Seakeeping and Manoeuvring
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Lecture No. # 11
Irregular Waves

Today, we are going to talk about irregular waves.

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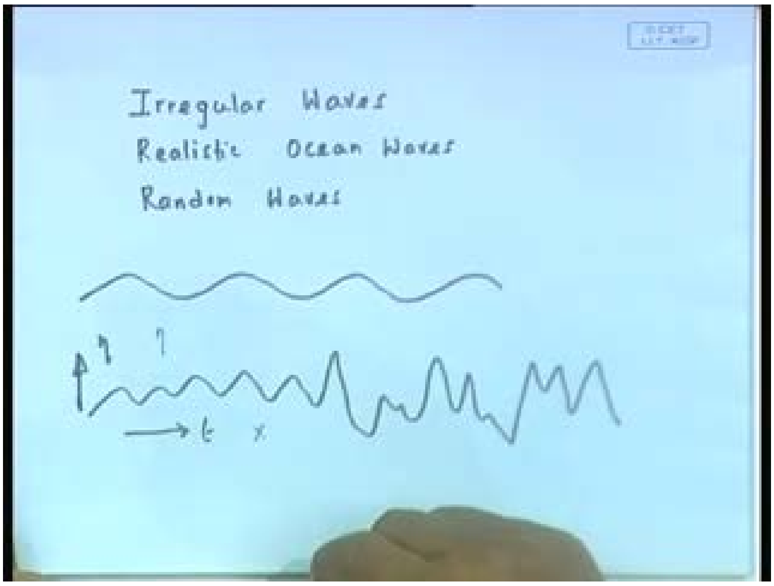

You may also call this to be realistic ocean waves. Sometime, it is also referred to as random waves. You can call by any name. The question that we are going to answer today is this – if you went to an open ocean, if you were to put a stick and measure the wave heights, you are not going to find very nice a sine curve, which is what we have been always talking earlier – regular waves. What you will find? Some kind of random thing; something like that. I mean if you put a stick in ocean, you are going to find a record, which will look along random say against time, the height; it will look like that. In fact, if you were to take a snapshot, a photograph, you would find the similar kind of random nature along special dimension; that is, it can also be a similar nature – eta and X.

Now, the question is this see – the open ocean waves or the realistic ocean waves do not resemble or do not look like nice simple sine curves; they look completely random in nature; you seem to think that there is no correlation, etcetera. And, it is this environment on which I am placing the object – the ship or offshore structure or whatever. It is these waves, which acts on the ship. And, I need to figure out or we need to study how a ship would respond to these waves; not to sine waves as such, because anybody will question – when I go to ocean, I do not find any waves which is sinusoidal in nature. Therefore, today what we are going to talk – how do we represent these waves; how do we classify these waves; how do we characterize these waves, so that I can study tomorrow subsequently what would happen when I place a floating vessel like a ship on these waves. So, this is a question that we are going to answer today.

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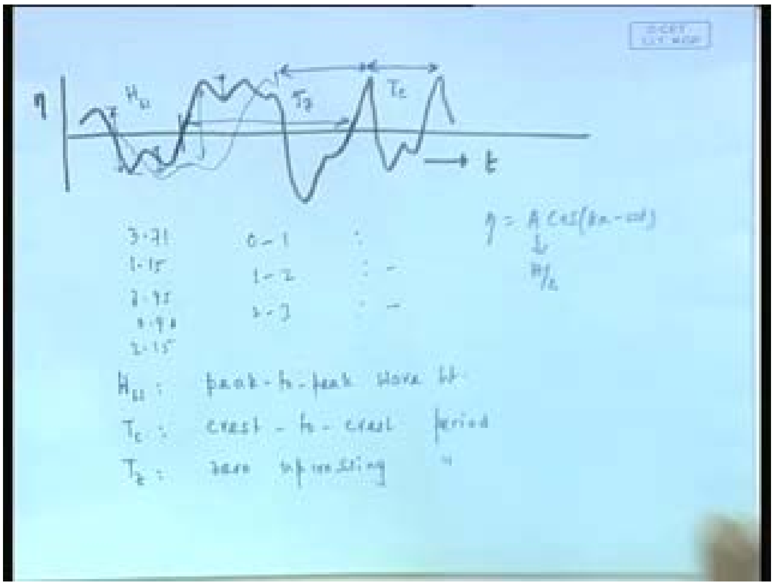

Obviously, when a signal is random, let me take t verses eta. The graph will typically look something like that. Now, what we could do is that we could analyze these waves. This is a random signal, irregular signal. We can analyze them statistically. For example, I can define crest to trough as height; wave height say H w.

Now, you take a long signal and measure all these crest to trough, etcetera. What would happen, you are going to find that this H w, which I am defining as crest to trough or trough to crest, peak to peak you may say. There are whole lot of occurrence; like you will find… First record shows 3.1; next one shows 2.1; next one shows 3.0, etcetera. So, you are going to get a whole lot of random record of heights; so many heights there are.

Now, what we can do is to make a statistical analysis – how many heights are occurring how many times in a signal? This is what we can call a histogram. Now, typically, what would of course happen is that you would not be able to find out exact value. For example, I (Refer Slide Time: 05:11) may have this first one in this example; say I just put some number 0.37; next one may be 1.15; next one may be 3.95; next one may be 0.98, may be 2.15; like that. Now, you know these heights. Like that occurring say 1000, 10,000, whatever. Now, the question is obviously, you cannot pin point the exact numbers, because up to second decimal or third decimal, the numbers would not repeat. So, what we will do, we will make a cluster. 0 to 1 meter how many times it occurred; 1 to 2 meter how many times it occurred; 2 to 3 meter how many times it occurred; we could make something like this; like we can analyze these quantities statistically. But, before I do that, let me find out other terms that exist.

See height is one parameter; it only tells me this crest to crest (Refer Slide Time: 06:08). What about this side? It does not have any measurement of this. For example, if I will stretch this whole thing, I pulled it this side, keeping the height same; I would still have height statistic same, but the signals are not same. For example, if I took say this; I just made it for example; I just stretched it. The heights will be same. So, obviously, height, which is a measure in the vertical direction does not say it all, because there are other parameters.

If I were to now measure something this side, what is this side? Period. So, what we could do here? Again period. What is a period? If you know in sine signal, it is repetitive; crest to crest or trough to trough or 0 to 0. So, here again, it is not all the same thing. For example, if I were to take the period, time interval between crest to crest, this is the crest to crest period; see here to here; here (Refer Slide Time: 07:03) to here, etcetera. I define this as T c. In other words, I will write down. First, let me write down this H. This is actually peak-to-peak wave W. This is one measure.

Now, remember, when we talked about regular waves, we always talked in terms of amplitude; not height. When you talk of regular wave, we have this A cos of kx minus omega t. And, A is nothing but H by 2. But, we normally used the term A – amplitude.

What is amplitude? Measure of the crest or trough from the mean level. Agreed? But, in irregular signal, what happen, this mean level is not known; you see you do not see it; you put a record; you are going to only find this graph; you do not actually find this black line (Refer Slide Time: 08:02). The mean level is not known generally. That is why it is a convention to use peak-to-peak, because you do not have the mean level from which you are drawing this line. All you are getting a record of this black line. That is why, in random signals, you normally use peak-to-peak. You do not use amplitude, but height. That is one thing.

