the similar magnitude because e z a is very small, therefore I am going to get the same magnitude which is reflected back. Therefore, I tell myself well this is the reflected component, this is the transmitted component, now I mean business, I am to find out the transmitted pressure wave. I am able to get the reflected pressure or the reflected shock wave and this how we do problem, but this was for the particular case of e z b greater than e z a in.

I do this problem, let us take the other example of e z b that is the second medium being less than e z a what is it will get well in this case let us consider the reverse lets still consider the case of steel let us consider the case of air as the medium b. Now, this a as the medium, therefore what is going to happen in this case lets again sketch out what is going to happen this the particular interface at which the two media came in with this is media a and you have the second media. This is b over here this is the interface between the two media and now into the media I have some like a shock is coming over here this is the amplitude over here what gets transmitted.

Well, I find that e z b is smaller and whereas, e z a is very much higher, therefore what gets transmitted is little lower this is what gets transmitted into medium and what is reflected. Well, if I take look at reflected I have e z b is less that e z a, it is negative that means what goes as a compression gets reflected as expansion, rather what is going to happen it is an expansion wave behind the expansion wave well. It is something opposite of this I have compression behind the expansion wave, it gets reflected a expansion wave. I will repeat this again because this is important you know you have a compression wave, which is moving towards the interface and what get reflected is not the compression, but just the expansion.

That means this is the pressure I have still the drop in pressure and what gets reflected is something the drop in pressure and what gets reflected is something like an expansion waves. What do we mean by this, you know why should why something which travels as a compression that is some over pressure get reflected as a expansion is you know you have this particular surface.

When it meets the surface over here well the surface relaxes because it is very much rarer and when surface relax. What happens is well the surface relaxes and therefore what expanses is going to be much it is an expansion process over here. Therefore, what we get is an expansion well wave or rather we tell ourselves well at the surface, I cannot really have any thing over here, but the media expands over here and what reflects back is something like an expansion wave over here.

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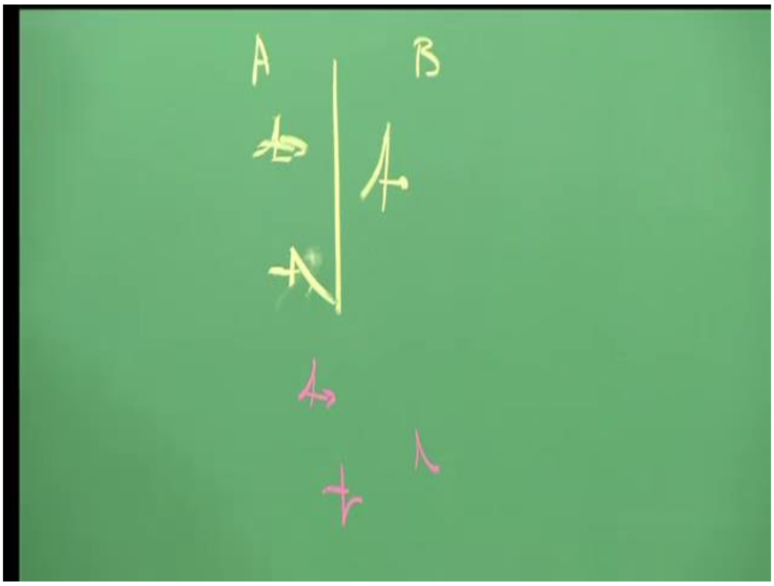

Therefore, we tell ourselves well based on this expressions I also tell myself that when the impedance of two media A and B are such that when a greater than b, I have a compression reflected as a compression back over here. Something which gets transmitted is even of greater value greater pressure which gets transmitted over here. The movement when I talk of the impedance of medium a being less than or impedance of lets us say medium of the second medium B being very much less than this.

What happens is we compression gets reflected as an expansion and I get transmission of a compression or a shock into the medium that is that shock reflection becomes an expansion. Therefore, I slightly generalise the problem and talk of the problem in the following context.

