Principles and Applications of Building Science
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Lecture – 16
Acoustic Quality Indicators – 2

In the last module we looked at few acoustic quality indicators, which included indicators of background nice level. We also looked at major component which is called reverberation time. We have few more indicators which we will address in the currents module.

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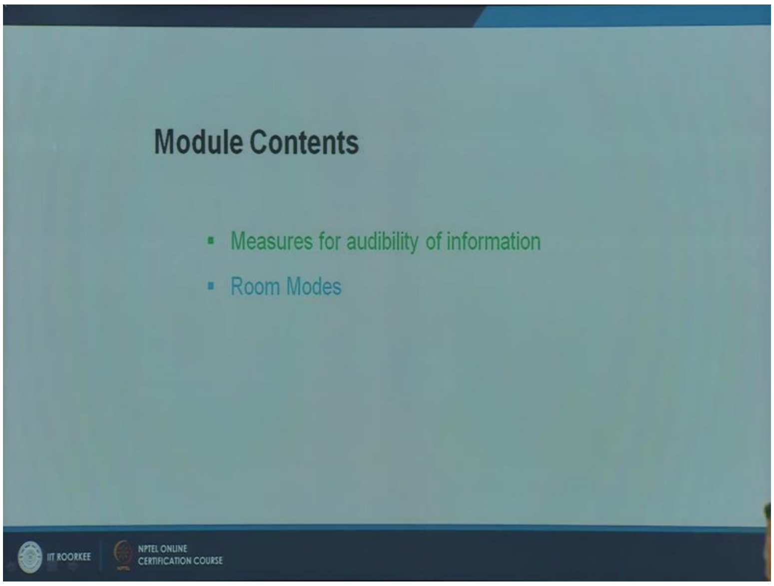

These are measures for audibility information, how much audible the information is that we will look out audibility of the particular information. Then we will talk about an important factor call room modes.

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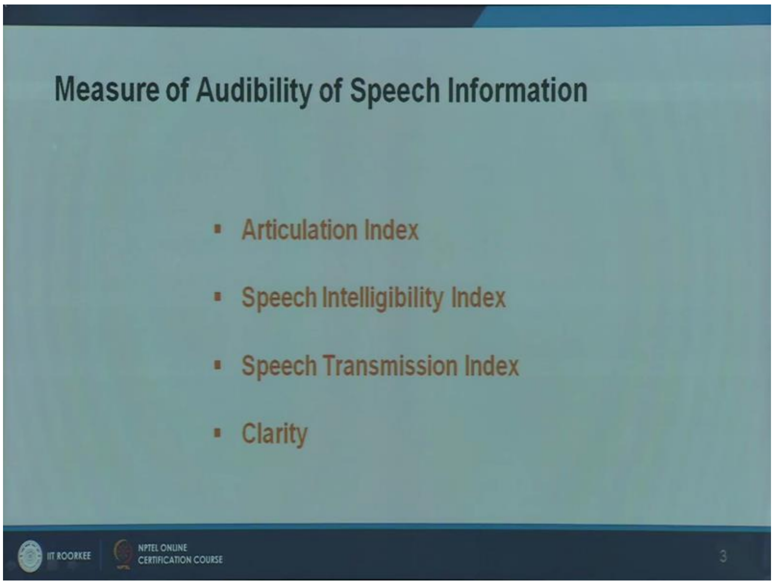

Audibility of a particular speech are music, depends primarily on how well you are able to here depends on, or it can be determined by the other three parameters, more or less they are the same the indicator are the representation is also similar, but it you know considerably where is from one another. First is articulation index, second is speech intelligibility index, and third is speech transmission index. There is another version of it available called RASTI. This is commonly termed as S T A. There is another version called rapid application speech transmission index RASTI. Then you have an indicator call clarity there are more indicators, I have only chosen four of these things to talk about. There are also indicators like definition envelopment. There are factors; first let us look at more clearly into these factors first. Articulation index it is used for finding you know, it was intended or originally developed to study the some privacy and intangibility requirement in open office spaces.

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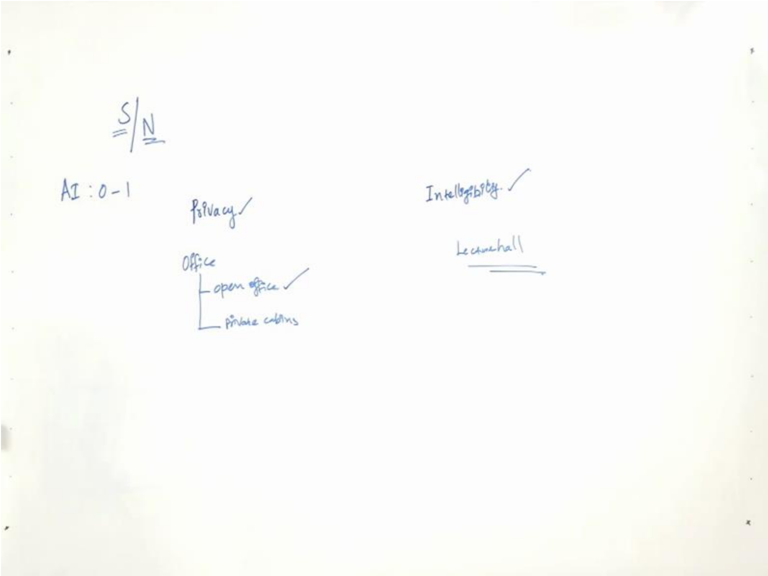

There are two things you have to understand; one is sound privacy, and second is intelligibility. Say for example, if you are talking about an office space you have open office, open plan offices, or you have private offices, private cabins versus a lecture hall. here you will require acoustic privacy, say you know whatever the person talks to the other, there is the conversation, or maybe there is the telephonic conversation, there is a discussion happening. The main criteria here, is to make sure this conversation is not heard to the next person. Why I specifically point open offices, it is one of the most challenging spaces for designing, acoustical you know for doing acoustical design. You have an open space were people are sitting, and you have to ensure that there should be only minimum amount of information which passes from at least one cubical to the next cubical.

So, the height of the patrician matters, the kind of observation you provide in the cubical itself matters, then the type of fall ceiling, the floor all these things affect the acoustical quality of open offices. Most common problem, if you sit in the open office say 50 people are sitting in that particular hall, you will have telephones ringing, you will have personal conversations, phone conversation, one two one interactions, people working around even the foot fall sound, lot of noise will be created and it is a single hall without much of the (Refer Time: 04:00). So, it will eventually spread out. So, the main challenge is, how do you arrest this. You will have to ensure acoustical privacy. On the other hand if you look at a lecture hall, the intention is the signal has to reach them in the fullest possible manner. So, you have to ensure the intelligibility, whatever the speaker is, you know talking about he is addressing, in full form, maximum possible without loses, it has to be delivered to as many ears are available in the hall.