Now, coming to the period side – this side, I can have one period T c, which is… When I measure the time interval between successive crests, this is called crest-to-crest period (Refer Slide Time: 08:40). Now, the other thing in… Of course, you can always say I can have a trough-to-trough period; normally, not used. Other period very important is what is known as taking time form here, where the signal has crossed. Here I need to have this zero line from some reference. In this case, to here; that is, when the signal crosses the level 0, if you can draw a zero line, then the time interval from first crossing of zero line to the next crossing of zero line – this is known as in fact, zero up crossing period; up crossing – it is crossing upward direction. So, this is called zero up crossing period. You can always say there should be a zero down crossing period. My point is therefore, even when you define period, there is nothing unique; it can be crest-to-crest; it can be trough-to-trough; it can be crosses upward to next upward, downward to next downward. Typically, the crest-to-crest and upward-to-upward is used to characterize; you cannot use all, so many of them. So, T z I call it zero up crossing period. Now, this is with respect to time.

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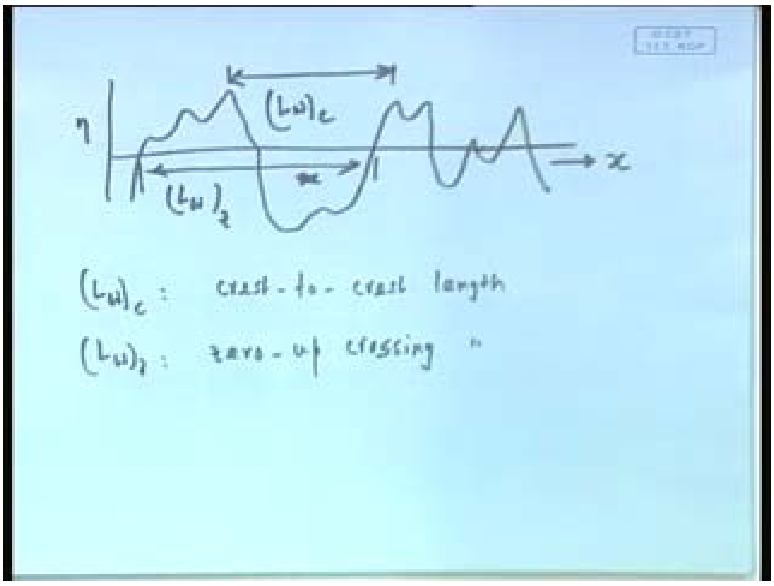

Supposing I were to take a signal, a photograph at one point x and I find this eta. Again, I will find this random something. This is the x distance remember. Here obviously, the measures are lengths. So, similar way, here to here, I will have what is called peak-to-peak length L w – c; that is, crest-to-crest length. Similarly, I will have here to here, zero up crossing length; I will call this z. This is going to be zero-up crossing length. So, what we are finding out is that when it comes to this horizontal axis, whether it is time or whether it is length means space dimension, I can have different kind of lengths or periods. In the vertical direction, I normally have only one, that is, H w – peak-to-peak height. So, these are the various parameters for trying to characterize a random signal. A random signal means everything is basically random.

I would like to give an analogy. You see when you are doing ship design, ship hull, what we do? We try to characterize the hull by lines then, but otherwise, we have some fixed number like block coefficient, water planning coefficient, etcetera. Remember that all of these, even if I have four, it is not unique, because I can always have a slightly different lines (( )) with the same values. But, what you do, you try to have some fixed set of numbers trying to characterize something that can have a wide variation. So, similarly, for a random signal, we will like to have some of the number. These are the typical ones for period. It is crest-to-crest or zero-up crossing. Length also same thing; height is peak to peak.

Now, let us look at the height. The height is the most important one, because… I will come back to this diagram again – this one (Refer Slide Time: 12:44); because everybody knows that higher the wave, most severe it is. You will call that… We always talk in a loose term that waves are so high; 30 meter high, 20 meter high; means height is a measure of severity. Stronger storm will give a higher waves, etcetera. So, height has… We also know that energy of waves is proportional to square of height. So, height is a measure of the energy on the waves; height is a measure of the severity, etcetera. So, height becomes typically more important to characterize waves.

Now, coming back to this, now, we have (Refer Slide Time: 13:26) a long signal, number of heights occurring, 1 million, 10,000. As I said, you met some kind of histogram. What we do is that we will try to figure out in cluster how many waves between 0 to 1. This can be any interval 0 to 1, 1 to 2, etcetera. Let me go to another diagram. But, we kind of make something like that see.

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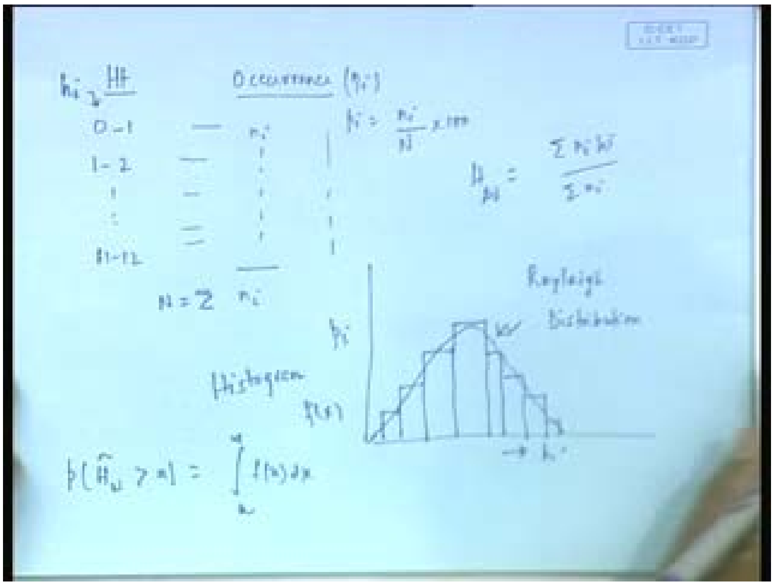

Let us say here heights and occurrences. You have say an interval 0 to 1, 1 to 2, like that say, etcetera. And, you have these occurrences here. Now, of course, what we can do, these are – we can say heights; let me call this to be h i's. This is occurrences numbers; let us say whatever number n i. So, if I do that, total signal is like this. As I said, why you do this cluster? It is not necessarily 0 to 1; it can be 0 to 0.1 if you want, 0.1 to 0.2 if you want, but a cluster. Now, when you do that, when you plot, obviously, I can actually have here a percentage occurrence simply by taking here as p i as defining at n i by N into 100; it is all simple know. Like the percentage occurrence, I can do that if I want.