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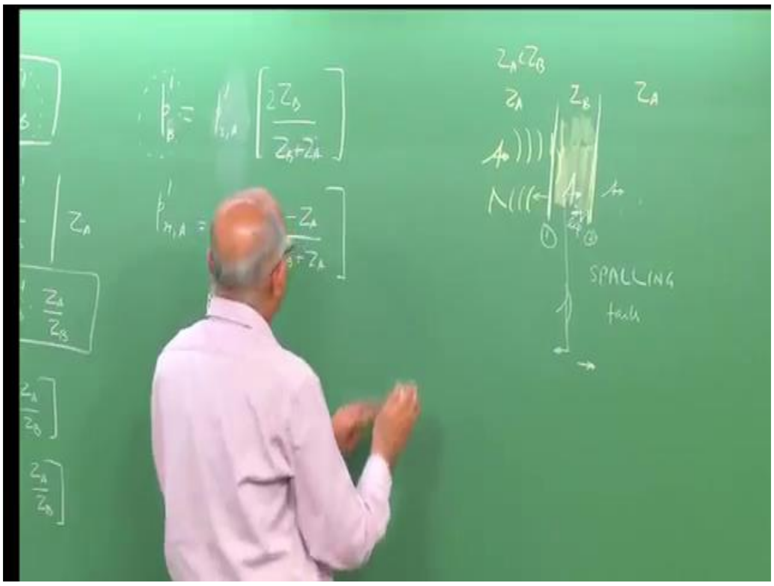

Let us say I have a medium over here some medium here, which let us say has a high value of impedance, let us say I have e z b over here, I have e z a over here, which is small impedance that means e z a is less than e z b. I have put this small impedance again over here e z a over here, what is going to happen, well this could be some material like steel or bone or anything which is heavier. Let us say I am talking of some heavier material over here some material and therefore when the pressure wave comes over here, what gets reflected is some gets reflected because e z b being greater than A.

It reflects as a compression wave, which means I have compression wave coming over here compression wave getting reflected over here. What gets propagated is larger magnitude of the compression wave. Let me show it in ordinary white choke, well I have a compression wave over here and when compression wave this is one interface, let us say interface one I have this second interface here, because I am considering this media to be restricted.

That means I have interface two when this pressure wave comes over here gets reflected as an expansion wave. That means it is something like this, it is expanding over here and what gets transmitted is something like a smaller compression wave over here. Let us take a look at this what will this result in I have a wave compression wave going, I have over pressure here behind this there is an expansion. That means behind this initial compression wave, I have expansion and particles over here are now moving away because it is an expansion behind this particles are moving here.

Then, what happens the reflected wave comes over here when the reflected wave comes over here I have expansion particles are moving like this. Therefore, an particles here which is subjected to the shock wave is pulling this in direction a particle which is the same particle or a similar particle. Then, adjacent particle is subjected to the expansion wave is pulling in this particular direction and therefore, what is going to happen the material gets pulled like this and the material fails and this failing is known as fall or spoiling of the material. Therefore, we tell our selves, whenever I have material whose impedance is higher than the impedance into which it is travelling.

Well, what could happen is when the value of the medium here is less than medium over here, I get an expansion and the particles, therefore one is pulling, another is pulling have a tensile failure. Therefore, we say a material spoils and therefore materials fails, therefore using this example that means we are now able to say something, we are talking of the of the transmitted wave, we are talking of the reflected wave.

Using this let us try to extrapolate and little bit and talk little more about the different application of this scheme and transmitted and the reflected waves. Let me use this table and again give one application which all of us are familiar, this we will keep. Let us record us in our mind, we tell ourselves well when e z b is such that it is less that e z a that is the second medium is less than the first medium well I have this first problem.