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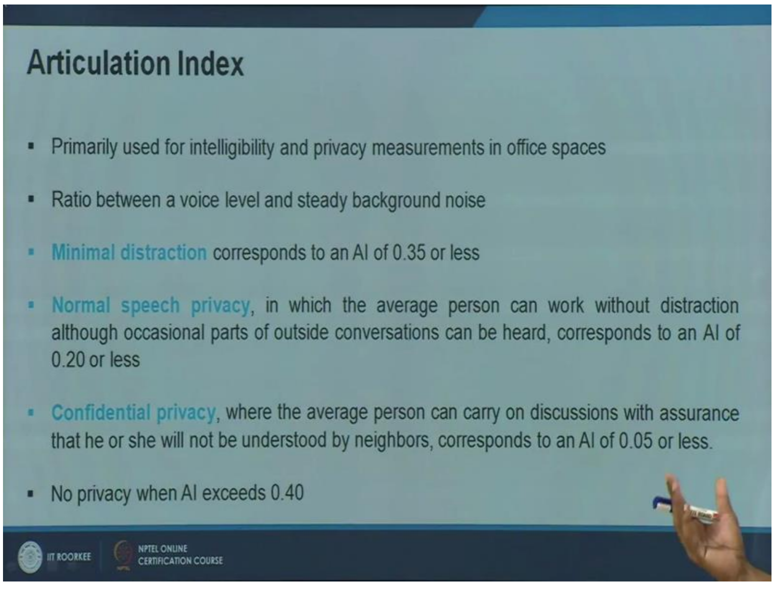

Articulation index was one of the attempts to you know decipher and translate the intelligibility and privacy requirements for open offices. Primarily it started there. It is actually the ratio between the voice level and the background noise. More or less this quality indicators if you see, there will be a factor of s by n; that is signal to noise. Even articulation index it talks about the voice level which is the signal, and the background noise level which is the noise. So, this is a, you know form of signalled noise ratio, a minimal distraction; for example, it ranges from zero to one articulation index, it ranges from zero to one.

One means perfectly audible, zero is you know you cannot here, there is total in audibility which means acoustic privacy. So, minimum distraction; for example, corresponds to an articulation index of 0.35 or lesser. If it is 0.35 or less in terms of articulation index, you are kind of assuming that, or you know you can ensure that you have attended acoustic privacy in a particular space. Then if you want confidential privacy say if it is a board room where financial discussions are made, you might have to ensure a total acoustic privacy which means, you have to go as slow as 0.1 or further low acoustic insulation plus absorption, both things are required, sound insulation as well as absorption of the emitted sound. If it exceeds 0.4 it means there is no acoustic privacy.

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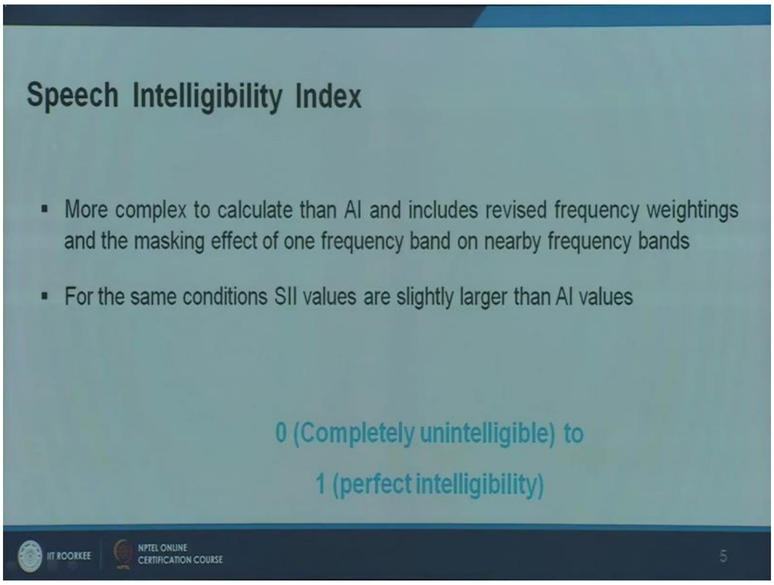

Speech intelligibility is more or less similar to articulation index, but it has certain revise frequency weighting, and also it includes the effect of one frequency band masking the other frequency, different frequency band sound is emitted, it includes the masking effect of one over the other, it is a improved version of articulation index, but the number also varies from speech intelligibility index, also varies from zero to one. Zero means completely unintelligible, and one is perfectly intelligible. So, if you are talking about speech intelligibility index in a lecture room, you will expect something above 0.8 or 0.9 the better it is which means the speech intelligible by 80 percent 90 percent. Whereas if you are ending up with an SII of, say for example, 0.4, which means the intelligibility is very poor only forty percent the sound is intelligible. It will create more strain on the speaker side, and it will result in less understanding or intelligibility from the listener's perspective. This is the same office that I showed you, we took measurement in different locations.

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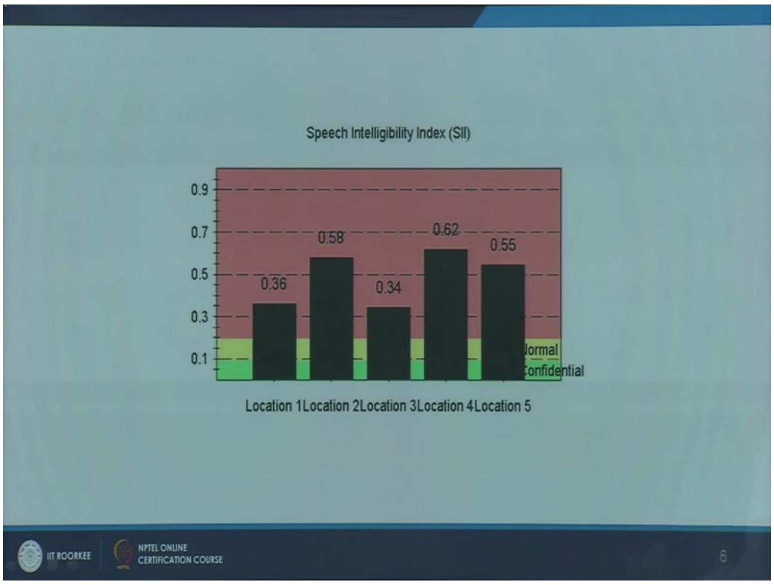

The speech intelligibility varies somewhere between 0.35, some places it went close to 0.6, which means the acoustic privacy is less, except for few spaces. Here the green band indicates there is the confidential privacy, which means the articulation index or speech intelligibility index is pretty much low, less than 0.1. If it is somewhere around 0.2 or lesser you call it normal speech intelligibility, or you have normal privacy. This is confidential privacy this is normal, and if it goes above the conversation is going to be intelligible.