I can actually have what is known as histogram (Refer Slide Time: 15:14). I can plot here p i verses this h i. So, if you do that, it looks something like… (Refer Slide Time: 15:28). Everybody knows this. The total area is equal to 1 if I take probability, etcetera; everybody knows. This is actually a… I can call this to be probability function also, effects. This is a typical histogram. Now, here comes the question… Now, of course, from this histogram, I can find out the values of average – what is average height, for example, H average. It is simply going to be that; n i into h i divided by n i (Refer Slide Time: 16:12); something like that. So, what I am trying to say is that all these we know – the average value, etcetera. Now, the most important question is it is like this; of course, if I know this function; if I actually call this; if I were making this much smaller and smaller, it is approaching a statistical function.

Supposing I call this (Refer Slide Time: 16:40) f x, then I can find out any quantity something like what is a probability, for example, of say some value say H w exceeding some given value. It is going to be simply a to infinity of f x d x, etcetera; it is very simple; I mean what is a chance that the wave height is more than this? You can find out statistical distribution. We will do some example for that, etcetera. Average – you can always sum them up and find average, etcetera. So, there is no problem on that. Basically, what we are doing, we are trying to find out the number of occurrences, plotting it; the plot will be an f x curve. And then, from there, I can find out average value of exceeding some given wave height and all quantities that I want to know.

Now, comes this question – now, people have been doing this for years together; oceanographer's job has been to characterize ocean waves. So, they have been collecting data and plotting histogram not only for wave heights, also for periods, etcetera. Interesting thing is that when you keep doing that, it turns out that this graph (Refer Slide Time: 17:55) tends to follow a theoretical Rayleigh distribution.

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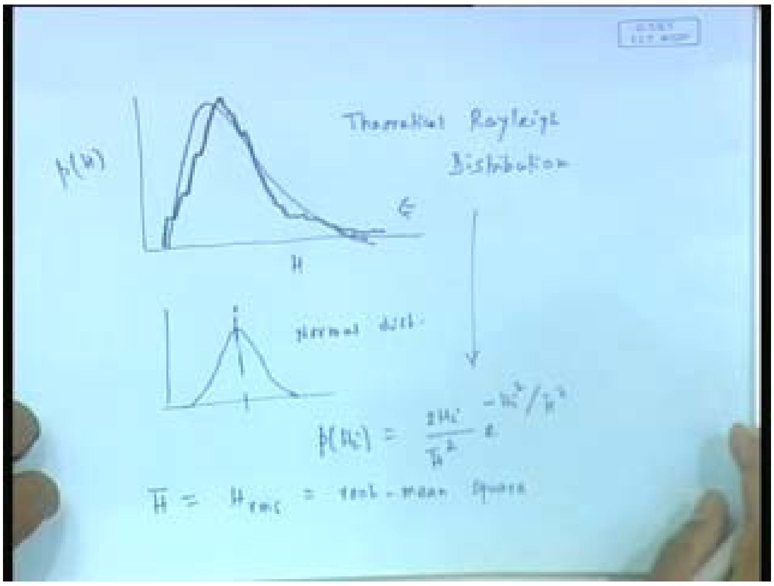

Now, let me draw one more. In other words, if I were to do this – let me call it now p of H, because this is what it turns out to be verses H. It turns out that if I were making histogram and of course, making continuous graph, it is following a theoretical Rayleigh distribution. You see what is the difference between this; of course, for this, I will write the formula later, but let us just describe, slightly characterize.

Now, supposing I asked your class, tell me your ages. What will happen? Somebody will say – very fine graph 21 years 2 months, 19 years 4 months, etcetera. So, if I make an average and if I plot, you will find out; mostly it will be a normal distribution. Normal distribution or Gaussian distribution is a bell-shaped curve; that is a normal distribution (Refer Slide Time: 19:30). It has an average; of course, it can be peaky and all, but it is symmetric about the average or the mean value. What it means? The chances – suppose the average is say 21 years. So, a chance that somebody has 20 years is same as chance 22 years. Both are symmetric about mean. So, whatever is lower and higher, have similar symmetry. This is a very common curve. And, in many natural phenomena it occurs. I just gave an example of age; it is also typically true.

But, here it turns out Rayleigh, which is biased, which is lightly hanged on this side (Refer Slide Time: 20:05). This is what; of course, you may say exactly this or not. Actually, if you fit the graph, it might turn out to be something; like some data might look like that; another will lo like that; but, it follows. It resembles closely theoretical

Rayleigh distribution. There is a very interesting like physical reason you can think of why it is so. You see what it means is that the chances of higher waves occurring are actually lower. But, lower wave occurring is always higher. Now, what happened, I always like to tell this that see when waves get generated when you blow wind. Suppose I blow wind at certain speed say 10 knots; wave will be created up to some height, because you have seen from physical phenomena, more is the speed of wind, more is the height of wave. Why? Because which will come later on again. I am just trying to give you now an explanation about some kind of intruder explanation about the ship.

See more wind blows; there are more energy to the wind; so, the more of the energy gets transfer to water. So, obviously, the wave height has to be higher, because more energy means higher waves, because energy is height square. If you fit more energy water, obviously, water will show up higher; wave heights will be higher. If you give more wind, obviously, more energy goes into water. So, now, think of this. Supposing I have wind up to say 10 knots; I will have all waves. Now, lower waves will also be there, because lower wave can also get excited, but it will be up to some height let us say.

Now, if I have 20 knots, again will be up to probably some height. So, upper bound is more or less fixed you see. But, lower bound always gives the occurring. Supposing as (( )) What I mean, if I blow wind at 30 knots, wind that would have been generated at 20 knots and 10 knots also gets generated up to 30 knots. So, there is a pull to the lower side. You see that always the lower ones are existing more. As a result, there is a hang towards this side (Refer Slide Time: 22:12). And, this gets thinner. This is one of the intuitive reason you may think; may not be exact reason to tell why such phenomena are not symmetric, because here one sided. With a certain wind, velocity u waves of lower up to some height is more or less excited; not beyond that. Another wind means again lower to up. Lower ones are always there. As a result, it is more like Rayleigh. Now, this makes our life very easy.

If this Rayleigh distribution turns out for this distribution, as you know in a normal distribution, this function have a theoretical… Like for this, it has a theoretical shape. It is given by (Refer Slide Time: 22:57)… When H bar is actually… H bar square is the… What is it? Root mean square; or, H bar is root mean square; basically, mean of the square of the wave heights, what is called the RMS (Refer Slide Time: 23:30) value, which is like standard deviation.