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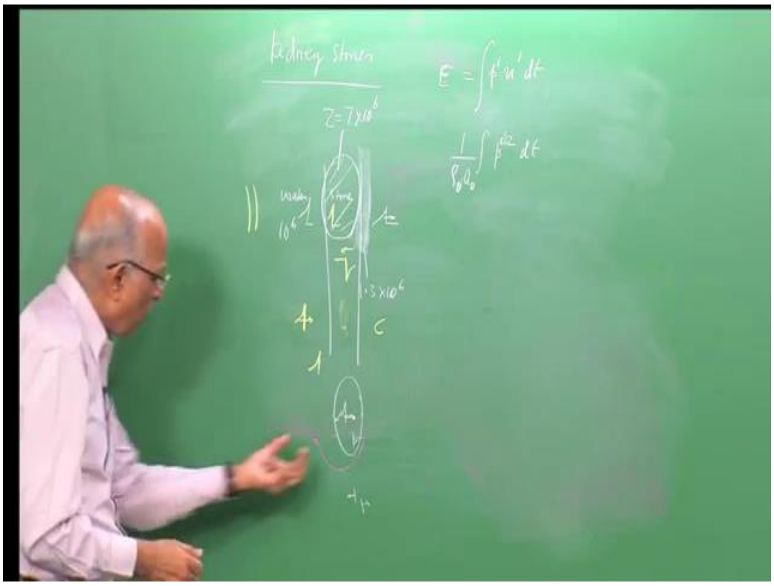

Therefore, let us see how it can be applied you know all of us are familiar, we talk of kidney stones when the calcium in the body is large or may be the food stuff we eat is such that we do not drink sufficient amount of water in the kidneys. We have stone being formed and therefore, let us take a look at this in the kidney well the stone is formed it is more like calcium may be a stone is formed, let us say over here. Let me now enlarge it and now small stone is formed, I said this is small stone, which is formed in there kidney over here, it is in medium of fluid and that fluid is something like let us say water.

Therefore, it is in water I have something like stoned which is formed in the kidney and the kidney and may be that as to the material of the kidney, which is like a tissue. Let us say therefore were talking of a tissue over here, which has a impedance let us say about 1.3 into 10 to the power 6, we are talking of a stone, which is something like a bone has a value of impedance that is e z over here is equal to 7 into 10 to the power 6. We say we have water, which is around 1 into 20 to the power 6, therefore we are talking of system where in I have a stone over here, which is in a medium.

That means that stone has a higher value of impedance compared to the impedance of water and the impedance of this. You will also recall over here may be water fat tissues and mussels have almost similar values of impedance around let us say 1.2 to 1.27 type of situation.

Here, I look at bone the value is higher if I look at air well it is very much less than this quantities and therefore, what is it happening, I have let us now label this thing together in some form. Let us say this is material a let us say this is material B medium B, this is medium C, well you know what is going to happen, let us now say I direct shock wave into the body. That means I focus the shock wave on to this particular stone over here what is going to happen well shock is going to go through this it gets transmitted. Well, it gets reflected, also I know I gets reflected and it get transmitted into this, well a shock get transmitted into this, but the moment it comes to the other surface, what is going to happen?

Well, I have the impedance which is less and therefore, it gets reflected and therefore, as a as a expansion wave that means something like this. It is an expansion wave this is an compression wave, this is an expansion wave and now in this particular stone if I consider then of course, something is further transmitted into this medium. It is quite small, what is getting transmitted, that means I have something, which is coming here it comes here gets reflected into this. Therefore, when I look at the picture of the stone what i get is well considering this as a body in which we are focusing our interested. Well, this is the incident wave and what is getting reflected is an expansion behind the wave which is propagating in this direction.

I have expansion process taking place, I have expansion taking place, therefore, the particles in the stone are being pulled like this because of spoiling, this is a tensile failure the stone fragments. Therefore, by passing shockwave into you kidney, I sort of fragment the stone make it into powder and it gets expelled of and this is one of the application that means I used the impedances to be able to crush the kidney stone. Well, it is not only kidney stone you know anything you know there are different applications, I can have. But therefore what is central is well the values of the impedance is what decides how much get reflected.

What is the type of reflection, I have will a compression get reflected as a expansion or rarefaction or will it still persist its expansion and what gets transmitted into the system well we will pursue on this a little later. Just to say where does this energy come from if I say well energy is equal if I say energy which is associated with wave is equal to let us say the pressure fluctuation into the velocity fluctuation is something like a energy associated.

