Energy Efficiency, Acoustics & Daylighting in building
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Lecture – 33
Noise & Acoustic Fundamentals (Contd.)

So, we continue with the fundamentals like we did last time and we looked into the range of audible sound in terms of frequency as well as intensity. And if you recall we said that 10 to the power minus 12 watt per meter square intensity, that is the lowest we can hear threshold of audibility roughly.

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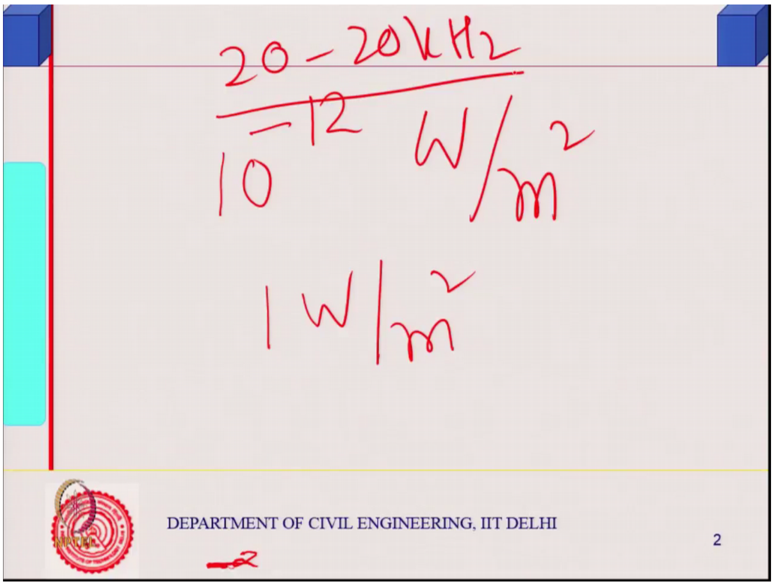

And 1 watt per meter square is threshold of pain beyond that it will you know you feel like a pain. Also we said that roughly around 22 you know 22, 20 kilohertz. There is a range of frequency so, audible range of frequency.

Now, this is physical you know physically measurable things or if not directly indirectly, but then human response is somewhat you know physiological issue a bit of feeling subjective issues are involved.

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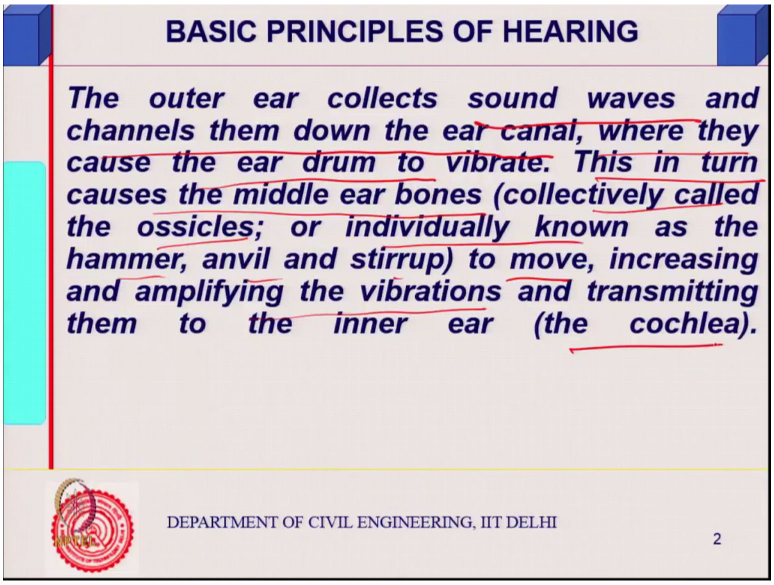

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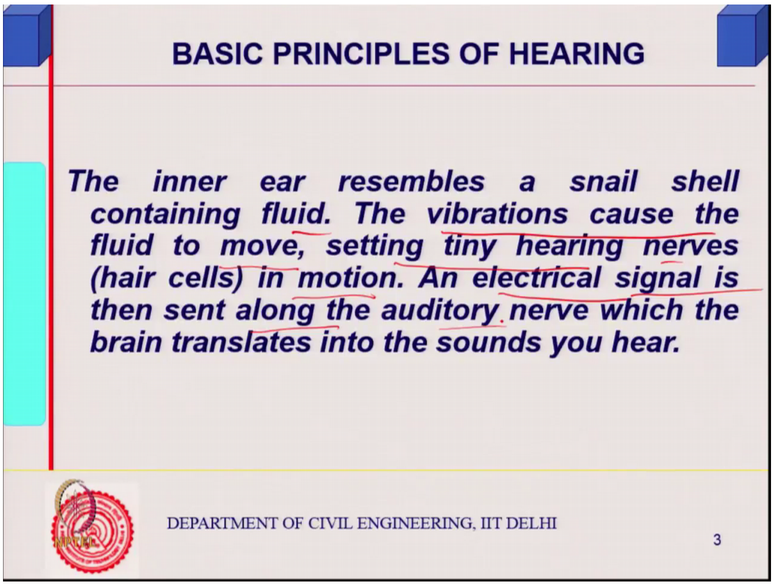

So, basically we got to look into the ear a little bit right.