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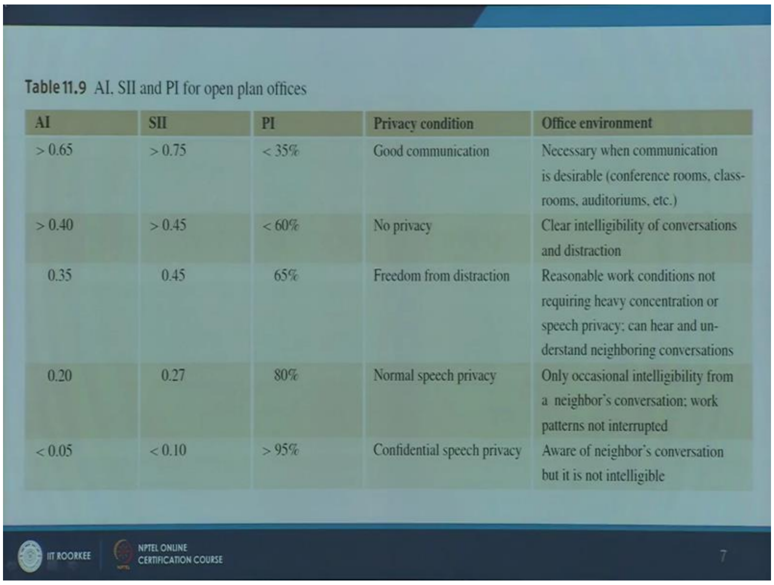
Table 11.9 AI, SII and PI for open plan offices

AI	SII	PI	Privacy condition	Office environment
> 0.65	> 0.75	< 35%	Good communication	Necessary when communication is desirable (conference rooms, classrooms, auditoriums, etc.)
> 0.40	> 0.45	< 60%	No privacy	Clear intelligibility of conversations and distraction
0.35	0.45	65%	Freedom from distraction	Reasonable work conditions not requiring heavy concentration or speech privacy; can hear and understand neighboring conversations
0.20	0.27	80%	Normal speech privacy	Only occasional intelligibility from a neighbor's conversation; work patterns not interrupted
< 0.05	< 0.10	> 95%	Confidential speech privacy	Aware of neighbor's conversation but it is not intelligible

A better understanding of it you can look at it. You can leave this column for low this is articulation index a i; speech intelligibility will be slightly higher than articulation index the numbers will be one to one, it will be slightly high. Say if you say it is about 0.65, or speech intelligibility is above 0.75, it means good communication. So, whatever is spoken you know is being understood by the other side, it is necessary when communication is desirable. Imagine you are in the conference room, in the conference room you need a good speech intelligibility. So, that inter personal conversations can be understood well. Whereas between the conference room on the neighbouring room or the cabin or an open office, you need a speech privacy, you know signal should not be spilling over, so that you ensure there is over hearing of these conversations, or one is not disturbed by the other, it is both way.

If the open office is very noisy we have to ensure speech privacy here. So, the speech intelligibility or articulation index has to come down. So, it greater than 0.4 there is no privacy on the other side if come as slow as 0.1 of speech intelligibility index, you have you know confidential speech privacy. You also have to know even that 0.1 are lesser speech intelligibility, the person is aware that there is the conversation happening, it is not a blanket insulation, we are aware that there is some conversation going on, but it is not intelligible; that is exactly what we are talking about here .We are not talking about a total zero proofing here, we are able to know that some conversation is going here, but you will not be understanding what it is. Whereas if you go to 0.2 0.3.

Whereas if you talk about say 0.35 or 0.45 of speech intelligibility index, you can here and understand what the neighbour is conversing. Common phenomena you find in open offices. You are easily able to hear what the fourth or fifth cubical the person is talking on phone. It is clearly audible which means speech intelligibility is relatively higher. As acoustic designer you will be expected to bring these things down in open offices. However these things measured, this are the directly measurable with instruments, but you have to conduct something called speech intelligibility test or articulation tests. Typically there are sets of words you know common reference text books, guides would give you, these kinds of words, they are more or less sounding similar.

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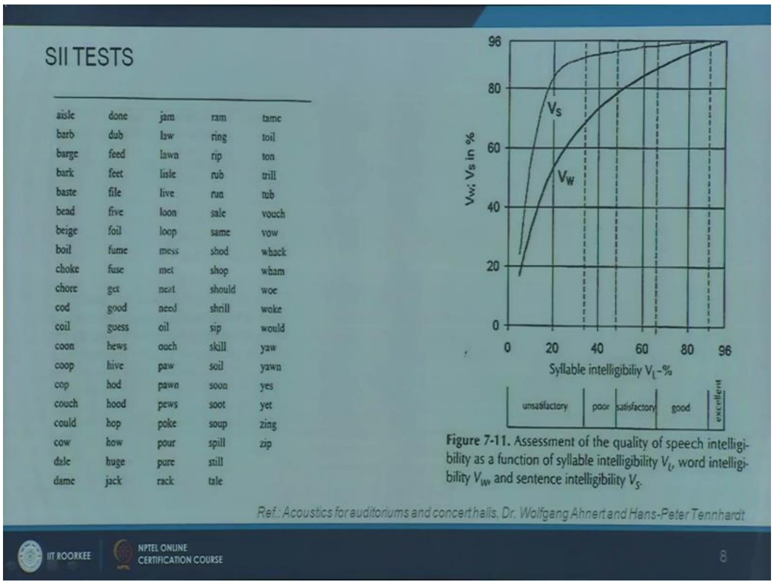

Say for example, barb barge bark. So, these are kind of you know the stress is same coon coop cop. If the speech intelligibility is good, you will be able to understand each of these words and write it down. These are typically a announcing kind of tests, where dictation kind of tests, where a person dictates these words ,and the audience they are asked to write down these words, or in some cases if you are doing for example, the speech intelligibility test with kids. You cannot ask them to write these words for example, you can give them pictures, you ask them to tick, but you spell the word, you ask them to tick the corresponding pictures, then you determine how much percentage of what you said has actually reach them.

Similarly, for halls for offices you do this intelligibility or articulation tests, you spell these words with, now new electronic certain things you can also measure it, but the typical conventional we have doing it is to do this articulation tests, where you spell the words then you start plotting it. There are three, things three levels in which understanding happens; first is the syllable level understanding, next is a word level understanding, and next is a sentence level understanding. You start plotting this you see how much percentage, you say unsatisfactory poor satisfactory or good or if it is more than 95 percentages, it is an excellent listening condition; that is intelligibility is more than 95 percent. It means it is an excellent listening condition; you can do this for syllable level, word level and sentence level.