Therefore, this is sort of the power because we are talking of meter per second, we are talking of Newton per meter square this is equal to power density. If I say d t and if I integrate well this is the type of energy which is coming. Therefore, what happens I can write you prime as is equal to p prime, rather I can write it as p prime square into d t 1 over the impedance of this particular medium what is associated let us say rho 0 into a 0. This energy is what is dissipated what is used for crushing the stone as well, therefore we tell ourselves, I can use this rarefaction to my advantage in some particular applications supposing we where to use some material to shield us.

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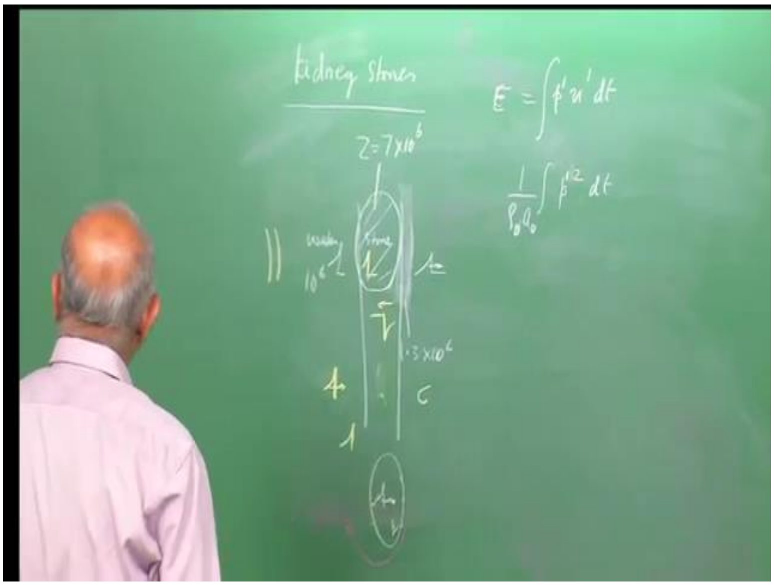

Suppose, there is a human being over here and he uses for as a shield some particular material say iron or tungsten or a heavy medium having a high value of impedance over here something. Let us say as an armour you will recall if we the spelling you use an armour you know if we use read the novels like maybe Arthur and its knights and all that.

You know they have all that they ride on horseback with armour and all that let us say you have an armour like this. And supposing let us say blast wave strikes the armour what is going to happen well the armour may spell, but we must also remember that the armour is going to transmit the wave into this medium over here.

Therefore, the armour what is used may really not be blast resistant, we have to keep this in mind we will take a look at it in the next lecture. An armour may not be really blast resistant what it resist is may be the fragment form the blast comes and hits it well if the impact is not to high. Well, it will reborn back it will help against lets us say a secondary of a blast rather than the primary effects that means if say well I am going to have a bullet proof thing over here. This is going to save my car or save my skin well it may not be very effective for a blast wave only thing what it does is well it protects you against the fragments well this all about the impedance we have been talking you know.

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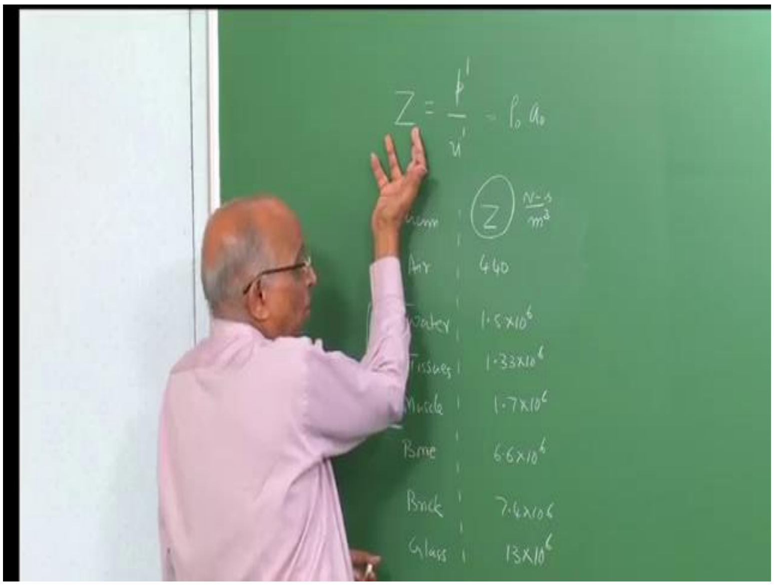

I also told you that well, these expressions are in the limits of weak shocks, can I really use impedances for strong shocks. And I also told you well it is not very wrong to use it the reason being, let us go back and see how this expression got derived.