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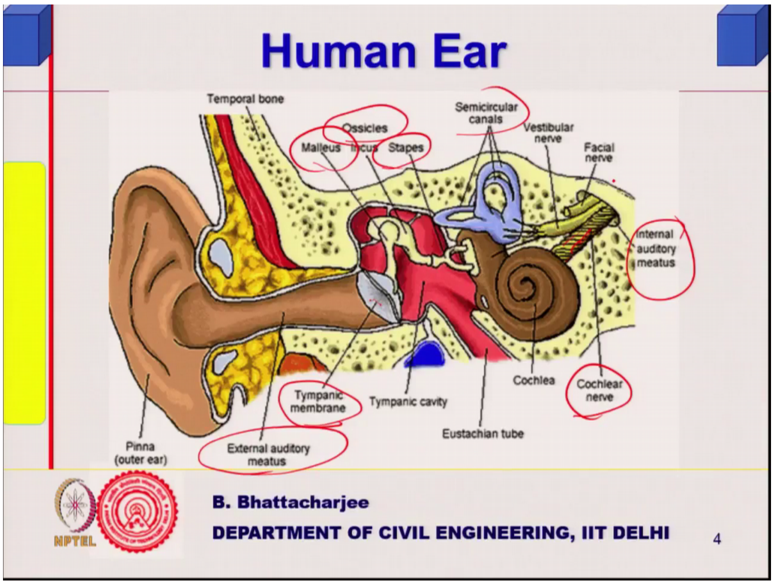

Human ear it looks something like this right. So, you have a canal external you know so, this is the canal and this is a membrane or diaphragm where the air like vibration about the mean position of equilibrium pipe you know acoustic waves; they will come and impinge upon it. Then this is connected to three bones actually this is one, this is one, this is another one.

We are now going to look into too much into the physiology of it, but this is a diaphragm this is very important and these bones actually transmit these vibrations right through this canals and all that to auditory nerves actually you know this is this of course, a cochlea which is again sort of a spring like a bone. So, finally they transmute this one this nerve transmit these signals to the brain and then brain recognizes; it recognizes like you have got what we call there are lot of there are software’s for yes together right. So, which you like actually recognize your voice and then train through neural network or whatever it is.

So, this is already trained so, it can actually recognize the voice. So, the signal goes through this so, you see there is something physiological about it. So, it is actually the vibration in the air which goes to the diaphragm which is connected to certain bones which will transmit this longitudinal vibration and then can convert them into electrical signals go to the brain right so, that is what is written here that is what is written here.

The outer ear collects sound waves and channels them down to ear canal, where they cause the ear drum to vibrate the diaphragm I was talking about.

This in turn causes the middle ear bones collectively called ossicles; or individually known as hammer, anvil and stirrup to move, increasing and amplifying the vibration and transmitting there to the inner ear the cochlea. And then followed by this is the inner ear resembles a snail shell, that is what I was showing you containing fluid the vibration caused the fluid to move setting tiny hearing nerves in motion.

Any electrical and electrical signal is then sent along the auditory nerve which our brain translate into sounds that we hear right so, that is what it is. So, there is something you know so, this is this is that cochlea, snail shaped which has got fluids, the bones, ossicles. This these are the ones must be the Latin names fine and this has the nerves which actually transmits so, that is the idea.

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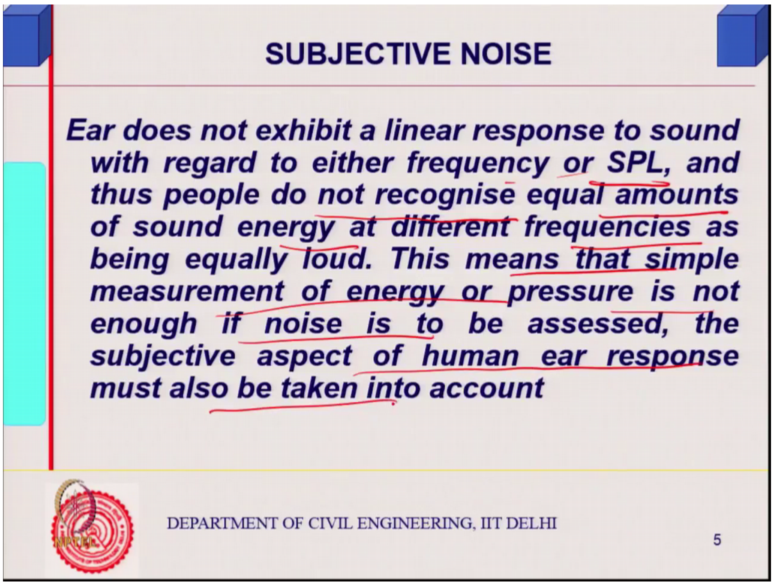

So, therefore, ear does not exhibit linear response to intensity right, which either frequency or sound pressure level or intensity whatever we call it and thus people do not recognize equal amounts of sound energy at different frequencies.