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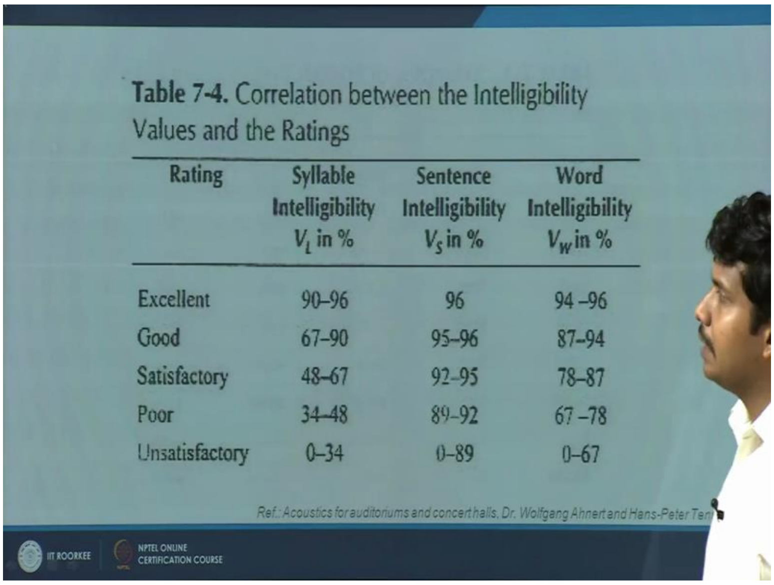
Table 7-4. Correlation between the Intelligibility Values and the Ratings

Rating	Syllable Intelligibility V_L in %	Sentence Intelligibility V_S in %	Word Intelligibility V_W in %
Excellent	90–96	96	94 –96
Good	67–90	95–96	87–94
Satisfactory	48–67	92–95	78–87
Poor	34–48	89–92	67 –78
Unsatisfactory	0–34	0–89	0–67

As I said the intelligibility as it increases, it goes from unsatisfactory all the way to an excellent listening condition.

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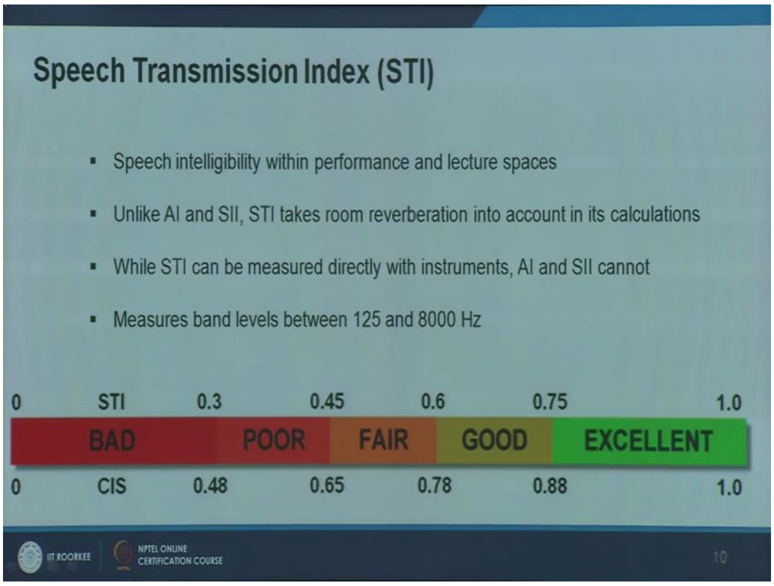

Another thing is speech transmission index which we talked about S T I. this also ranges from zero to one, if you look at it zero which is bad. On the other side you have one which is excellent. It is similar to articulation index or speech intelligibility index, but different in terms of the index are the number range zero to one, it is also a you know range zero to one, but it differs considerably from articulation index and speech transmission index. It considers room reverberation into account in it is calculation.

This is one primary difference between articulations speech intelligibility indexes, and the speech transmission index. why you know you have to do the dictation tests for determining articulation index and speech intelligibility index STI, speech transmission index can be directly measured with instruments, or it can be directly derived with certain measure parameters; say if you know the reverberation time, if you know the frequency, then you can actually determine through certain calculations I am going to show you, using that you can determine what is speech transmission index. It is measured between one, you know primary importance is given to 125 hertz to 8000 hertz, another version of it a rapid speech transmission index.

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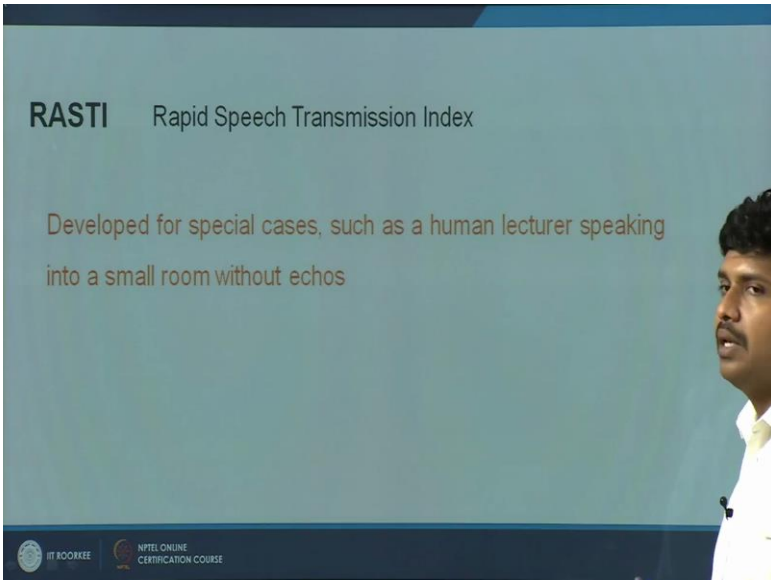

It is a modified version of it primarily used in lecture and you know amplified sound systems, where they are used, you use, rapid speech transmission index in place of standard speech transmission index, both are more or less similar just the numbers would vary.

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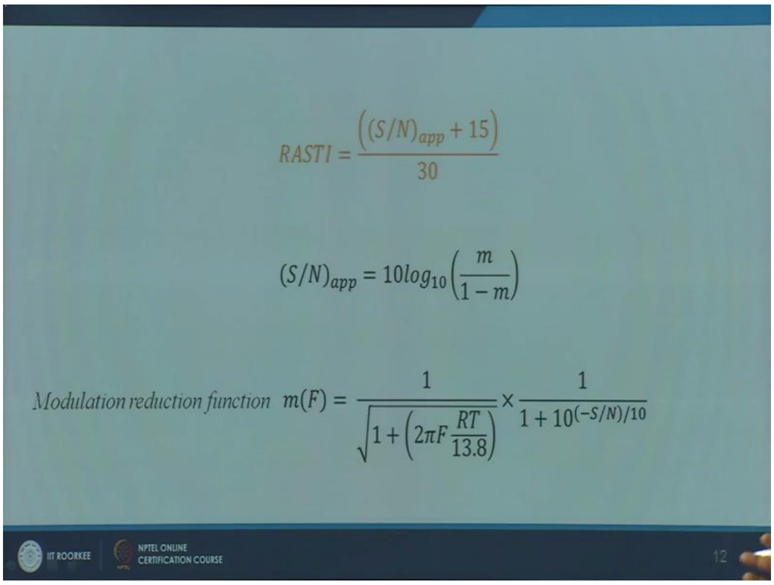

How would determine RASTI for example, RASTI is more commonly used index. RASTI is signal to noise ratio apparent there is a relation here. This you gets signal to noise ratio you get from an index call modulation reduction function. This depends, this modulation reduction function depends on the reverberation time and the frequency, apart from the basic signal to noise ratio in that particular frequency. So, every specific frequency determines this modulation reduction function. Then you find out what is the apparent signalled noise ratio, with that you can actually calculate RASTI. Similar formula is therefore, speech transmission index also, more or less the same formula applies there with a minimum you know little bit of modification. So, we talked about articulation index, then speech, you know speech intelligibility index, and then speech transmission index. Let us look at clarity of sound. These are certain common you know terms, but they have lot of meaning in terms of acoustical design.