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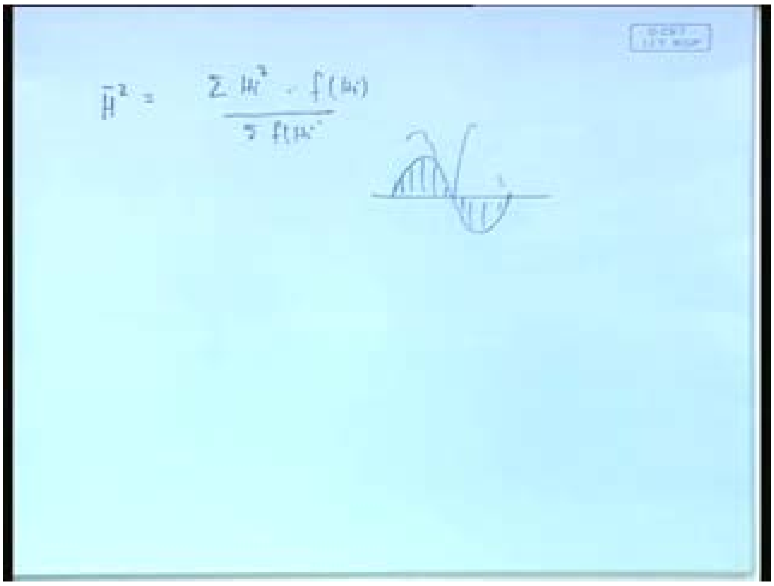

Or, actually, we can define this like this – H bar square… Then, that is the probability of H i divided by… Whichever way you call. Essentially, as you know, it is mean of the square of the heights. See you must be knowing this. If I were to take a signal like this; now, if I take an average, the average become 0, because plus and minus goes to 0. So, that is why, this idea came to square it and then average it. When you square it, this will become like that; this will also become like that and you get an average something. As you all know, sine theta is 0 to pi whatever; 0 to pi if you average, 0; if you took root means square, it is not 0. So, that is why, the idea of root mean square came. And, that is why it is used more frequently rather than the mean value, because there can be signal, which if goes to negative, then it becomes 0.

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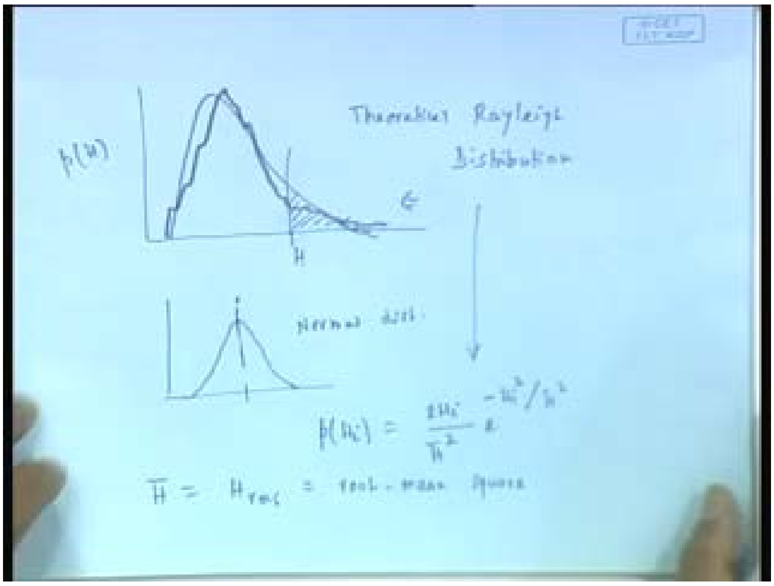

Now, the interesting point is that if you have this root mean square, then this function can be defined in terms of root mean square (Refer Slide Time: 24:50). Later on, we will find that this is also connected to the area of that. Anyhow that is different. That is actually that total sum anyhow.

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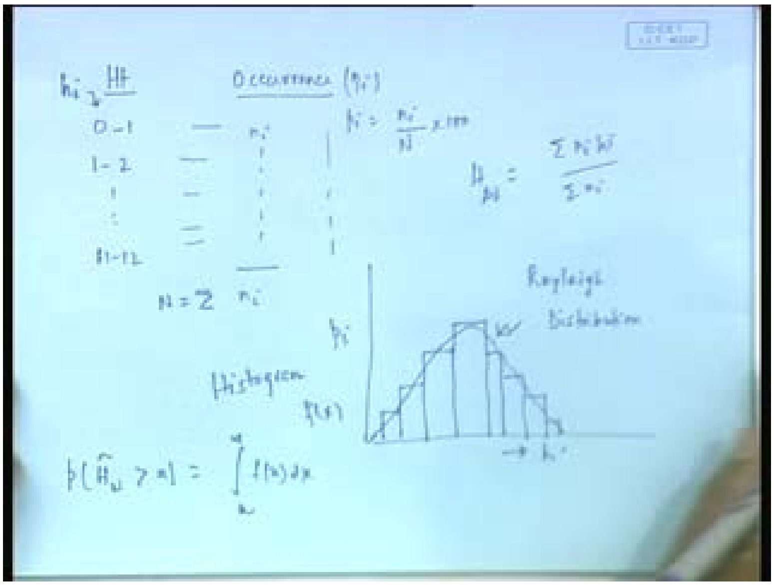

Now, the question is that it is very interesting. Then, supposing statistically I have collected whole lot of data. I have this first set of data like this. Now, I have found out… Oceanographer found out that most of the distribution. The histogram looks like a

Rayleigh distribution. Now, I can actually figure out this particular graph by simply taking the RMS value of this signal and then fitting this graph (Refer Slide Time: 25:27). Then, I will end up getting the shape. Once I know the shape, of course, I can easily figure out every quantity of statistical importance. For example, if I know p H i, I can find out what is the p of H i exceeding H star? That will be just area from that to this.

Supposing I want to find out what is the probability of wave height exceeding this (Refer Slide Time: 25:48) value; obviously, that is this area. So, what I mean, this can be done theoretically from here. I can do it because I know H bar. So, all that. Having said that, one of the most important concept we need to tell. So, we have… See in this (Refer Slide Time: 26:09) signal, things like H average; that is simply average. We have also H root means square; that is, H RMS what we say. It turns out of course that if this Rayleigh distribution relation (Refer Slide Time: 26:30) holds good, then H root mean square and H average are related by some constant; you can theoretically find out.

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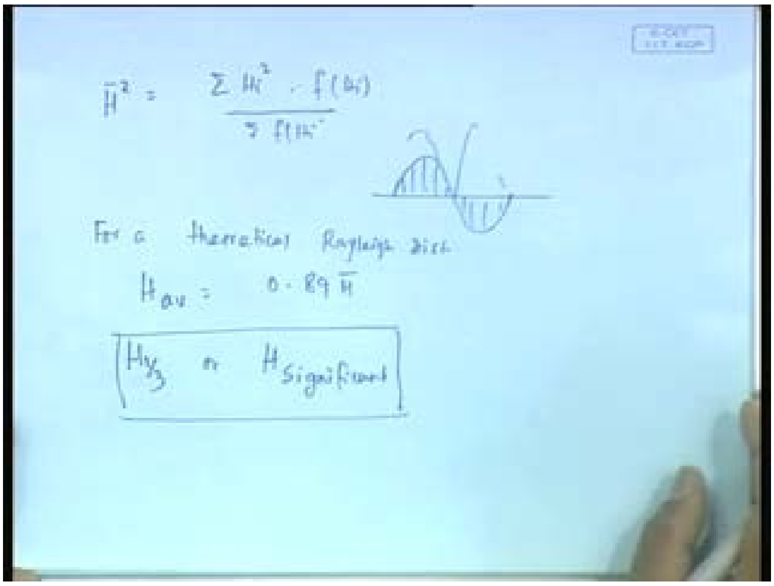

In fact, what would happen that for a theoretical Rayleigh distribution; H av equals 0.89 H bar. Like that the relation exists. This is all theoretical. Question is that supposing I want to signify severity of a wave, should I use RMS value, should I use average value? What should I use? Here comes a very important concept in our subject of ocean wave, which is known as H one-third or loosely, it is called H significant. This is the term that is important, because mostly when you go to practice, people will tell you, in single one number severity of waves by stating its significant wave height. What is it? This is what we need to find out.