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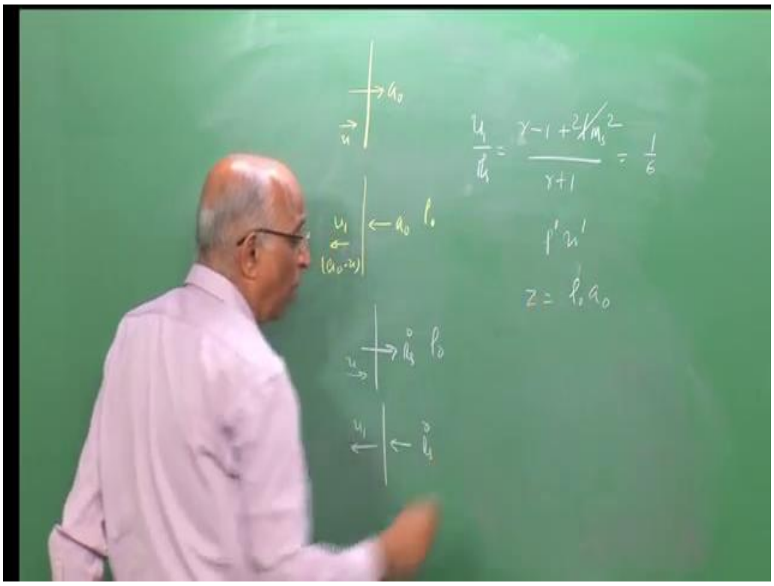

What did we tell ourselves, well I have the medium over here which is propagating at a velocity a 0 sound speed and what happens I wrote the equations when the wave is stationary. I have the medium rho 0 coming towards it with a velocity a 0 and what happens in this case the velocity behind was u that is the particles are following this. In this case, the velocity we called as mu 1, which is equal to in this frame of reference it a 0 minus u corresponding to u over here. Now, if you tells us instead of acoustic wave something like a shock wave is propagating r s dot into a medium could be solid could be liquid could be any medium over here.

Then, the particles here is following u and therefore, in the frame of reference the shock stationary I have r s dot and this medium is now moving with a velocity u 1 you know what did we do in the earlier classes. We got a expression for u 1 as a function of r s dot and what did we get you got u one by r s dot when the shock wave is quite high. Let us say a large number what did we get the value as equal to gamma minus 1 plus 2 over m s square divided by gamma plus 1 m s square is high. Therefore, this term gets knocked of this comes out to be for air it is around lets us say typically around 6 or so for different material the values will be smaller or larger depending on the value of gamma.

If the gamma is small it tends to be a little larger, therefore you have u s by r s dot, now if you are taking how did we get this value we set from mass balance equation. We were able to be neglected the value of rho prime to u prime that is under this condition we got e z is equal to 1 over e z is equal to rho 0 into a 0, that means we said that the particulate velocity and the density of fluctuation is small.

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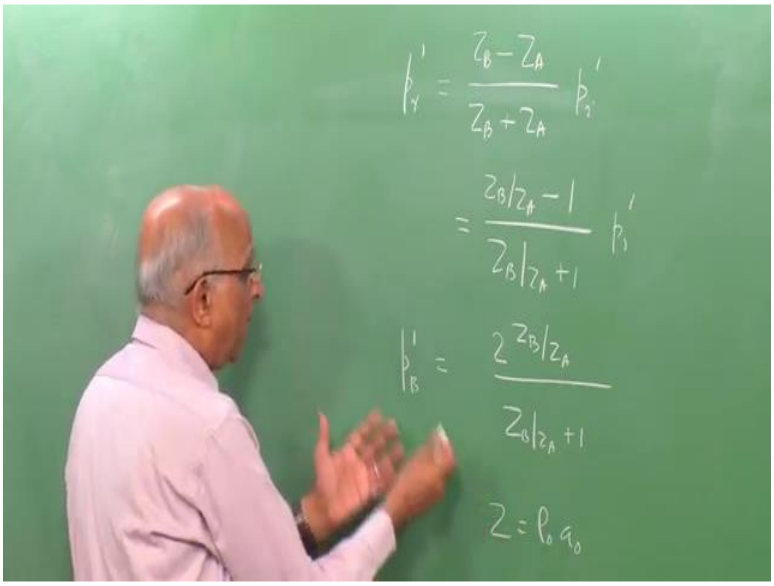