Our ear is frequency sensitive that we have seen because at you know low frequencies very low frequencies below 20 K, we practically do not hear and above 20 sorry below 20.

Student: (Refer Time: 05:01).

Hertz we do not hear and above 20 K we do not hear. So, therefore, its sensitive to frequencies and its sensitive to frequency therefore, even same intensity you do not perceive it equally loud same intensity you know. When we are saying threshold of audibility; that means, you can really hear Feynman is very loud, but it this loudness or sensitivity of the ear to intensity varies with the frequencies right.

The simple measurement of energy of pressure is not enough to noise, if you want to assess the noise you must know at what frequency the pressure or intensity is. Then you can you know estimate how what would be the perceived loudness or something like that right. So, the subjective aspect of human ear response must be taken into account and people have done such experiments.

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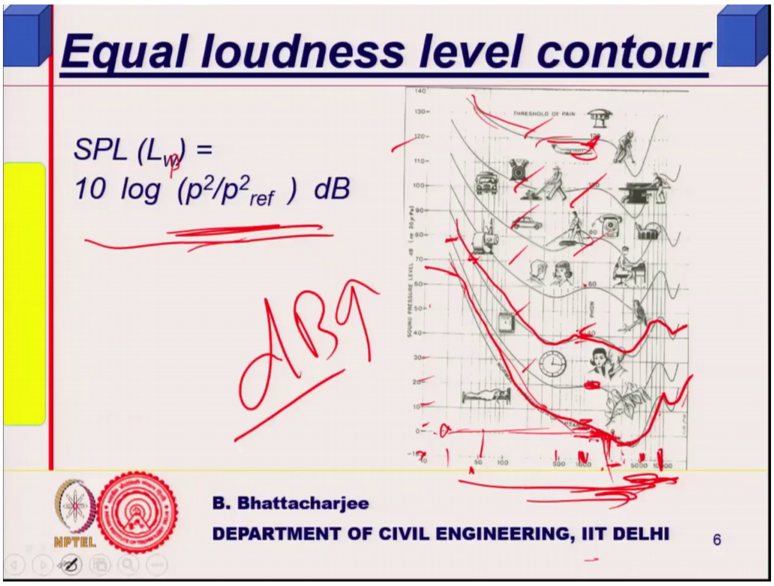

And they generated what is called equal loudness level contour, equal loudness level contour.

I have defined that decibel other day if you remember sound intensity level pressure level etcetera and this is what we said sound pressure level would be, this should be L P not L W, this should be L P 10 log p square by p square reference in decibel and this is what is equal loudness level contour. I am not very sure how much you are able to see it, but in this axis we have got frequency, this axis we have got frequency this is the this is a form we can see that this is in terms of curve. So, this axis is frequency this is 10 kilohertz, this is 5 kilohertz, this is 1 kilohertz, 500, 10 hertz you know something like this so, this is in log scale frequency always we put in log scale and this is sound pressure level that is in d B.

So, it is already relative scale dB so, this dB cell 0, 10, 20, 20, 40 etcetera. There you know equal distance because already logs we have taken log and then relative scale. So, what do you observe with that at low frequency this is the threshold level that you can just barely hear so, you need high dB to just barely hear at low frequencies. While at say something like you know this is 2000 or 2 K, 1000 K you are somewhere there and somewhere here this is more sensitive to it you require much less d B. For example, 0 this is this is 0 phon actually 0. This is you just can hear by definition this is our 0 because the relative scale 0 d B.

So, this is the threshold line similarly you can see that curves are here this is 40 dB at 1 K, at 1 K 40 dB this line is 1 K. So, 1 kilohertz let us take 1 kilohertz as a reference, where you find near that the sensitivities maximum. The least dB level, here the dB level say let us say this is 20 dB at 1 kilohertz and the loudness that you perceive, you will require 60 dB to hear it at this frequency right or let us say 50 frequency 50 you never need. You know for 20 you would need actually 70 dB so, 70 dB at 50 hertz is equal to 20 dB at 1 kilohertz, 1000 hertz right because ear is more sensitive to higher frequency such as 1 kilohertz, but beyond that again it you know it shows this kind of behavior right and we as we are going towards the ultrasound towards the ultrasound range.

