Higher Surveying

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Module - 9
Hydrographic Survey
Lecture – 34
Modern techniques for hydrographic Survey

Hello everyone, welcome back in the course of Higher Serving. Today we are in the 3rd lecture of our module 9 that is hydrographic survey ok. In the last two lectures we have discussed the fundamental aspects of the hydrographic survey and in the next lecture that is lecture 2 we have discussed that how to conduct the field procedure in order to collect the hydrographic data ok. There we said that we are collecting the x, y and z information ok. Our main emphasis our main emphasis or the stress was on how to acquire the position x y at a given time and under the given situations ok.

So but we have assumed there that we are going to collect z information also or we are going to collect depth information also, right. So, we have said this thing there that let us assume that we are collecting all 3 data x y by planimetric position and the z by some instrument called sounding pole or the echo sounder or the lead line fine. There we said this thing and we assume that yes, we are collecting all the 3 data and then we can create the three-dimensional portray of my seabed or the riverbed, it was the idea here.

And then we also looked into the various applications especially how to for the rivers or streams how to calculate the volume or flow fine. So, that was the idea we have all the developed in our last lectures. However, today we are going to talk about the eco sounder well because, it is a modern instrument for conducting the hydrographic survey ok. Why do we require the echo sounder? Let me tell you very specific reasons first of all the hydrographic survey is very very expensive because it is subjected to the many a logistics, let us say the boat itself.

The arranging the boat, arranging the crew, arranging the instrument and again the limited time window is available why because, let us say there is high tide on certain day we cannot conduct our hydrographic survey in the river or in a big river big lake or in a sea, that is the first limitation.

Secondly, crew is also has to have a comfortable state of mind in order to go to the sea or some places fine. Now, all these factors are always there and that is why we have limited time, window in order to conduct the hydrographic survey. That is the reason we look for some instrument which could be very fast or which could acquire the data at very fast rate that is in the minimum time and that is why any electronic instrument is preferred ok.

So, echo sounder is instrument that we use in order to do the hydrographic survey at very fast rate well way, why because it is using acoustic wave ok why acoustic waves? Because, acoustic wave or the sound waves travels in the water ok. So, again we are going to use the time of flight principle or phase base principle in order to measure the depth of the water bed well why not other ways for example, microwaves or optical or maybe LiDAR. Yes, we also use LiDAR in order to find out the depth of the water bed however, it is capacity is somehow limited compared to the acoustic wave.

On the other hand if I consider the microwave what happens is microwave? It is absorbed in the pure water or I can say it in case of saline water in sea it is allowed to pass but it is not reflected or it is reflected back from the seabed, right. So, basically the microwave is absorbed in the water fine, except saline water or the sea water, fine. That is one thing here ok. And that is the only reason we measure we use the acoustic waves or the pressure waves in order to measure the depth of the water ok.

So, in this lecture we are going to talk about the echo sounders that is a machine or instrument that is capable of transmitting the sound waves or sound pulses and it also it is also capable of receiving those sound pulses and measure the time difference or phase difference. So, let us go into this lecture.

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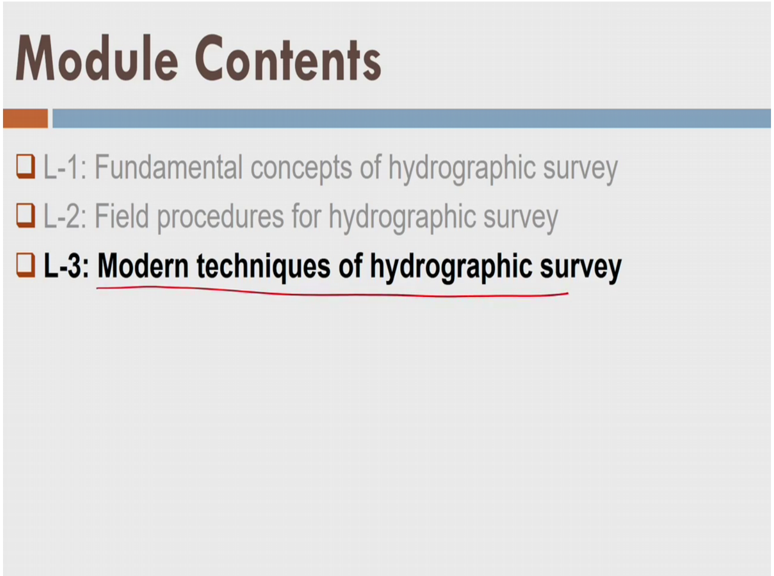