Now, what does it define we see that the product of the changed components, mainly the velocity u prime the density rho prime the product of them are still very much smaller than the product of the initial density and the shock velocity. Therefore, I can use this same derivation which I used for acoustic impedance again and therefore, I tell myself I now can specify the impedance has something like initial density into something like the shock speed.

However, we also note the following when we derived this expression let me rub it out and put this again when we derived this expression again for the impedance we related the reflected pressure. What did we get it as equal to we got the reflected pressure as equal to e z b minus e z a divided by e z b plus e z a into the incident value of the pressure. I can also write as equal to dividing by e z a i get e z b by e z a minus 1 divided by e z b by e z a plus 1 into the incident pressure that is that initial shock speed initial shock pressure and be related to the related pressure.

So, if I look at the transmitted pressure that is p b prime what is it we get now we get instead of getting two e z b i get two of e z b bye z a divided by e z b by e z a plus 1 oh what is it we observe the transmitted pressure. The reflected pressures are ratios of the two impedances e z b by e z a and not the absolute values and therefore, I can still continue to use e z as equal to rho 0 into a 0 for the medium and solve my problem. Having said, that let me come back to the last part which I want to do today and therefore let us visit this problem of formation of craters again in the context what is being transmitted and what is being reflected.

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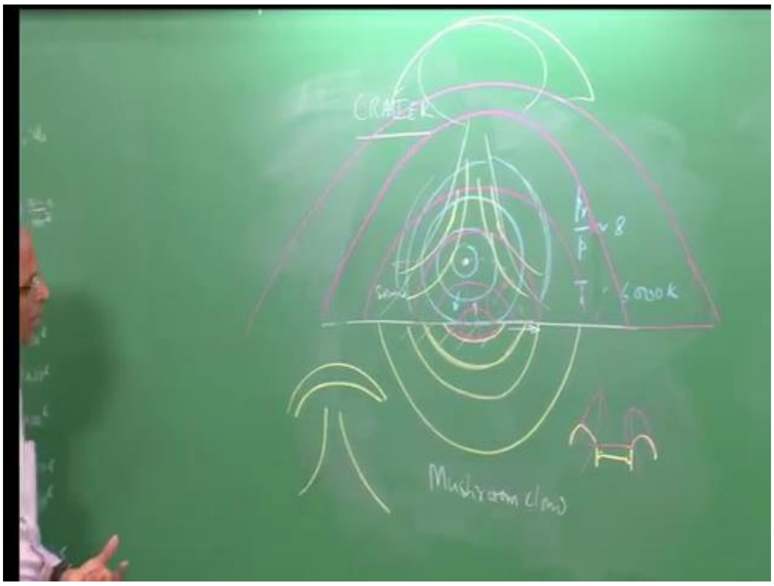

Let us revisit this problem of let us say crater let us put everything thing together what is a crater we said well a carter could be formed on the earth. Well, it could be a sandy soil it could be a rocky soil, I could have either a surface burst or I could have in depth explosion. Let us not consider this two things let us consider where in some energy is or an explosion source an explosion is in the air above the above the surface of the earth. Let us say it at some height and the movement an explosion, so originated what happens well a wave gets transmitted as time progress the wave travels forward this is at small time larger time.

Let us assume that the explosion is quite powerful a wave comes and strikes over here. Now, the impedance of the earth is going to be higher than the impedance of the air above it. Therefore, well a shock is transmitted into the inn in the medium, let us say well I have the shock getting transmitted into the medium the blast wave travels into the medium, but more importantly well we talk in terms of reflected waves. Let us show this reflected waves in red let us say reflected waves that is from here a reflected forms over here a reflected waves travels forward over here.