So, at low frequencies sound is I mean ear is not as sensitive as 1 kilohertz or you know 1200 or something like that 5000 hertz so, sensitivity of ear is less in low frequency. But you see you look at this one this curve which is 120 hertz at 1 K, 120 hertz at 1 K. The variation is much less in other words when level increases significantly towards threshold of pain, effect of frequency gets somewhat reduced. Only here you find you see this curve is steep this curve is somewhat less stiff less stiff right. So, 120 at 1 K so, this is this values written 20, 40, 60, 80 at 1 K so, we take one kilohertz as a reference point.

And the decibel level at that say 20 the loudness of the 20 decibel level to in 20 dB at 1 kilohertz you call it 24. Loudness that one would perceive this is from subjective experiment on healthy people, taken from the book by bar neck or this they are in many books actually barn x has got sort of acoustics, classical acoustic books actually written. So, people have done experiments on healthy subjects asked them to like we talked about thermal comfort remember so, you know the same thing similar here loudness level the comfort acoustic comfort you are looking at noise comfort against noise.

So, people are subjective healthy people who are subjected to noise and frequencies where its say decibel level you vary the frequency and say 1 kilo 1 kilohertz you say in keep it at 20 decibel, then change the frequency lower the frequency and increase the decibel level, people will respond this is equally loud as loud as 20 dB at 1 kilohertz. So, that that is how this sort of curves are generated and these are 20 unit of loudness is phon which is not exactly intensity. It is the loudness of 1 dB 1 phon is loudness of 1 dB at 1 kilohertz which would actually require much higher dB at 50 hertz or loudness of 20 dB at 1 kilohertz is 20 phon.

Loudness of 40 dB at 1 kilohertz is 40 phon, which will correspond to something like 70 dB in 100 hertz because following the equal loudness level contour. So, these are called equal loudness level contour, equal loudness level contour this 120 phon, this 100 phon, 80 phon and so on so forth. So, 80 phon curves means loudness you know curve for loudness corresponding to 80 dB at 1 kilohertz right 80 dB at 1 kilohertz. So, quite often you will find we express the noise not exactly simply in linear d Bs we call it. This is linear dB measurable because sound pressure level can be measured easily by various kind of transducer amplify it and you record it so, that will give you linear dB linear, dB you know no variation in frequency.

But you can have frequency sensitive amplifiers which will you know which will amplify selectively filter it out you know so, selectively at higher frequency it will you know at certain frequencies will amplify other frequencies will amplify less. So, these are these are used in sound level meters I will just come to this and you will find that like you would have heard the court order, is that during the Diwali time noise level should not exceed 60 dB right. Well like the OIT noise level should not actually increase 60 dB outside the OIT which it does sometimes it has maybe 100 dB so, that is you know.

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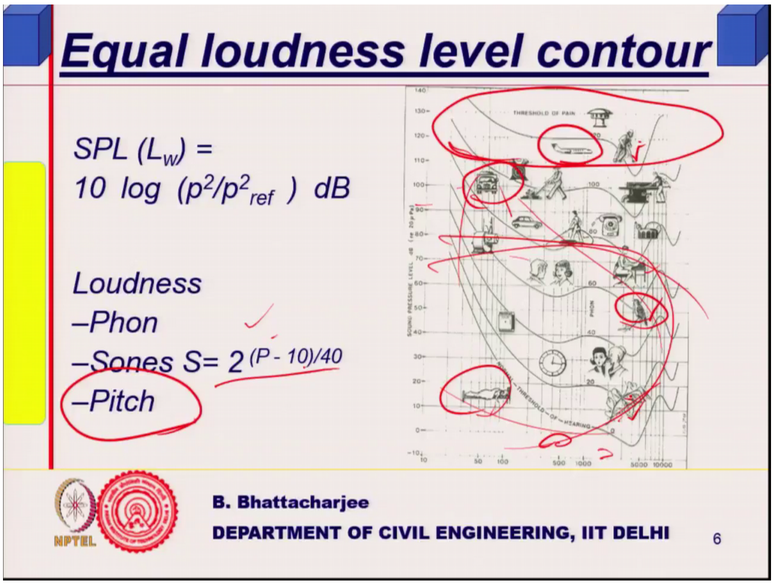

So, loudness is phon and as I define 1 phon is 1 dB at 1 kilohertz loudness of 1 dB at 1 kilohertz. 100 phon means loudness of 100 dB at 1 kilohertz which will be a more dB more pressure, you know pressure level has to be higher at lower frequencies.

Slight at higher frequencies again it reduces down so, you know you can see that the curve tends to go up. So, your sensitivity reduces sensitivity is maximum here sensitivity is maximum so, but then we have taken a little bit away from it as a reference frequency that is 1 kilohertz. So, this is the equal loudness level contour for 120 phon, it is 120 at 1 kilohertz 1000, 1 kilohertz 120 and sensitivity is more somewhere around somewhere around maybe 2000, 2500 or 3000 hertz and beyond that again sensitivity reduces.

So, but loudness level has been defined with respect to 1 k right. There is another unit called Sones, we will not look into there much because physical measurable things are important from our design purposes, but if you want to convert let us say something related to human ear also your sound level meter must be able to take care of this kind of thing we will see that how it occurs.