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Before we get in to defining clarity you take; in x axis I will have time, here in a millisecond, last time know we started with millisecond went back to second, let us now stick to milliseconds. This is as usual this is sound pressure level in decibel. Imagine there is a trigger; there is a cracker fire cracker, or an impulsive sound. This is a first instance; say this is zero, fine number zero. From here there will be some amount of time related with this figure.

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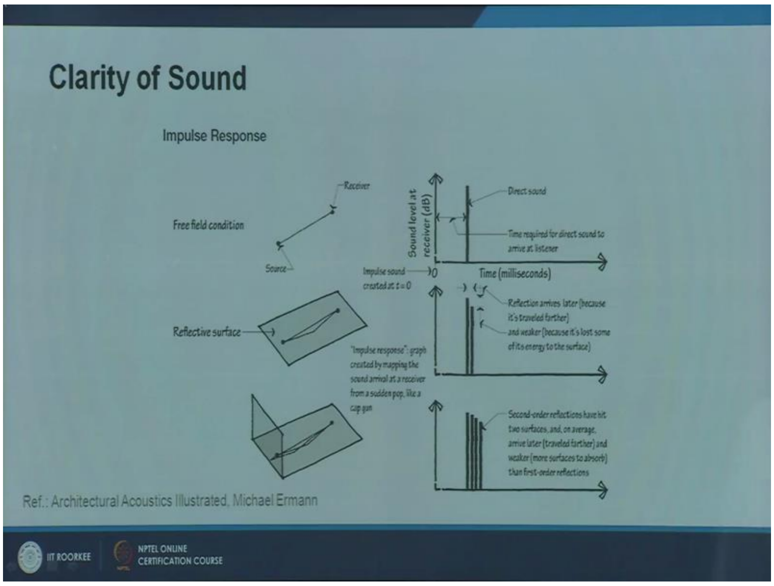

This is a direct sound; the source and the receiver are here. So, from source to receiver, it will take some amount of time to reach. So, this will be the direct sound. Imagine the sound is emitted somewhere here at 0.0 millisecond, if you take that as a cut of, the person will hear the sound after this. So, let us take that as a first point. Now there will be reflections happening. So, imagine you have a floor plane, the first reflection the sound, which is directly emitted here, gets reflected on the floor, and then hit's the person again. So, you start hearing. This is r 1 this is direct, this is d, which is indicating direct sound, this is r 1; that is the first reflection. Then you have a ceiling slightly tall ceiling, and then the sound goes off hear it comes back. After a while you start hearing reflection two.

Similarly you have side walls say for example, in plan-view this is the source, this is the section, and this is the section. So, if you take plan view you have a wide wall. So, this is the direct sound you had the floor and ceiling reflection, then you have this is in plan; you have r 3 reflection 3, you will have r 4. So, so many reflections would happen; then there will be a reflection from the rear wall. So, it will hit the rear wall, it will come back r 5. So, so many reflections would happen, as and when additional sound will come, this will be adding up followed by r 3 r 4 r 5, it will eventually decay down.

Now, whatever sound which is reaching your ears before 50 milliseconds, there are two thrush walls we are talking about; 50 milliseconds and 80 milliseconds whatever sound reflections which are reaching you, before 50 milliseconds, would actually reinforce no original sounds. Human ear will not be able to decipher, which is the original sound and which are the reflections, because before 50 milliseconds before you recognize and respond, they will actually come to your ears, which means we are actually reinforcing the original sound, this is for speech performance. When somebody is talking see if it is classroom or a lecture hall you take a threshold of 50 milliseconds which is really useful reflection; like I said, earlier some reverberation is needed, initial reflections. These are called initial reflections, initial reflections are useful. These reflections will in fact help reinforcing the original sound.

So, the direct sound does not seem like very dry phenomena, whereas if it is for music, some instrument is played there for musical performances. You take a threshold of 8 milliseconds, before 80 milliseconds whatever sound comes to you will reinforce their direct sounds. You will not be able to you know distinguish between the direct sound, and the reflected sound you will also ensure the continuity. The first syllable versus the second syllable; say if somebody reciting poetry, or if somebody is playing wind instruments. The first spell versus the second spell, it will ensure there is the continuity of sounds. So, sound is not a direct you know distinct set of signals, rather it becomes a continuous wave form. So, you can appreciate the music much betters. So, 50 milliseconds threshold, and 80 milliseconds threshold are important .Now let us look at the details of clarity in detail

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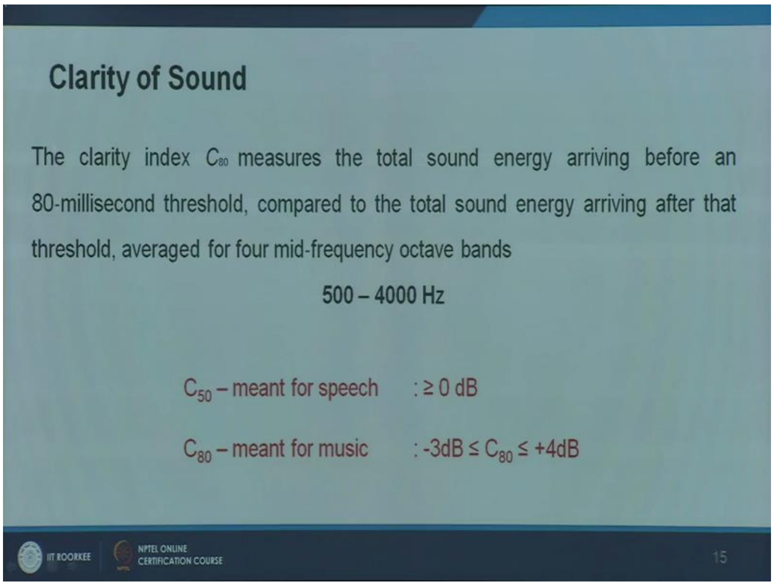

Clarity, we are talking about 50 milliseconds 80 milliseconds level. Let us first define what is clarity. Clarity is the total amount of the sound energy arriving before certain threshold, it can be 50 milliseconds if you call it c 50, it can be 80 milliseconds if you call it c 80. It is actually the ratio between whatever sounds signals arrive before 50 milliseconds or 80 milliseconds, and those which are arriving after that. So, initially we talked about late reflection, initial reflections, you have late reflections. This is you refer, initial reflection you refer as useful reflections, this need to be avoided. Actually clarity will help you attain or distinguish between initial and late reflections. You have certain thresholds, how much clarity is allowed you know in terms of c 50 and c 80; we will look at it, primarily estimate between 500 and 400 hertz.