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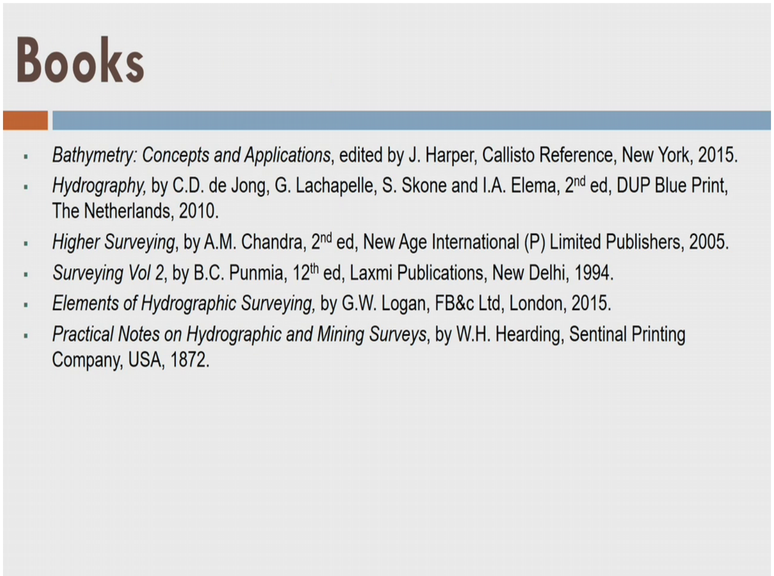

So, we are in the third lecture modern techniques of hydrographic survey. These are the books we have already discussed.

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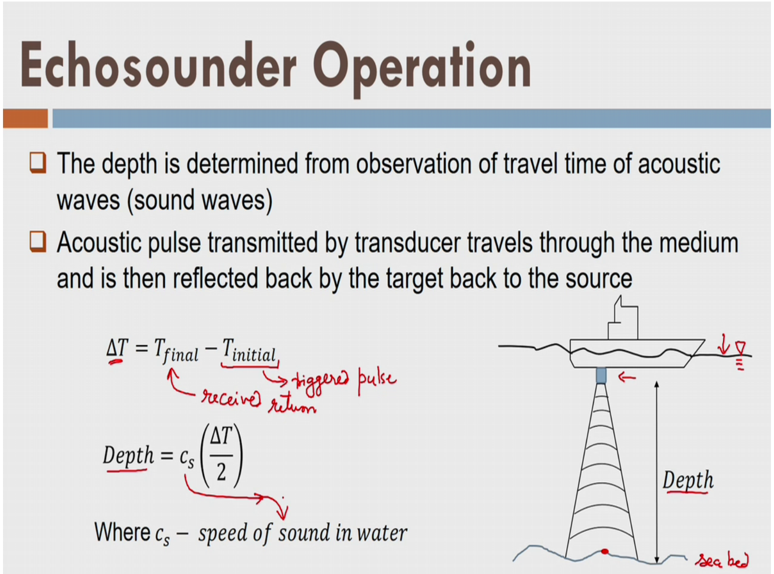

And let us start with the basic concept of the echo sounder. So, the depth is basically determined from the observation of travel of travel time of the acoustic waves or the sound wave. That means, if I have a instrument that is transmitting the sound pulses of sound wave what happens here. Let us say there is a water level at the bottom of the vessel we have mounted an instrument.

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So, mount an instrument is sending some pulses and pulses are traveling in the form of wave fronts as we have seen before also and now it is interacting with the river bed or the seas bed ok. Then it is reflected back and it is once it reaches to the vessel or the vessel bottom or the instrument receives it and so the time measured between the transmitting and the receiving is measured and that is called the time of written ok.