Student: (Refer Time: 14:31).

Sorry.

Student: (Refer Time: 14:34).

P rms pressure, P rms because I said that I will talk whenever I say P I will mean P rms only and p reference this is what we defined in the last class right p reference is 2 into 10 to the power minus 5 Pascal, 2 into 10 to the power minus 5 Pascal. We have actually you can find it out. I did not so, you see what we said was how did he define these sound intensity level.

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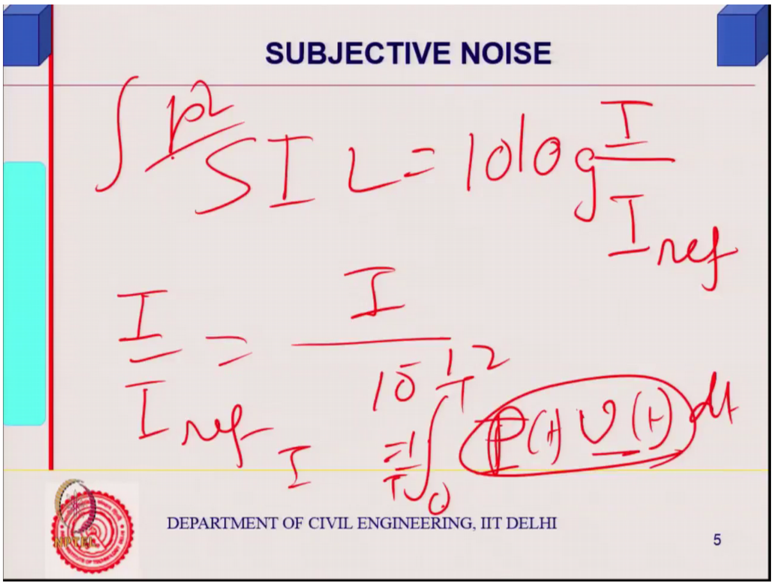

We defined sound intensity level remember sound intensity level, SIL which was 10 log I by.

Student: (Refer Time: 15:17).

I reference and how much was I reference 10 to the power minus 12 watt per meter square 10 to the power. So, this is you know this I by I ref is I by I ref is nothing, but we are taking us 10 to the power minus 12 I that is what it is right. Now, I am talking of reference pressure now how is I related to pressure p square by rho c remember that because we said that I you know we integrated it I into u, I mean velocity or particle velocity as a function of time both as function of time because that gives me the power. Sorry pressure multiplied by acetone pressure multiplied by this is what integrated from over the full cycle and then divided by.

Student: (Refer Time: 16:15).

Time period 0 to T, these are all function of T d t. That is what it is right and v that velocity can be written as.

Student: (Refer Time: 16:24).

That is right so, therefore, I will I have integrated p square by and we found out the RMS we said that so, basically intensity is intensities.

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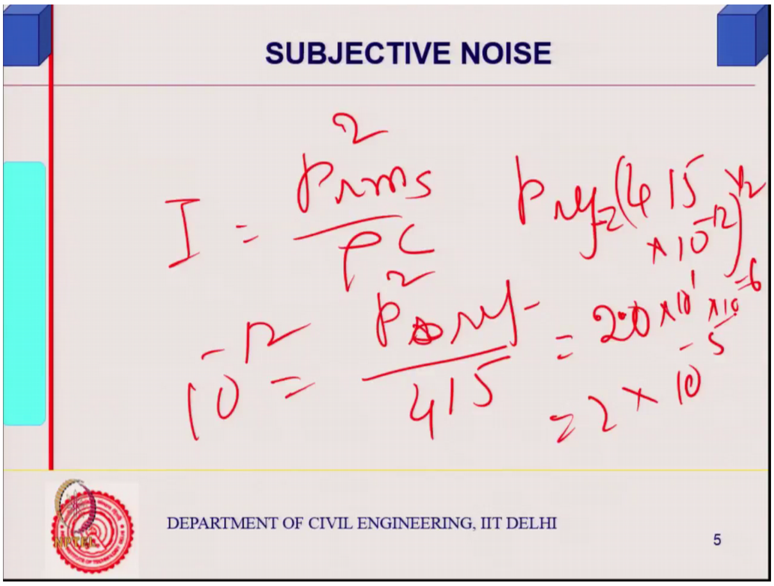

Student: P rms divided by.

Right P rms square divided by rho c right and now I am talking of reference I reference. So, I reference is 10 to the power minus 12 is equals to P ref I will call it, P ref square and rho c was 415 standard temperature and pressure that is what I said so, you can find out now, P ref will be equals to 415 into 10 to the power minus 12 to the power half right. And this will be equals to 400 will be how much 20 rough roughly 20 something. I mean 21, 22 something of that kind you know or right 2, 2.0 into 10 to the power.

Student: (Refer Time: 17:32).