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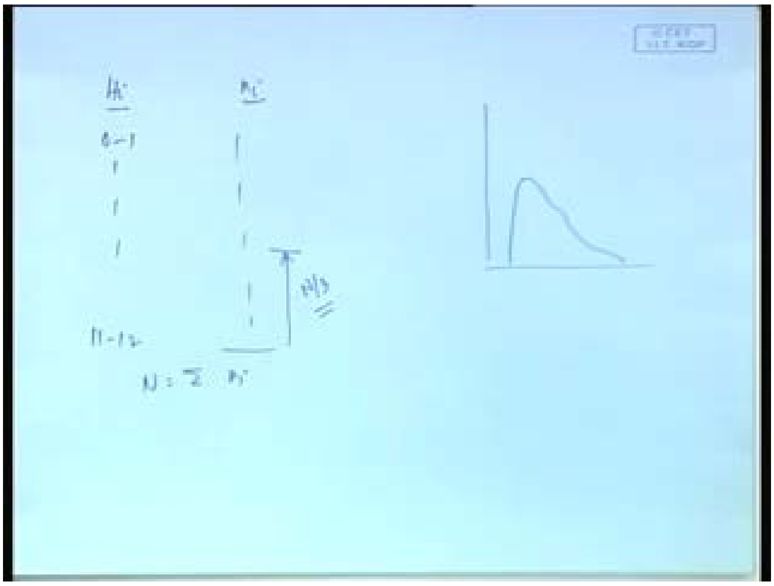

Now, you see what happen… I need to draw this again. Let me again call this H's and n's. Let me just write this as this way only. Say some value; say I just went to this thing and this value something; total number N. Now, what is happening, remember what I said, there is always a pull towards the lower heights. Now, if you make an average, people felt that average does not really signify the severity of a wave or some kind of sense of wave. So, this one-third significant came. Meaning of that is that from the top highest, you go this side to n by 3 number of waves; one-third of the data.

Suppose there was 1000; total N was 1000; I will give example of this later on, because this is very important for any point of view. So, we need to give this example. Suppose from here (Refer Slide Time: 29:01), I take one-third of the total number of the waves, which is… If it is 1000, it is 330, 33; then, take those waves and average it. Then, I will call that to be one-third significant wave height. Actually, the word should be not significant; it should be called one-third significant.

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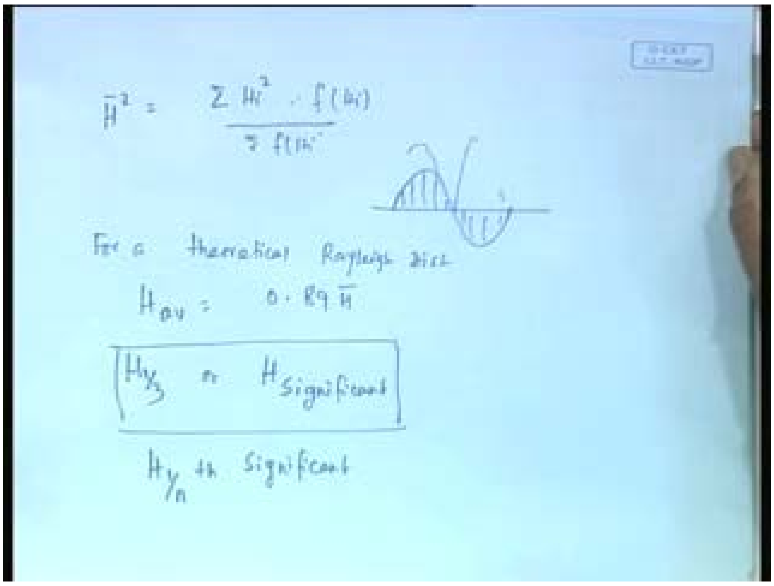

And typically, I can have H 1 by n, which means what I can do is that I can take one-nth of the highest total signal. If I average that, then it is called one-nth significant wave height. For example, in this example (Refer Slide Time: 29:49) only, if I were to take from the top n by 10, that is, 100 highest wave; average it; I would have got one-tenth significant wave height. If I write it 10 waves only, I would have got one-hundredth significant wave height. So, you can have all kind of H one-nth significant wave height. However, by default, H one-third significant wave height is used so frequently in our subject that we call H one-third as significant wave height by default, although strictly the term should be H one-third significant wave height. And, you understand?

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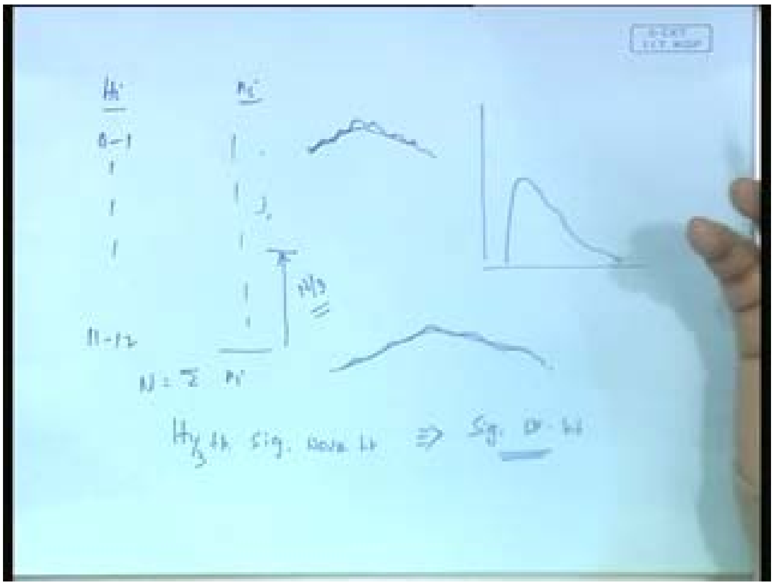

See what I am trying to say is that H one-third – we call this as significant wave height loosely. And, why it is used? Same thing; if I were to use, I will get a lower value slightly, because there are too many waves of small heights always existing. So, it does not give a practical feel about the severity. That is why people felt it has become a custom actually. It is not that there is any general rule or something; it has become a custom. That we would think one-third significant wave height to be a better measure for representing a particular wave, because that would have eliminated all these averaging over these small waves. See small waves are always there. Small wave ripples if you see any place.

If you actually go to any ocean, you will find that any big wave is actually riding over ripples (Refer Slide Time: 31:32). You will not find a sine curve; you will find small ripples riding over there always. If you ever take a cruise or something or go on a ship somewhere, you will find that the waves that you find is not very smooth, but it has always small breaks here; which means always the small waves are existing. So, if I count them and use them for average, the average tends to get pulled down to the lower side. You might end up getting an average of say 2.5 meters when significant average would be 3.2 meters. As a result, the word – significant wave height is more used. That is a very important concept, because in all most all of our subject, we always use significant wave height, not average wave height. Now, we need to actually do some kind of an exercise for that.