So, using this time I can find out the two times of the depth, fine and that is why we say that depth is half of the delta T by 2 ok. Now, you can see the operations here this is the instrument. So, here is the echo sounder instrument mounted at the bottom of the vessel, as you can see here and this is your water level fine. Now, this is the operation where it is sending the pulses towards the seabed and now this is the point where it has interacted with the seabed. So, this is your sea bed or the bed of the river whatever fine.

Now, this is the total beam width and now with in this beam width again it is written back and now we measure this depth here, fine. And depth is given by this delta T which is initial time when we triggered the pulse at this time and this is the time when we receive the pulse ok. And now we can see that it is a total time and if we divide this total time by 2 I can find out the depth and this is nothing but the speed of the sound in the water.

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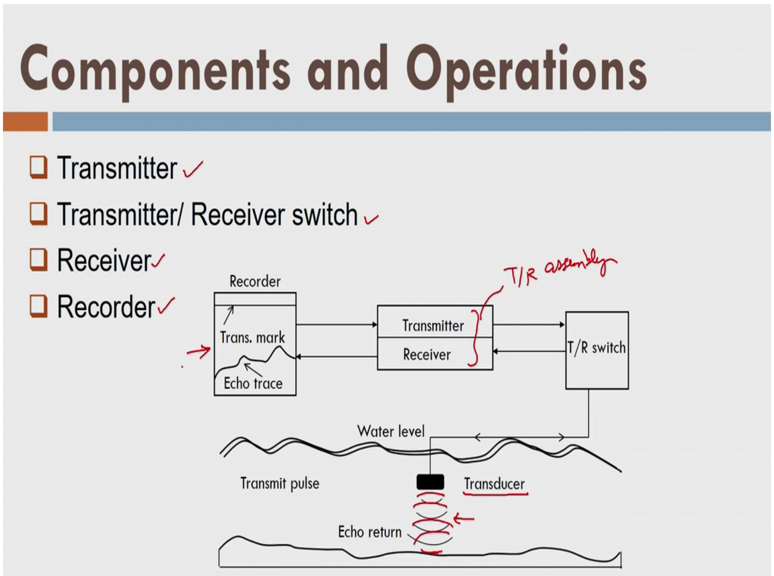

Now, you can look into the operations of the eco sounder. So, it has basically a transmitter or we can say that it has transmitter here as it is shown here the transmitter receiver assembly here, fine. This is nothing but assembly ok now, we have some transmitter receiver switch which can switch on and switch off the operation, ok.

Later about the transducer, what is the transducer? So, these are transducer which is sending the these pulses and these pulses ones interacting the surface of DC and it is returned back again like this and again it is received by the transducer. And this is the kind of operation we have shown here and so we have receiver, we have recorder ok.

So, once the transducer records the signal acoustic signal it converts back to the electrical signal and that electrical signal is recorded by the recorded here and so the mechanism of the recorder could be any. It could record on a paper that means there is a role paper and this paper is moving and recorder is having a needle that is with the ink it is recording the pulses or the reflected pulses ok.

On the other hand, nowadays we have the electronic system where these pulses are recorded in the form of electronic data. So, any mechanism is possible according to the available facility or the availability of the modernization to us, fine. So, that is a kind of operation one should understand about the echo sounder ok. Now, we have said that there is something called transducer. What is transducer?