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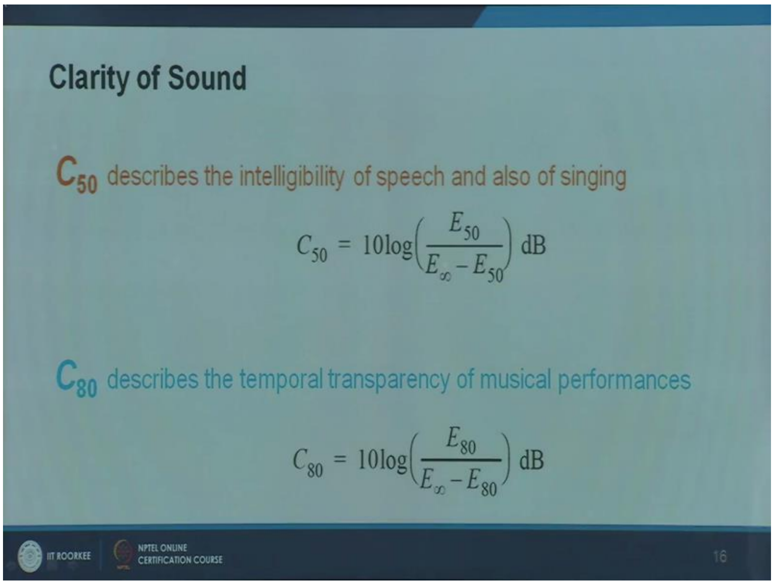

The formula is very simple e is a sound energy, if you say c 50, it is energy which is arriving within 50 milliseconds, and this is the whole energy which is arriving. Infinity actually means you are taking a longer time domain minus e 50. So, you are actually subtracting this this goes to the numerator, and whatever comes after, this goes into the denominator. It is expressed in terms of decibels again 10 log of the initial energy 50 milliseconds within that and the late energy. Similarly, clarity of 80 initial versus the late, this is the crucial factor which will actually help you improve the acoustic performance of the hall, even if reverberation time is within the limit, you have attend the reverberation time of one, which is permissible; for example, for a lecture hall or a multipurpose room, you have to keep in track of what clarity you are attaining, which is an additional implication or additional indicator to other for the acoustical performance of a particular space.

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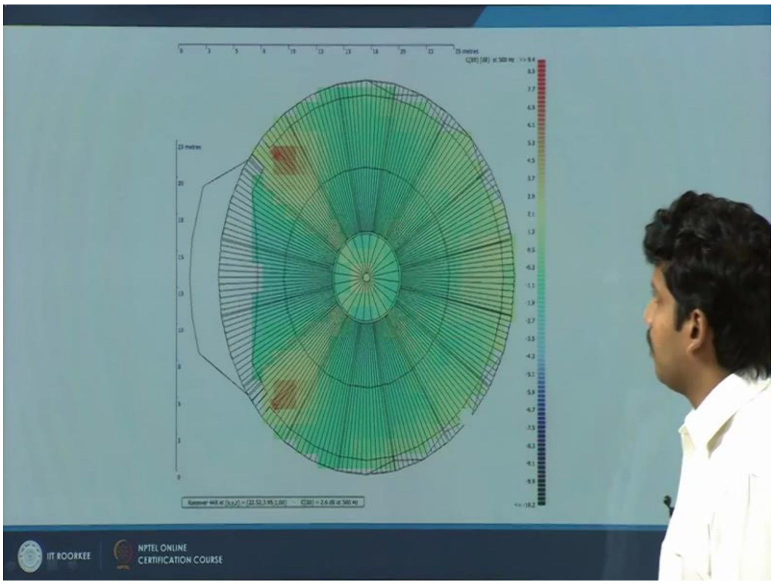

A same hall that we talked about the circular, you know hall which we were saying in the previous example, by determined the clarity, this is that 500 hertz as I said it is decibel clarity you have speakers here. There is one set of speakers, there is one more set of speakers in this, this is the podium, and people are seated here. So, the clarity actually varies with respect to position considerably. Imagine you are sitting close to this in the speakers through; the clarity is pretty high 2.93, which means it is. See essentially it is signalled noise ratio, zero or minus negative number indicates the noise is more signal is less, which is not preferable.

In these areas the signal is strong compare to a noise. So, more or less your clarity values are ok, but if you go towards the periphery or in the centre areas, you are coming close to zero, or sometimes negative values which mean the noise levels are more, compare to the signal itself, which means you have to start working your acoustical treatment. There is another parameter which is called articulation loss of consonants, in which specifically you know that vowels and consonants are there. Vowels are more strong if you are talking, just pronouncing a e I o u the words they know, the syllables are not lost much whereas, consonants are more softer, you will incur lot of losses, when you spell consonants. So, acoustic quality is also indicated in terms of the loss of constantans. So, when the person is talking, how much amount of consonants is lost?

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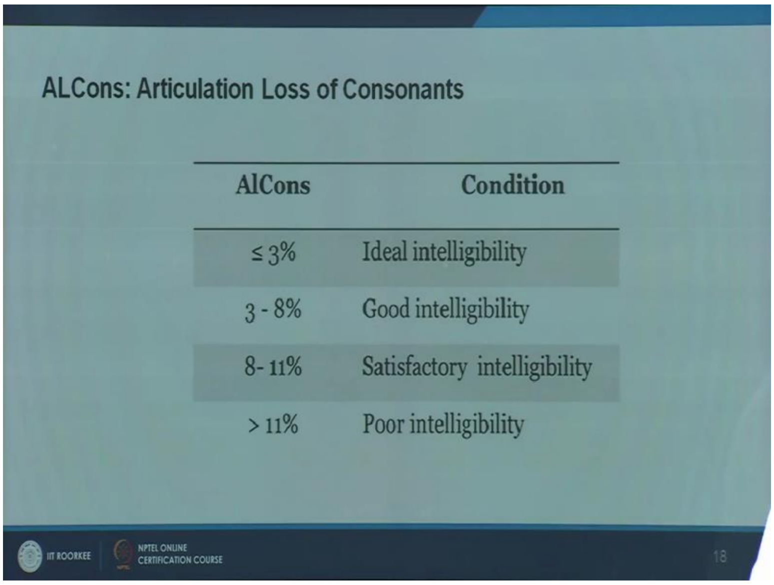

For example if more than 11 percent consonants are lost, which indicates poor intelligibility, when the concern loses less than or equal to three percent, which means the intelligibility is ideal. You can somewhere target between you know 5 to 6 percentage or maximum of 8 percentage, it is still good. You can allow up to loss of 8 percent loss of consonants, this is another indicator. You are not getting two into to much in to detail of articulation loss, or I will call this commonly referred to, the other three parameters are very useful, useful indicators. Later you know one of the following modules I will show you or demonstrate one example of an actual auditorium, where these parameters were tested and measure, I will be showing you through a demonstration how these parameters varied. The next crucial thing which one has to understand is, the term called room mode. Room mode is actually a reflection phenomenon.