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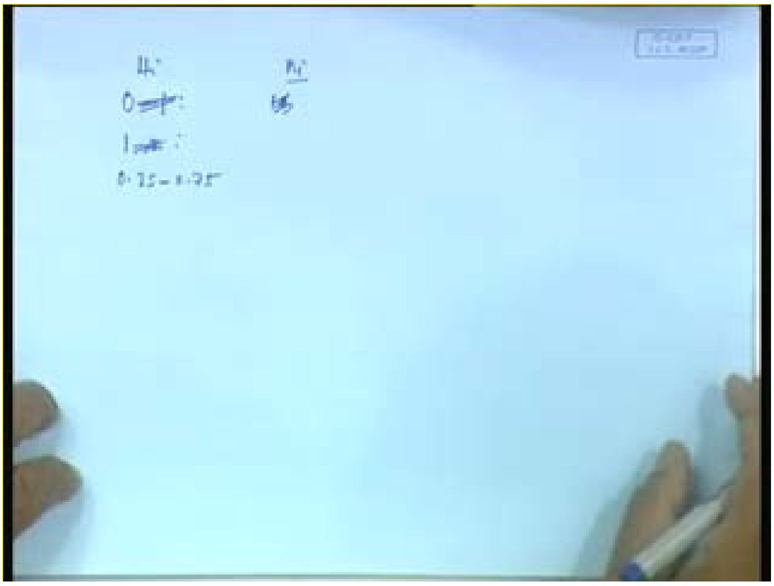

Maybe let us take some example; otherwise, see 0 to 1 meter. Let us say I am just writing this again – H i; I am trying to work out; and, this number. You can actually operate on also probability p n i. All these are same thing. The main point is that you must take that one-third values and average it out from the top. Say this occurs say 10 times; say 1 to 2 meter – I just write this; or, here let me write it 15. No, actually let me take this example rather here 0.25 to 0.75; rather let me take one more page; rather this way I will do.

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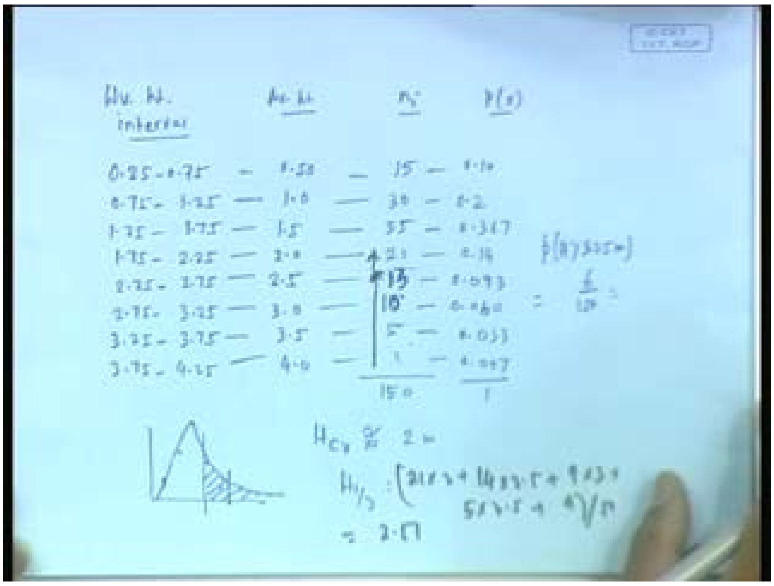

Average; there is the frequency quotient if I write now. Let us say 0.25 to 0.75. So, this is 0.50. Say it occurs 15… or rather let me write the whole thing down – (Refer Slide Time: 33:48) 0.75 to 1.25; 1.25 to 1.75; 1.75 to 2.25; 2.25 to 2.75; 2.75 to 3.25; 3.25 to 3.75; 3.75 to 4.25 – up to this. This is 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0. This is certainly 15 times – 30, 35, 21, 14, 9, 5, 1 – 150; 0.10, 0.2, 0.367; we are going to easily work it out to find out – 0.14, 0.093, 0.060, 0.033, 0.007. See I have a purpose for writing this. The purpose is like this – if you look at this distribution, you will find out the there is a… If I see this, I have something like 15 here; then, goes to 30; then, goes to 55; then, goes to 21 here, 14 here, 9 here. If you see, you are going to find that it is going to be like that.

It is not symmetric; you see (Refer Slide Time: 36:00) here – peak is here; only two here higher, but there is much more drag on the lower side. Now, if you see also here number of this occurrence, this is the very realistic data. Number of waves occurring; high ones are much lower; low ones are higher, but the lowest one is not the highest. Always there is a peak. This always happens, because when a wind blows, there is always a particular height that is excited most. But, there are also large number of lower ones. You see large and lower ones. So, the purpose of showing that you will find that this to be a bell-shaped curve.

Now, here if I want to find out average; see for example, there is a question there – what is average? Very simple; average is simply you multiply this with this, this with this, etcetera; this with this, this with this, etcetera. So, I will end up getting H average. Let me see how much this thing is (Refer Slide Time: 36:53). We have to work it out. You can figure the age average value while you do that; that is, 0.5 into 15, 1 into 30, etcetera. There will be some value of age average. Let us see how much it could be. If we have a calculator, we could have done it. But, let me think… I cannot offer, but it is going to be something like let us say maybe 2 meter or so. Let me see this – around 2 meter or so if you work it out.

Now, what is the… Let us say from this if I want to find out what is the probability of for example, H exceeding say 3.25 meter or this value. This is going to be simply these numbers – 5 plus 1 – 6 divided 150; straight forward. So, you can easily figure it out. There is going to be some number or whatever. Now, the important point is to find out from here (Refer Slide Time: 38:09) let us see. This is where I wanted to tell you. Let us say one-third – H one-third. How do I do H one-third? You see here – this confusion comes sometime; I need to have from here average of that top; how many? 50. Now count it. 5 plus 1 – 6; 6 plus 9 – 15; 15 plus 14 is 29 plus 21 is 50. Actually this example that I took is becoming exactly 50.

Supposing if it becomes 50 for example, we will do that for one-tenth let us say. We will do that for one-tenth. So, here all I need to do is to average up to this much, because up to this much; from here, when I go to this point (Refer Slide Time: 38:53), I get to one third of the total waves. You see I went quite high, but I go to one third of this wave. So, I just have to average this out; 4 plus 3.5 into 5 plus 3 into 9 plus 2.5 into 14 divided by 50. So, if you do that, you are going to get the average this thing – something like up to this much. So, it is like 21 into 2 plus if I just put it, then 14 into 2.5 plus 9 into 3 plus 5 into 3.5 plus 4. This divided by 50. So, this is going to give you something like 2.51. But, this was a very nice example. But, what happens if I want to do H one-tenth. You see H one-tenth is… Let us do H one-hundredth, because I wanted to show you that it is not falling the number. H one-hundredth would be one and half waves in this example; or, what I am trying to say, suppose you are doing H one-tenth also, it would have been 15 waves.