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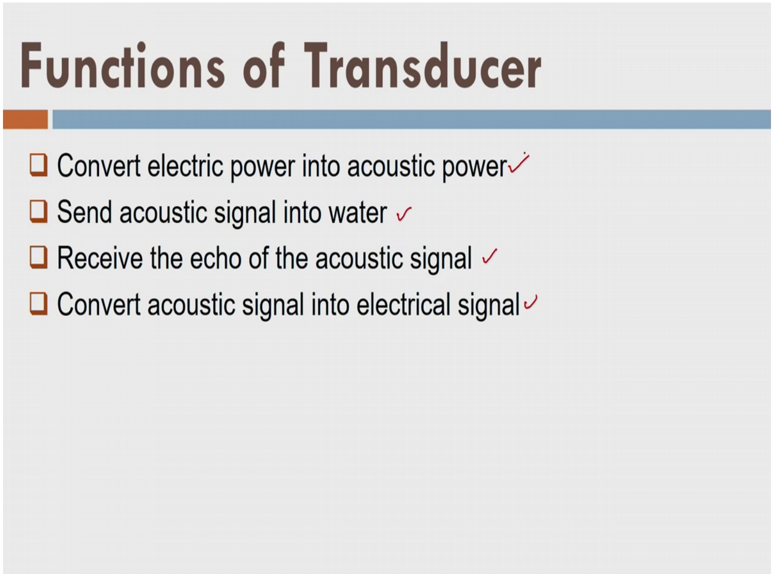

Transducer is a basically a device that converts the electrical signal into the acoustic signal. That means, it first collects the or first it is connected through the electrical supply and now within the electrical supply what does it do basically it vibrates for example and it creates the sound waves. That means, electrical signal is converted into the sound signal or sound pulse or sound wave, fine.

This created sound waves or sound pulses will travel through the water distance and once it is reflected back from the seabed or riverbed it is collected back by the transducer ok. Then transducer will convert the acoustic signal into the electrical signal again and that electrical signal will be recorded by the recorder, right.

So, you can read it yourself that this is the operations of the transducer, fine. So, transducer is a very very important component of my echo sounder and more over I would like to say that transducer is a very common term ok. In case of any other instrument it basically converts the electrical signal into some other physical quantity for example, here in case of echo sounder it is it converted the it converts the electrical signal into the sound signal, fine. So, in other instrument the transducer might be working according to a requirement.

So, now we see that what are the characteristics of the eco sounder that affects or that decides the wave we perform our survey? Remember the purpose of using the echo sounder is the first purpose of using echo sounder is to perform the hydrographic survey in minimum time, well or to minimize or to maximize my potential of performing the hydrographic survey in a given time window, fine.

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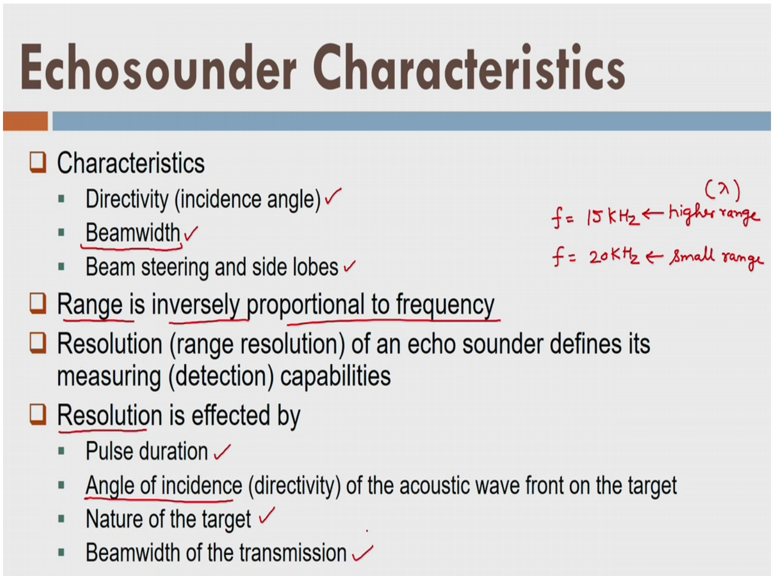

So, now let us look into the characteristics of the echo sounder. So, first is this the directivity; directivity means at what angle it is directing the pulse towards the free surface or the sea bed surface ok. Then we have beam width we will consider all this thing and then beam steering and side lobes ok.

So, beam width is nothing but the angle formed by one pearls or that is deciding ok. Remember we have beam width is very common concept that we have seen in case of LiDAR as well as in case of radar, right. So, this is also an active remote sensing method where this beam width is important factor ok.