This is the wave reflected wave travels, this is the direction in which the incident wave is travelling. Now, there are a few things at this particular point when I have a strong shock or a strong blast hitting this surface we told ourselves yesterday yes the value of the reflected to the value of the pressure behind the incident shock is almost around 8 for that is the over pressure behind the shock is 8 times behind the incident shock. Therefore, the pressure over here is extremely high and because of this high pressure well blast goes here stronger strength is also formed yes the impedance of this is high. Therefore, the pressure wave is quite strong and this because of this high pressure over here, get this reflected wave.

You also will remember that in yesterdays class we defined we determined that temperature behind the in the wave behind incident wave for strong values for mark number of ten the value is around something like 5845 Kelvin lets around 6000 Kelvin. Therefore, you know the reflected shock is now travelling in a medium whose temperature is already increased because if the incident wave because of this temperature increases the sound velocity in the medium is high. Therefore, this reflected wave now travels quite fast it travels faster than the incident wave is travelling forward this are that incident waves travelling forward. Therefore, the reflected wave travels faster than the incident wave and since the travels faster as the incident wave is coming over here.

What happens is reflected wave travels faster and in fact over takes the incident wave and what a person see far away he sees the signature of the reflected wave and not the incident wave which strikes the earth. Now, let us take a look what is going to happen now let me extrapolate this over here let me put this lines in a in a better fashion in a more spherical. I have this line coming over here.

I have this line coming over here and still it goes further it goes over here, when I have this height pressure coming over, I also get some waves something like seismic wave which travels along the surface of the earth. I have these transmitted waves which are travelling over here and now I find that well that reflected waves are over coming here they are strong and because of the expansion behind the reflected waves well it takes particles out over here. It sort of sucks the particles and the particles are pushed over here something like this and there are situation what I get above the surface of the earth is well the particulates are taken out over here.

I get the reflected wave signature over here this is of something like that of mushroom it looks like a mushroom cloud it is in the shape of a mushroom something like this. Therefore, I get something like the things that are taken care of and I have a cloud over here from the reflected wave and what the signature what gets from the reflected pressure the destruction is much more than from the incident wave, which one does not even see 0.1 second. Let us take a look at what happens here the transmitted wave goes over here the transmitted wave well compresses the material over here behind it there is an expansion wave and you know the this material fragments over here and because of the expansion the materials gets thrown over here a crater is formed.

That means I have a crater the material gets thrown over here comes over her a lip of the crater is formed over here. Therefore, I have a diameter of the crater which forms with a lip over here and this how in the earth I have spoiling and ultimate I have a crater of diameter d not form which we said is proportional to the explosion level. Therefore, an explosion above the surface of the earth looks like a mushroom cloud and this is a signature of an explosion we must keep it in mind. Therefore, with this back ground, if you like to put things on an impedance together you know there are certain parts in our body which contain air water.

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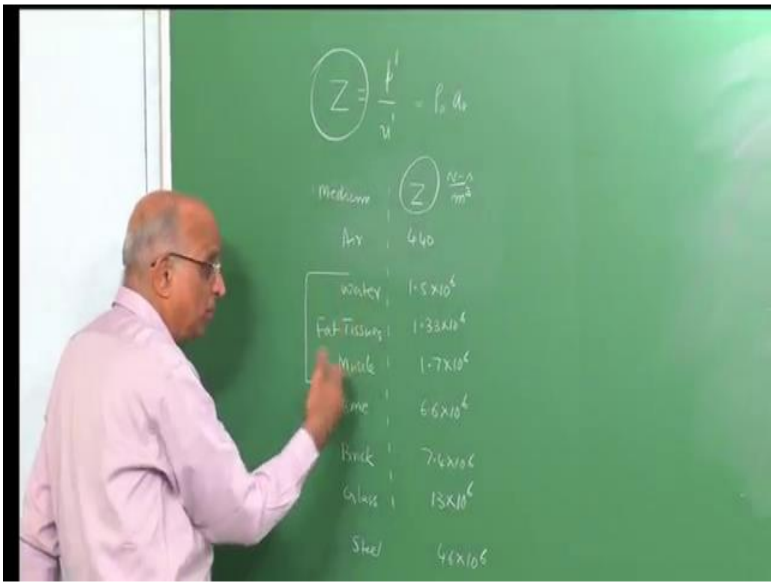

Let us say the flesh around it lets say it contains air it contains some water it contains fat tissues and bones and all that therefore, whenever the material contains air in addition to water and tissue.