Now, supposing you find out that if I add (Refer Slide Time: 40:14) these, it becomes more than 15. Let us say… Let me just change this number – I make it 13; I make it 10. So, if I want to do H one-third or one-tenth, what happens? That is 15. So, if I go 5 plus 1 – 6 plus 10 – 16, what I should do? I should do one of this, 5 of this and 9 of this; not 10 of this. That is what I wanted to tell you. It is not that you have to take all the waves; you have to count from here – 1, 2, 3, etcetera. Count up to where you have one-nth of the waves; it need not be up to this exact line. That is what I was going to tell. This example – it turns out that it is falling, the wave it was chosen. But, you have to take up to that point; you will get therefore the particular concept of H one-third. So, what is happening therefore, if I look at this diagram, it is actually average of this side (Refer Slide Time: 41:09); one-third total number from… It is the average of these heights; one third of this from the top-side height is one-third height. One-tenth will be this side. So, this is the concept of significant wave height.

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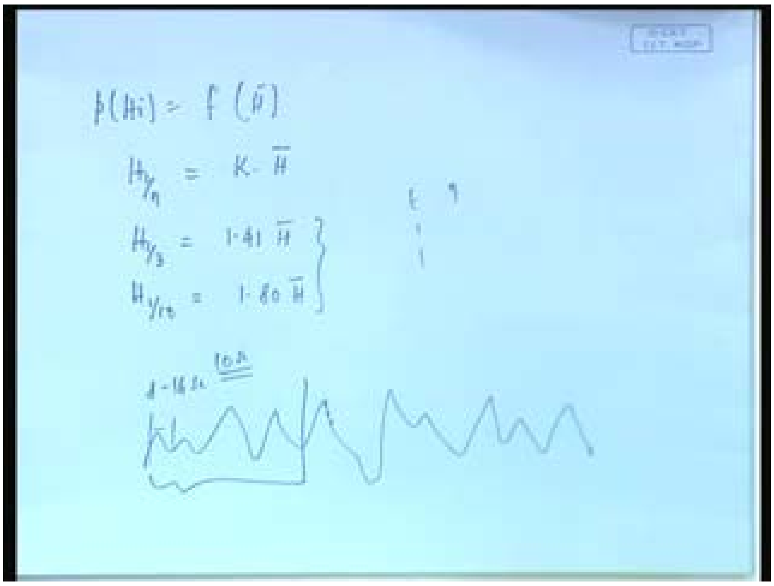

Now, the interesting point is that it turns out if I were to use a Rayleigh distribution, because in Rayleigh distribution, I know this p of H i as a function of H bar. Basically, that is what the expression is. So, what happens? All the quantities of H one-nth can be expressed as a constant into H bar. This constant expression is available if I have a given theoretical distribution. For example, H one-third becomes 1.41 H bar. H one-tenth becomes 1.80 H bar, etcetera; like that.

What happens is interestingly that when I have the (Refer Slide Time: 42:27) signal, nowadays, what is happening, I will have this long signal collected. The data voices are all over; Indian government has their satellite also – ocean sat going around collecting data. So, you will have hours of data, millions of these kind of heights. So, what would you do? If I want to have statistics, I will… Another thing also I want to tell you here that the average period of that is how much? About 10 seconds? If you see this time period around 8 to say 14 seconds; say average of 10 second let us say. So, if I collect 1 hour of data, how much of peaks you expect approximately? Suppose I collect 1 hour of data, that is how much? 3600 seconds. So, around 360. So, if I collect continuously data, then what will happen? I will end up getting very large data say. So, what often people do is that you cluster these things into some time intervals. I am talking from the point of view data processing. You cluster this for let us say every 1 minute; then, average this value and take that as a wave height. So, you have then this, this, this; like that reasonable number of data.

What I mean, instead of taking the raw data directly, sometime what you do, taking every peak, you make time lengths. For each time length you take an average and that is taken to be the number, because otherwise, what would happen? You might end up getting 1 lakh data points. So, then you will end up getting something like more reasonable data points. This is a question of data analysis; whichever way you do, you can do. Nowadays, it is very simpler, because what would happen, you see the digital data points are giving you basically this time verses eta like 0… There will be what is known as sampling interval; maybe 40 per second, one-fortieth, one-twentieth; depending on the system, how much of load you can take. Then, it is all digitized data and you can in a computer analyze them to find out… Basically, through computer only you will find out how many heights are occurring at what, etcetera.

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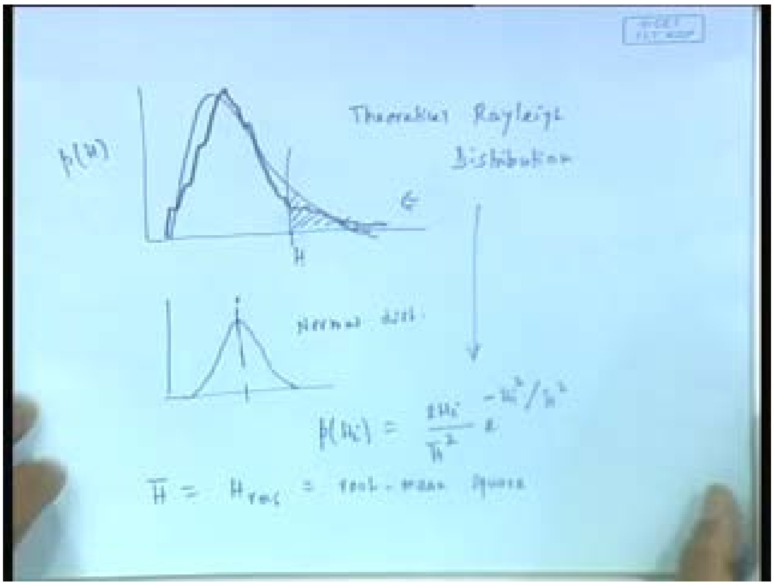

Now, having done that, you do not plot histogram anymore. What you can do, straightforward, you can find out the RMS value and go to this (Refer Slide Time: 44:56) graph – e by H graph and therefore, plot this. That is, go to this; take a signal; figure out H bar. Automatically, computer will give you… Then, plot this, because it fits more closely. And then, find out for the signal all parameters like H one-third, H analyze etcetera.

Now, having said that, what I want to tell you, I have collected long set of raw data. I could statistically analyze it. I find out they follow Rayleigh distribution theoretically;

that means, slightly not symmetric. I know what is meant by H one-third, H one-tenth, etcetera. But, does it tell me all? Still this is only height as I initially told.