What about the beam is steering and side lobes? Similar to radar signal and LiDAR signal the main signal is concentrated about certain frequency and there are some side lobes in that is kind of you can say let when we practically generate the sound energy these side lobes will also is there as a noise or sometimes as a part of the signal ok.

Now, we can see here that range is inversely proportional to the frequency. That means, if I generate the frequency of 15 kilohertz or frequency of let us say 20 kilohertz. The range travel by this pulse will be higher, why because, the lambda will be small or lambda will be higher, I can say that wave length will be higher ok. At the same time this will travel for small range and range has the same concept as we have seen in LiDAR or in radar that means, it is a slant range if instrument is kept to vertical.

And it is sending only one pulse towards the ground surface what will happen I will have 0 incident angle, right. That means, the vertical of the sea bed which is horizontal and the direction of my pulse are matching or the direction of line or sight are machining so, that is I am incident angle is 0 ok.

In that case what will happen, the range that we call a slant range will be equal to the vertical depth of the water surface or the seabed, right. So, that is idea the moment it is tilted by some reason either deliberately or by some error that this is my slant range or which is not equal to the vertical depth of the seabed from the water surface. So, that concept one should understand here ok.

The resolution or the range resolution, right of an echo sounder defines it is measuring or detecting capabilities and we will discuss some example here how to find out that ok. Then basically the resolution is affected by the pulse duration or sometimes it is also called the pulse length, we will discuss the two terms ok. Then angle of incidence as we told that angle of incidence besides the resolution, right.

What happens in case of the angle of incidence is inclined or more than 0. In that case the length travelled by the sound wave is more or I can say that the pulse duration or the pulse length effectively increases here, right ok. Then the nature of target that means, how my target behaves with the sound waves and then beam width of the transmission or the transmitted pulse here, right. So, let us look into a simple example.

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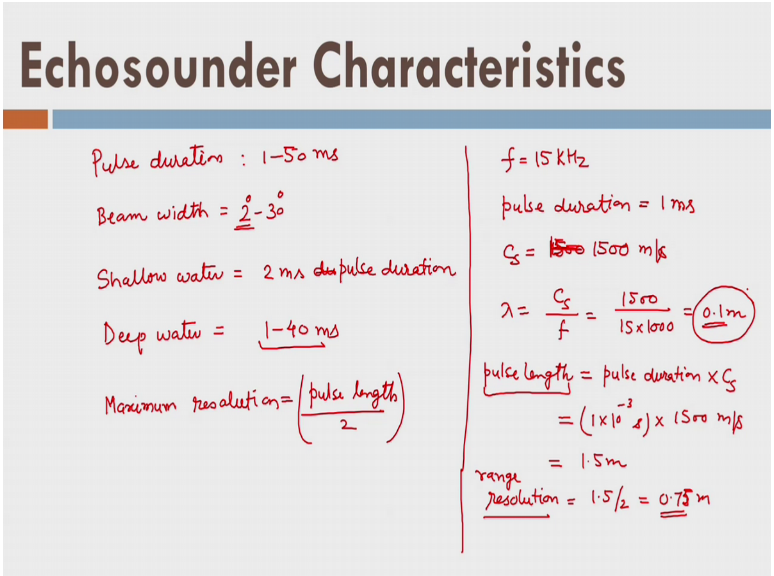

Let us say, first of all I would like to tell that what are the ranges? For example, we have the pulse length or pulse duration in the range of 1 to 50 milliseconds. Then we have beam width it is in the range of 2 degrees to 30 degrees you can see here. And you can compare this figure with the other active remote sensing methods for example, LiDAR in case of LiDAR it was in the milli radians. So, you can compare now the beam width of the acoustic system or the sonar system, right.

So, now, it is nothing but the, yes you can compare the beam width of this echo sounder or the acoustic system to the beam width of the LiDAR or may be radar. In case of LiDAR the beam width pass in the range of millisecond or milli radians ok. Now, it is very high 2 degrees ok so both these remote sensing methods are quite different although their operations or the logic could be similar, fine. So, let us look into the other aspect ok. So, in case of shallow water we prefer 2 millisecond duration pulse ok. In case of deep water we have the first duration in this range we prefer in this range 1 to 40 milliseconds ok.