1 into 10 to the power minus 6 so, they will come into 2 into 2 point something into 10 to the power.

Student: 2.03 (Refer Time: 17:39).

Minus 5 so, that is what you can find that P reference comes out to be that right, P reference comes out to that right. I think I will have more discussion on this later on, I think I will have more discussion on this later on so, that is what it is. So, we are saying P reference is this right so, phon we define, sone is another unit of loudness which is.

Student: (Refer Time: 18:04).

2 to the power phon minus 10, phon value minus 10 divided by 40. I do not think I will go into this further because you are not going to use this pitch is what pitch is a the.

Student: (Refer Time: 18:20).

Frequency as we perceive you know its physical thing is frequency, but the way we perceived. For example, I you know like as you can see this is an aero plane, surround 500 hertz right and this is a motor car of the good old days, truck somewhere there, somebody snoring is here right and some bad singing is somewhere, there whispering concrete cutting machine and so, on so these are this is a typewriter, telephone of the good old days today of course, you have all varieties. So, the you know that you see you can you can do you see something interesting this is at the leaf.

Student: (Refer Time: 19:02).

The plant which link right and natural this is natural this is natural this is definitely artificial so, all these are relatively artificial this is very much natural and our ear is most sensitive to the natural things. See the sensitivity the ear is very close to this is you know because it has evolved over the millions of years of human evolution process we adapted ourselves to the natural sounds right. You know river rapids, which is the small waterfalls or something like that or similar sort of thing actually so, they are you know human ear actually. Similarly, the eye is more sensitive to that light which is maximum in the suns sunlight yellow right.

Somewhere around 500 and for 550 nanometer that is very sensitive you know yellow ours eyes is sensitivity eye is very much well temperature similar things I do not think I will be able to say, but you know it is it follows that whoever Faxes Frackner’s law. So, anyway coming back to this pitch is the way you distinguish frequencies your ear distinguishes that distinguishes the frequencies so, these are the low frequency thing somewhere there right.

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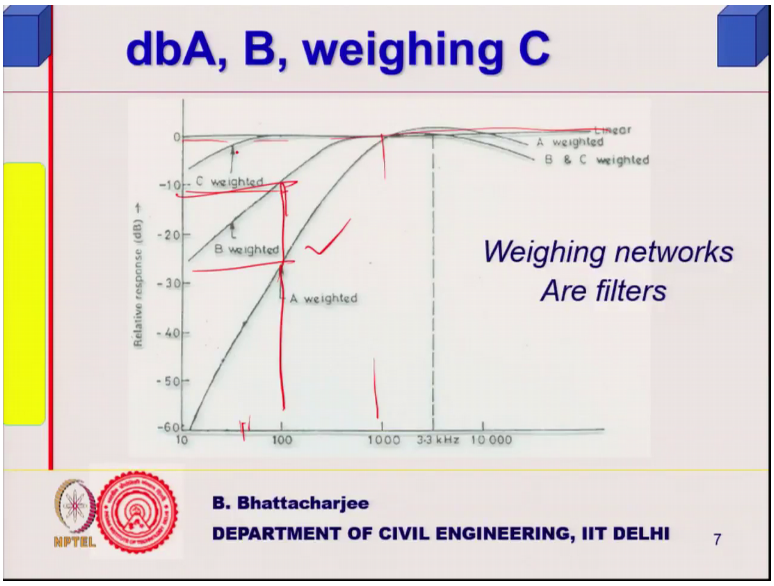

So, instrument got to take care of all these measuring devices right after all I want to specify you know, when I am designing for noise control I want to specify well noise levels should not be more than this. Now, this I could have done by doing it in terms of simple dB linear dB without any you know without being sensitive to frequencies.

So, this is called linear d B, well no modification whatever is measured by your sensing device transducer you just amplify them and that is what you get the pressure level pressure you can measure so, pressure square divided by p reference square and 10 log of that would give you the level of the decibel level decibel level right. Now, but as I said your ear is sensitive less sensitive to low frequency so, what I can do I can make amplifier system such that they will selectively or amplify less at low frequency like this I will come back to this.

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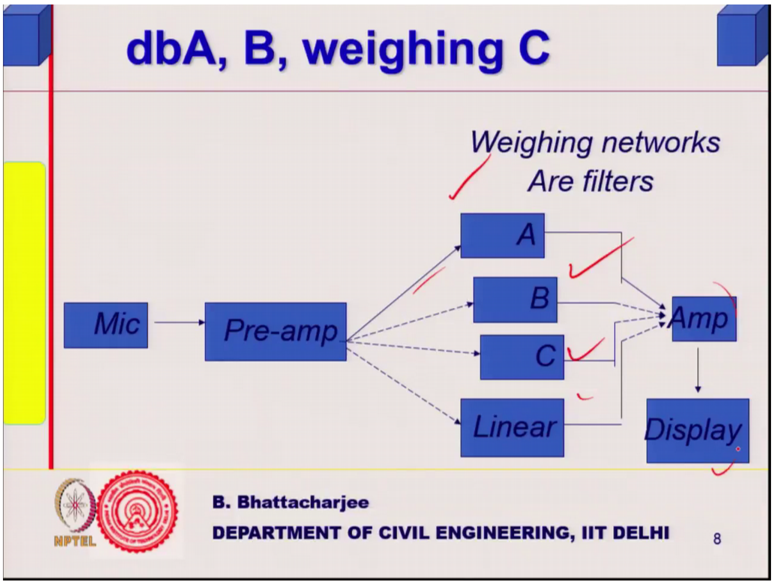