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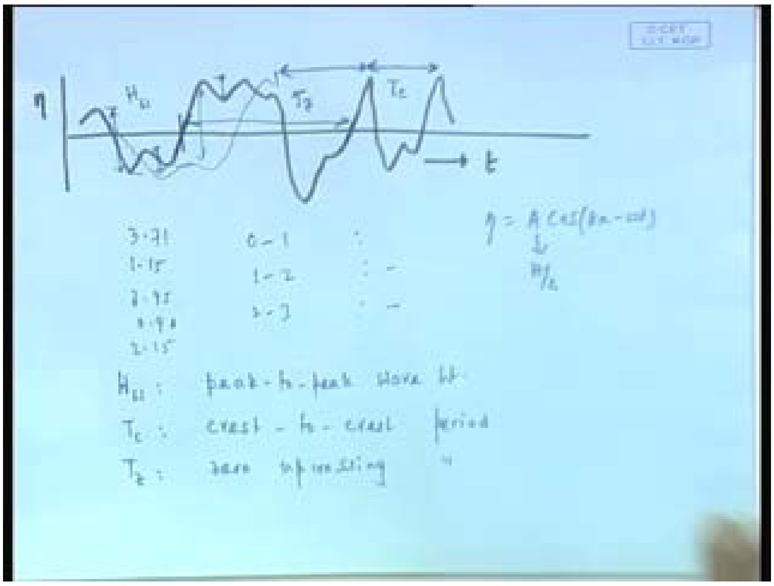

Does it really give me the ocean characteristic? The answer is no, because I do not have the time information. For example, this signal as I told you, I could stretch it having the height same. And, the analysis will give me the same histogram. You understand the point that what I have done is only the height I have analyzed. What about the quantities in this direction? That is length per period. We have not done it. Now, you can say, look, I can separately analyze T z; that also people have done. Even T z if you do like H, you will end up getting a graph and this also turns out to be Rayleigh distribution. So, what would happen is that you see we have done statistically individual quantities – H w, T c, T z.

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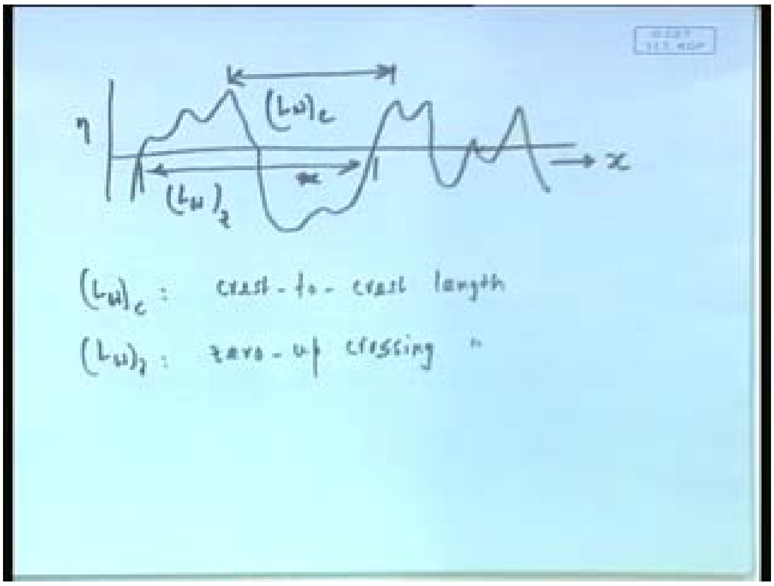

If you want, L w z, L w c – all of them you can analyze. Normally, of course, you see we do not collect this data, because remember, collecting these data requires you to take a snapshot over a distance, which is not done. Typically, you have a data boy located at some point; it is collecting data at that location; that is against time. So, mostly you are collecting… And of course, we know that theoretically, length and period are connected to each other through dispersion relation. So, in practice, these (Refer Slide Time: 47:21) are collected, not the length.

But, having said that, let us say I have a histogram for H w. I know that chances of wave height exceeding 10 meter is source. I also have a histogram of T c. So, I can say that chances of a wave occurring more than 15 second period are so and so. But, are they not connected to each other? Can I have… You see this information do not relate to. For example, it cannot tell me which height and which period are related? For example, I can have a very high wave of small length or very high of large length; this analysis would not detect that, because this analysis is not going to relate to me the height connected to the period. So, I therefore, still do not have a full description of ocean waves for a given state.

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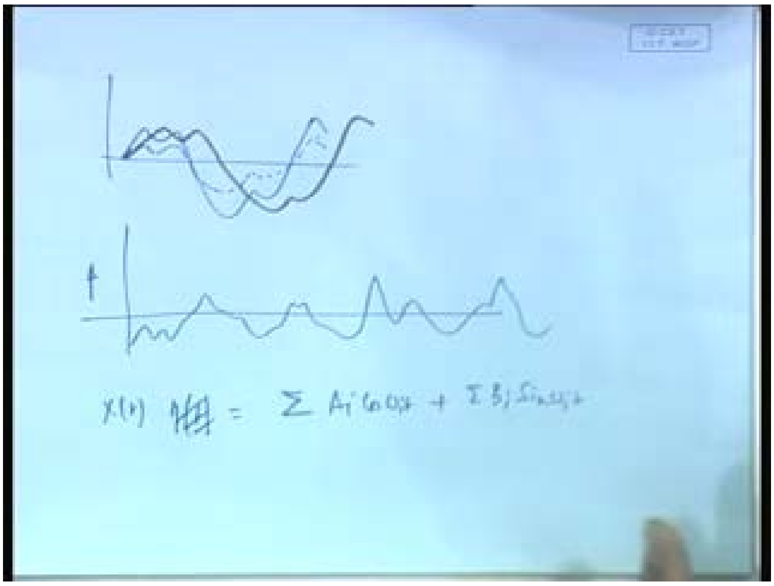

As I said that, if I were to take a signal, I just take an example of this. And, another one, I just stretch that as if it is stretched. If I were to take these two signals and do the H, height spectrum or it is not a spectrum height histogram, answer is same. Period spectrum – answer is not same. On the other hand, for the same signal, if I just lower it down to (Refer Slide Time: 48:52) – like that I will have period signal same, but height histogram different. The point is therefore, we need a kind of description where the height and period are connected to each other. Remember that period is length. Therefore, height and period essentially implies also the slope of the graph, because period is length. So, height and period means height and length means H by lambda means slope, steepness of the… So, I need a description of ocean waves, which also gives me this steepness of the graph. Now, this is what we will be talking. Later on, about how we can generate this (Refer Slide Time: 49:46).

Now, having said that, because we have still little more time, I will come to this signal process (Refer Slide Time: 49:52). You see here; suppose I have a random signal; never mind what signal it is – electrical analysis or whatever. What happens, remember that you all know Fourier analysis. Actually, any signal I can always represent that in terms of a series of sine and cos curves. So, we will see this concept that eta t can be represented as series of say A i cos omega i t plus B i sine omega i t. Actually, I should have called it H here. Let me call it to be any signal; let say X t.

We will see that this becomes the starting point as we will see next class for representing random waves or random signal as a wave spectrum in which the amplitude means height and the period means frequency, will be connected to each other. This we will see next class when we actually go for spectrum. But, what today we learnt is important and interesting observation that wave height distribution is not normal, but Rayleigh. Therefore, I should use H one-third more as this. And then, it is being Rayleigh, everything is connected to each other. So, up to that we have learnt in today's class. With that, I will end today's class.