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If you have a particular room of this, you know you can think of the same four meter by four meter room that we were talking about. You have a sound source then when these parallel wall surfaces are really reflective, certain frequency. Again when you talk about room mode, it is very much frequency depended, it is highly depended on the frequency, and it is also depended under room proportion; that is the height the width length of the room these are very crucial determinants of, whether you will incur room modes or not.

They occur primarily, no frequency range, especially in small rooms. If it is a huge auditorium, or if the room is primarily used for, you know made a high frequency range sounds you may not be facing problems with room modes, but whereas, recording studios are very small rooms, you will actually be finding room modes is a problem. You have a term call standing wave do not cancel each other, when you have specific thing just take a cross section. You find that there is a source here, and there is the wall the other wall surface, you have these particular wave phenomena which are forming. It will actually disturb.

This is the kind of resonant thing, where it will not allow normal decade of sound, it will persists the sound, will not be decaying down, as anticipated in your reverberation time calculation r t will not tell you, whether you will have room mode or not. There is a separate 6 you know set of cross checking that you need to do depending on those things, you will be able to find whether room mode would occur in a particular space or not. In this case a particular set of wave, you know specific frequency might develop standing waves. Standing wave is something which is perfectly fitting, the peek to peek here. It may be 1 2 4 5, it may be as many, up to certain numbers it may be you know, just one wave, or it may be more in numbers also, but they do not decay easily. What happens a specific phenomena, if you are a receiver, you walk along from this end to this end, you will find a minimum sound minimum; say if the, you know noise level from source of 60 d b, at this point you will be experiencing 50. Here it will again peek to 60 or 60 d b.

So, as you walk through you will find 8 to 10 d b difference, or may be more you know exaggerating the numbers, but you will be able to find out a difference starking understandable difference, perceivable difference as you walk from one side to the other. To give you a very simple form of representation, this would imagine you are in a classroom, listening if you are seated here, the kind of you know sound experience, and the loudness of the sound, you experience in this point say point a, would be considerably different from this particular point b. Here if you are sitting here the sound level would be much higher, whereas here the sound level would be lesser. This is exactly what we are trying to check. This is one common check which people will do for smaller rooms like I said, especially low frequency ranges, in order they are ensure this phenomena does not happened.

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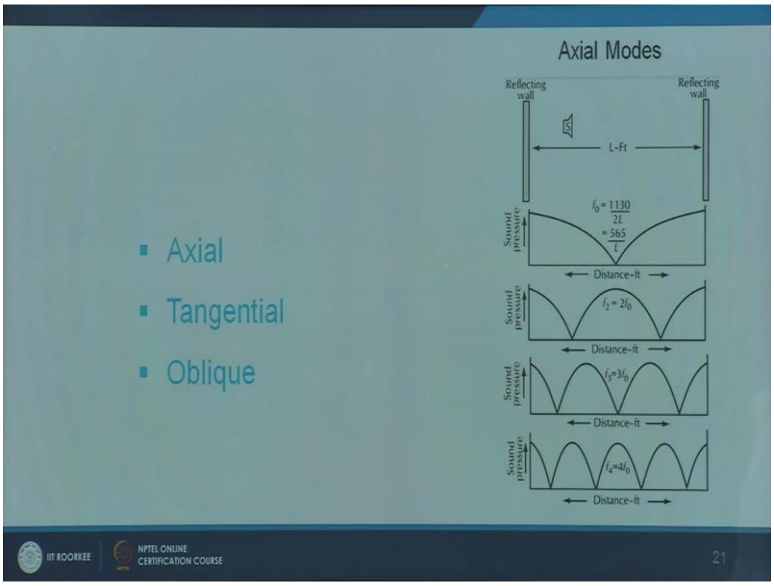

There are different types of room modes the one we are talking about is, an axial mode where it is directly the source and the listener, sorry the source versus to parallel walls. There is a standing wave which is just stuck here, this wont decay that easily. Again you can determine the dimensions, we will look at it shortly, as I said it can be one it can be more in numbers, depends on the frequency and number of the distance, the width or length which ever you know, is shorter it might happen or it is proportional. There are tangential modes and there are oblique modes.

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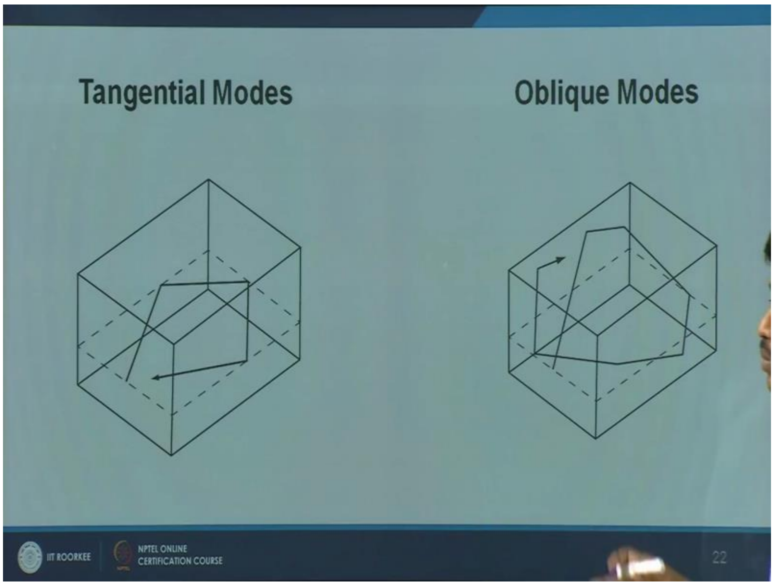

It can also happen tangentially to surfaces, vertically or horizontally, or it can be oblique happening all across in three dimensions. Simple formula would help you find out whether two things can be found out at which frequency standing wave will form. For example, if you have a room of dimension; say 4 meter by 4 meter you have this dimension.