I will come back to this yeah something like this I have a microphone which is basically the transducer which will pick up the sound then I have some pre amplifier system; obviously, first you know you would have nobody does these days, but good old days used to actually assemble transistors because you know good old days I am talking of no televisions really in a big way so, you know student level, hosted hostiles people will do shouldering purchase a printed circuit board put in their transistor and the you know capacitor and all those. Today you do not do this you do not have to.

But then there is a preamplifier stage, then these are weighing networks these are some kind of electronic networks. What they will do is? If you choose a it will amplify selectively more at higher frequencies and cut down at lower frequency. This B does this a little bit less at lower frequency and C does very little. Whereas, linear does not do anything if you straight away amplify equally, it is not. It does not look at the frequency first and do not you know do not amplify frequency selective. So, I will come back to this again so, these are actually filters sort of weighing networks these are used and you have linear no filtering.

A weighing network it cut down it cuts down practically follows about 40 phon curve, it cuts down the cuts down the sound at low frequencies more so, these are negative values. That means, if actually is 100 dB and you are following a weighing and at 100 hertz it will read it will display 70 near 72 or something like that and at 1000 hertz of course, there is no change. At 50 hertz because this is log scale it might show something like 60, but if you choose B weighing network same sound B weighing network, it will show something like 90 for 100 dB right something like 90 for 100 dB and if you have chosen C it will show you 100 only.

So, can you did relate this somewhat related to this sort of curve we had it is if you have predominantly high level of sound then you might use C weighing. If you are predominantly somewhere in the mid range you might use B weighing, but you have to pre decide which one you want to use. A weighing is commonly used for most of the noises because you might have somewhere you know levels could be somewhere around this zone 70, 80 maybe 100 also somewhere around this zone.

So, you will find that whenever noises are specified somebody will specify dB A or dB B or dB C usually dB A so, you will find the codes will say the noise in a residential area, should not be more than you know traffic noise or external noise should not be more than 45 or 50 dB A right something like that and inside the room it should be still lower or whatever it is.

So, this is specified in that manner the dB A values, dB A means that at low frequency low you can you know ear can tolerate low frequency so, you can have higher d B. So, at every frequency finds out based on this curve sort of curve and sum them up together the dB total intensities and you know filtered into intensity into the or pressure levels are summed up special squares are summed up and then equivalent dB cell found out.

So, dB A, dB B, dB C, these are used for or dB A is largely you will find that you know like when the code says or NGT National Green Tribunal or something it says that noise level should not be more than 60 d B, you know you know in a residential area, during festival time of crackers festival of cracker time or something like that or if you have a if you have a some sort of any kind of ah microphone usage it should not be more than that. So, this weighing networks are used to simulate actually human ear response human ear response right.

So, this is their filters actually and this is how there as I said so, you choose basically so, now, see this is dot dotted line means you can choose there is a switch toggle switches could be there so, you choose either this filter or this filter or this or linear means it will show then amplifier and then display. So, display will be lower actuality means higher measured pressure level is higher, but display would show less after going through this processes right. A B C weighing networks are based on a is 40 phon so, it follows 40 phon curve you know like I said the 40 phon curve so, if you from the 0 level if you take that dB values at every frequency you get 40 phon curve.

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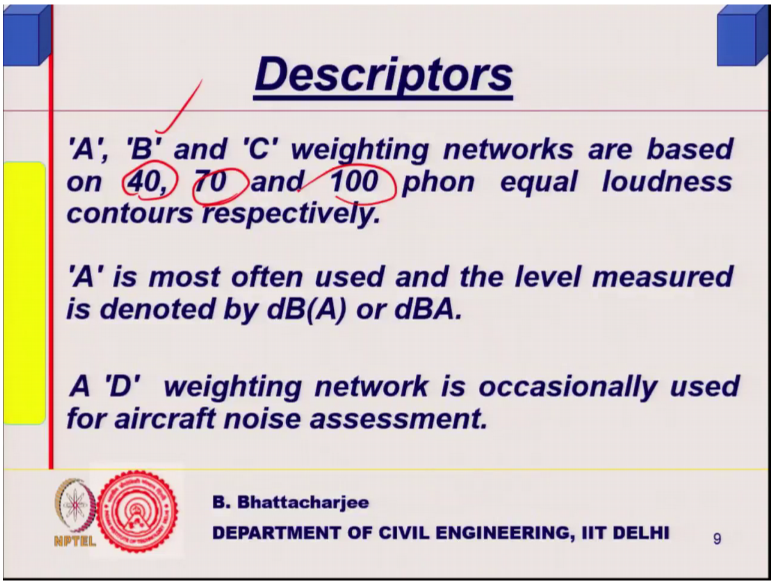

This is 70 B's, 70 phon curve and c is 100 phon equal loudness level contour respectively right so, that is how actually it takes alright.