Now, how to give the resolution or the maximum resolution? The maximum resolution is nothing but pulse length divided by 2. I think that these logics are very very simple for all the active remote sensing method but the question is how to calculate the pulse length here, fine. So, let us take a simple example here let us say we have frequency of 15 kilohertz that means, at every 1 second and 3, so many pulses.

So, my pulse length will be equal to y, right and we have this pulse duration of 1 millisecond ok. And then we have speed of the sound C S equal to 1500 which is an ideal value millisecond meter per second ok. Now, what is the wavelength? First of all the wavelength will be speed divided by frequency. I can here do it to the this calculation very fast and ultimately I get 0.1 meter here, you can do it yourself and you can find out, fine.

Now, the pulse length how to calculate the pulse length here? Pulse length is given by the pulse duration into speed of the sound. So, it is pulse duration is 1 millisecond into speed of the sound and finally, it comes out to be 1.5 meter. And now what is a resolution here? The best resolution the best resolution that can be achieved is 0.75 meter.

Now, you can see here that the lambda or the wavelength is point 1meter but still our resolution is 0.75 meter, right and that is the depth resolution or the range resolution, fine. So, now, you can understand what is the effect of pulse length or the pulse duration on to the resolution here, right and it is nothing to do with the lambda.

But one more factor I would like to tell here. If the lambda is higher the pulse will travel to a longer distance in the water at the same time if pulse length or the wave length of the pulse is smaller. That means, frequency is higher it will have higher resolution and that is a kind of effect of the frequency and the wavelength that means, higher the wavelength I have lowered the resolution but at the same time I will have greater depth that can be traveled in the water, fine. On the contrary if higher the frequency I will have lower depth of travel but I will have a very high resolution. So, this is kind of compensation or this kind of tradeoff between the frequency and the wavelength of the any remote sensing system.

So, now, let us consider that what is the effect of the beam width on the depth measurement? First of all we have already defined beam width in LiDAR as radar ok. Does it mean the same thing here? In fact, the beam width term is a kind of universal term in the physics which means the same thing for all the remote sensing technologies, fine.

So, LiDAR we have defined that, we define the beam width in such a way that there is a cone which creates footprint and that footprint should give me minimum 50 percent of the reflected power. If I compare this power the reflected power to the transmitted power. So, same thing we have define for LiDAR, radar as well as here also we have defined. So, we will look into that aspect also that what are the physical limitations on the beam width that is imposed by the machine or the hardware of the transducer.

But before that let us look into the what is the error in the depth that I should expect if I there is a error in the position of the tilt sense or position or tilt of the transducer ok. So, let us imagine that I have a transducer which is fitted at the bottom of the vessel and it is through in the pulse vertically, fine. So, I am measuring the depth D of the water of the sea bed ok. Now, let us assume that there is some tilt in the vessel platform and as a result this beam or the pulse will be directed to some angle called theta angle compared with respect to the vertical ok. What will happen now? Because of this the sound wave or the sound pulse will travel for a long distance and the change in the distance or the longer distance we should know how much has been traveled ok.

Now, if I assume that this is my depth of the water that will be wrong. My depth of the water is this ok, but I should know that how much distance it has travelled so that if I know the vertical the deviation of this pulse or the direction of this line of sight with respect to the vertical I can calculate what is my correct depth. So, that is the idea here ok.