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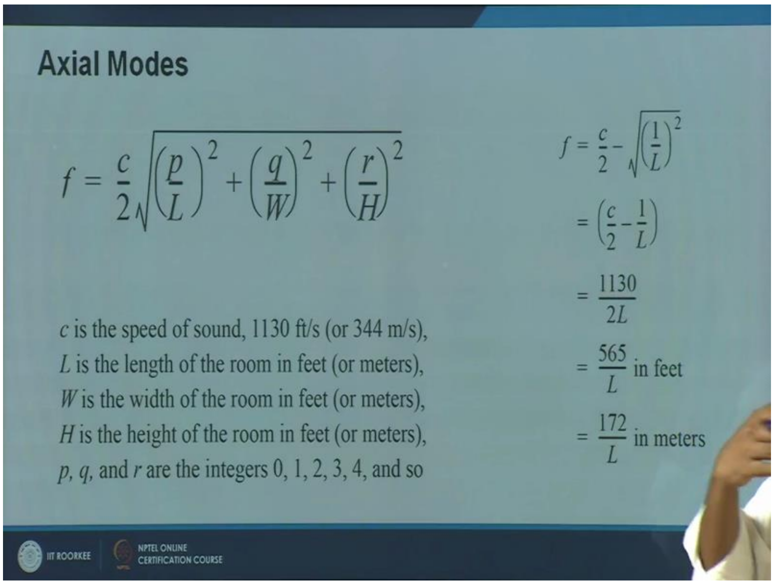

Length width both are same you have the height; three meters. Now you can substitute length width and height; this will be more number, which number of mode it is; the first mode, second mode. This is the velocity if you find out substitute, this you will be able to find out simple, if you solve this say for one dimension, you forget width and height; since it is axial. Let us take one by one if you want to find out first in terms of the length, which is four meters, you will just have to say 172 by 4, which will give you the particular frequency at which standing wave might occur. Say somewhere close to 40 hertz you will probably experience standing wave. If you are room is meant for certain instrument which is playing a note at 40 hertz, you might experience a standing wave which will spoil the whole appreciation of the music itself. In that case you will have to provide treatment again in that particular low frequency range.

So, it also tells you which frequency, you have to actually provide treatment for. As the you know room width reduces further, instead of 4 meters, you take a 2 or 2.5 meter, then what happens here; say if it is 2 meter you will have standing waves forming somewhere around 90 hertz 85 hertz, somewhere close to 86 hertz you will have standing wave, which means as the room width comes down, or the height comes down, any dimension of the room comes down, we will start experiencing room modes at slightly higher frequencies. Whereas if you have wider rooms, the room modes occur very low frequency marginal; say instead of four meter room, you imagine a 10 meter room. The room mode probably the first mode which can happen would be somewhere around 17 hertz, which is more or less, which your ear cannot detect. So, it is not really crucial thing, where as if a room mode is occurring at a 100, or 125 hertz, it will be a crucial thing to address. There are specific nomograms with which you can find, what is the appropriate size proportion of the room; simple ones x and y dimensions, it will tell you in which region the room mode would occur, and how do you avoid it.

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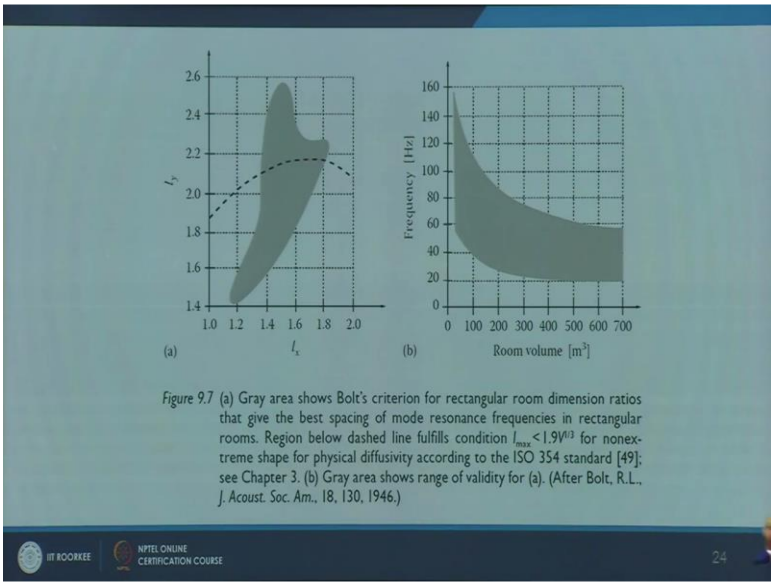

These are call Bolt's criteria, it also varies with volume and frequency, a simple thing the reference chart with which, you can actually determine whether my room ratio. Say if it is 1 is to 2 1 is to 3; say 4 meter by 8 meter room, 1 is to 2, whether this ratio is ok or not. If you have to adjust this, then you will have to say; for example, since here we were talking about only axial mode. So, two of these things were neglected. Instead if you are talking about a public mode, all the three frequencies will come into picture. So, one by length one by width one by height, will give you the oblique mode as it goes on it will increase. Eventually the frequency of occurrence will also vary. So, appropriately you can determine using this nomograms, what is my perfect room ratio, height to; say for example, width, length to width, how do I determine this nomograms will help you understand.

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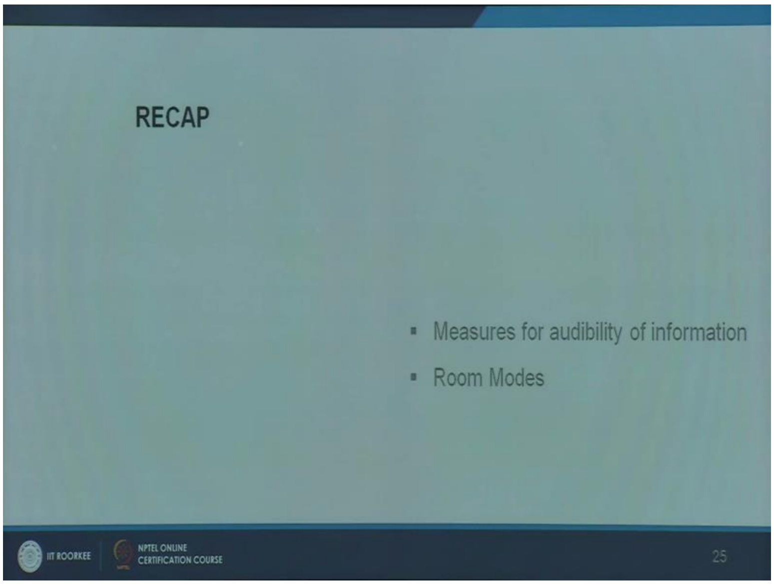

To give you quick recap of what we studied now. We studied about certain acoustic quality indicators, which you know we left in the previous section; we started with the reverberation time. We start with reverberation time in the previous section. Today we looked at articulation index, speech intelligibility index, and speech transmission index as well as RASTI. Apart from that we looked at a phenomenon called room mode, which is a crucial thing for smaller rooms, and in low frequency sound pressure levels.

Thank you.