A most often used and the level measured is denoted by dB or dB A that is what you will find that you know like also the specifications would be many a times in terms of dB A or the way it is written sometime people use D weighing network also for aircraft noise assessment and there are other ways of assessing the noise as well I will come to them.

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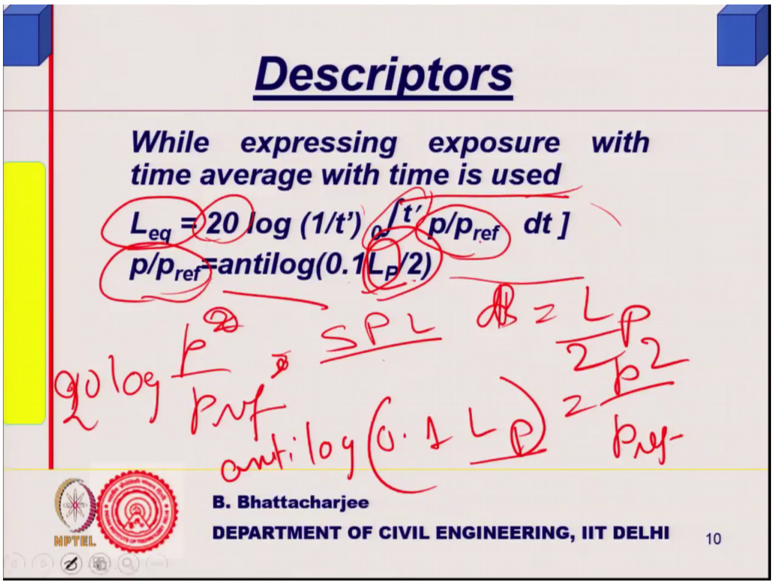

So, these are some of the descriptors, but there is this is this is at you know like at any instant I was talking about right.

But if you look at let us say you are next to the next to highway or an arterial road of a city which are which also American ways of calling it is a highway in the city also you can have. I mean one is of course, you have great separated highway which you find mostly Europe the even in the city if the highway passes great separatory do not enter there right, but America everything is highway; obviously, you enter you do not get out like that they are great separated again.

So, highway or arterial road if you are close to that the noise will be there for the whole day right so, I must have a way to measure the noise average noise level, average noise level in some manner I must have a way to measure the and average noise level in some manner. If I am to design something some noise protection devices some things then I must have an idea of average noise level or peak noise level and least noise level.

You know distribution of the noise over the period of time right distribution of the noise over the period of time so, average sometime time average you use time average you use a measure during 6 am, 6 30 am, 7 am etcetera until 12 midnight and back may be 24 hourly or if there is no noise after midnight then you can leave it at that point. So, measure it over the whole period of time and you might actually take an average, but remember you cannot add the d Bs because their relative scale. So, 60 dB plus 60 dB is not 120 d B.

What you can add? You can add intensities, this is a scalar quantity or you can add P rms square because intensity is related to P rms, P square divided by rho c. So, you can add P square because P is a function of time so, there is a problem you cannot act like that so, dB cannot be added.

So, you can integrate when you are integrating you can add p by p ref delta t, but 20 log will come here right. I mean this square you could have integrated because these are all reference I mean rms both are in rms time terms. So, 20 log if you have measure from 0 to t dash time divided by 1 by t dash time, that will give you the average level during that period of time L equivalent that we call as L equivalent L equivalent right.

So, and p by p reference is how much antilog of point 0.1 L p by 2 ok because white is we said that p square by p reference square right, p reference square 10 log of that that gives me.

Student: dB value.

S P L dB value so, if I know L p. I mean I am calling this as L p right so, L p divided by 10 is 0.1 L p point 0.1 L p right and antilog about 10 to the power this or antilog of this antilog of this antilog of this is equals to p square by.

Student: p reference.

P reference square right now if I you know p reference square or I can I could have actually divided this by you know because this could have been 20 log in like this I could have written 20 log p by P reference. So, divide this by L p by 2 that is what I am doing L p by 2 multiplied by 0.1 and antilog of this is p by P reference, p by P reference is this we can calculate back we can calculate back just to we will do that again. Maybe I will just do it from here again I will just explain this again. So, you can have a quick break and then take some questions from you and then we will come back again.