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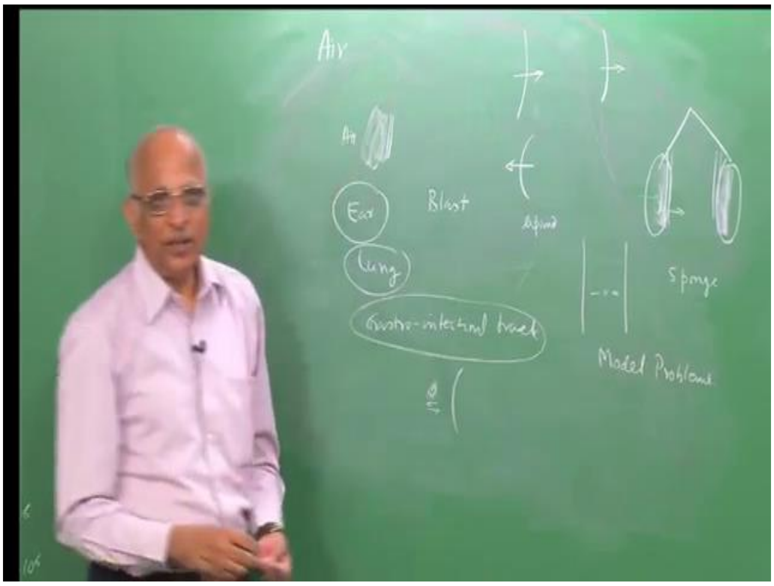

If I say water and I have tissues well the impedances is not that different because we find the impedances of the same order, but if I have something like air over here there is radical change in this because of this what would happen? I could have destruction of the materials because of the expansion and pulling that is the spoil type of failure and therefore, you know the organs of the body which contain air art maybe you have a drum and you also have lung. Our lung which contains air and water you also have something let me try to put the third thing you have the gastro intestinal track which also contains air in addition to the liquids what it contains.

Therefore, whenever you have this air in the medium you know it is more susceptible to blast failure because of the expansion wave associated with the reflection after the compression waves which results in failure. Therefore, this you know the damage of ear the damage of lung the damage of gastro intestinal track in our human body is something which blast wave very capable of doing. In fact you know look at a human being you know he does not seem to be materially affected, he is still there as one single pieces, but this particular organ gets drastically affected. Therefore, what is it we have done today lets quickly summarize, what we have done before we tell what we must be doing in the next class in today's class we started off with impedances of different bodies.

We looked at how impedances will affect how much of the of the shock wave get transmitted into the second medium and how of it gets reflected we also found if the impedance of the second body is less than the impedance of the first body. Well, what gets reflected back is not a compression wave or it is not a shock which is which can compress the body, but which it expands it and this in a particular body of dimensions, given dimension is capable of causing damage by the tensile failure point 1.2. We now know how to calculate the transmission and the reflection and we applied it we said, well it has been used for fragmenting the kidney stones it in practice.

If I have suppose I want to protect my house over here let us say if I want to protect my house, well it is not sufficient for me if I just put some material over here, which is a heavy material and which will with stand because the wave can still transmit over here. I can still have blast damage for the inner thing, which means the choice of blast resisting require some choice.

We also find those materials which have no impedances like I use sponge materials, let us say the sponge materials is something similar to muscle material. You know it can fail, but it can absorb the blast wave, therefore with this I stop here and in the next class what we do is we will look at mechanism of how the blast wave destroys object. We will look at may be the over pressure impulse and also a little bit on the impedances, we will summaries what we have done in blast waves and try to do one or two small model problems.

Well, thank you.