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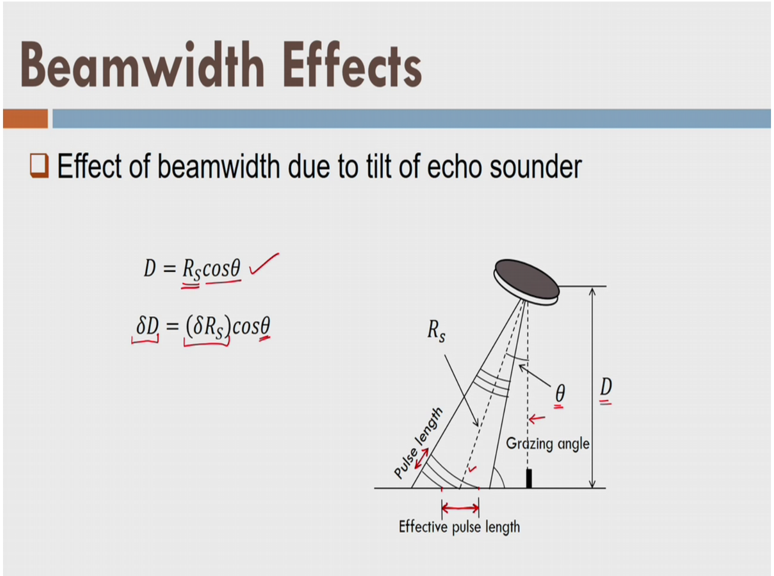

So, let us look into the slide here. So, now, this is my depth D here and by some reason the transducer is tilted with some angle theta which is shown here. So, this is the center line here ok, fine and this is the center line of the tilted pulse ok. What will happen here? You can see that this is your pulse length marked here, fine which is the giving with the resolution and that will be if I make it horizontal that will cut here and here.

So, this becomes my effective pulse length or the horizontal resolution here ok. But apart from that if you look it very carefully that distance D is the function of the inclines range R s into cos of the theta, right you can see it here that if you take the cos theta you will find out this relationship. Now, let us assume that there is some error in the range and as a result you can expect this error in the depth estimate also for a pulse which is inclined at an angle theta here, ok so, that is the meaning here, right.

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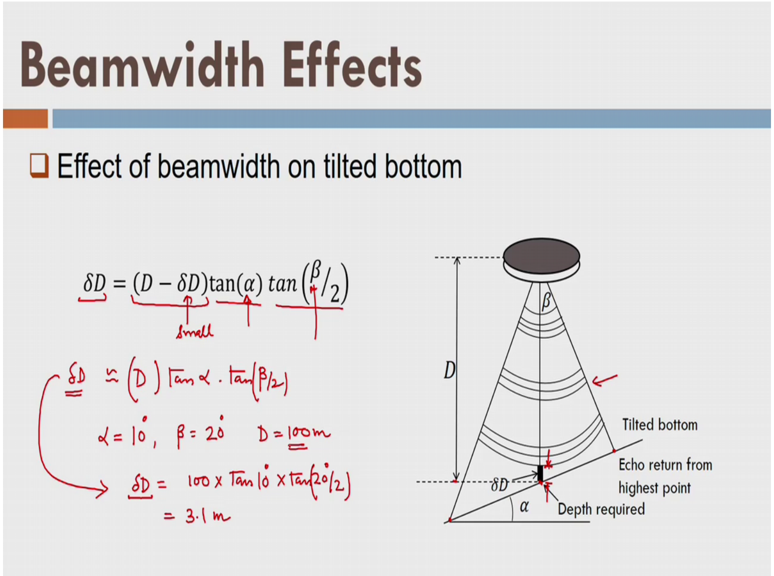

Similarly now, if the transducer is vertical but transducer is positioned very correctly at the bottom of the vessel, so let us assume that transducer is placed at correct position at the bottom of the vessel that means, it should throw the vertical pulses only in the direction of gravity. However, the bed is tilted at angle theta or at angle alpha with respect to the horizon, right so, what will be the effect?

So, you can see here that this is the depth suppose this bed is here which is an average position of the bed or this is the average position of the bed here. So, this is the average position of the bed because it is passing through the midpoint. And now I can say that this is the depth we want to measure at the center point, fine of this inclined bed or at the center of the beam width, fine. Now, there will some error delta D in this measurement and this delta D can be given by this formula where it is D minus delta D into tangent of alpha where alpha is the slope of the bed and beta is the beam width as indicated in the figure ok.

Now, this delta D is approximated as that which this is approximately 0 or close to 0. And compared to this thing I will say that this quantity is equal to D. So, I write it D into tangent of alpha into tangent of beta by 2 so, that is the formula we get ok. Here we assume that there is no error in alpha and beta measurement, right ok.

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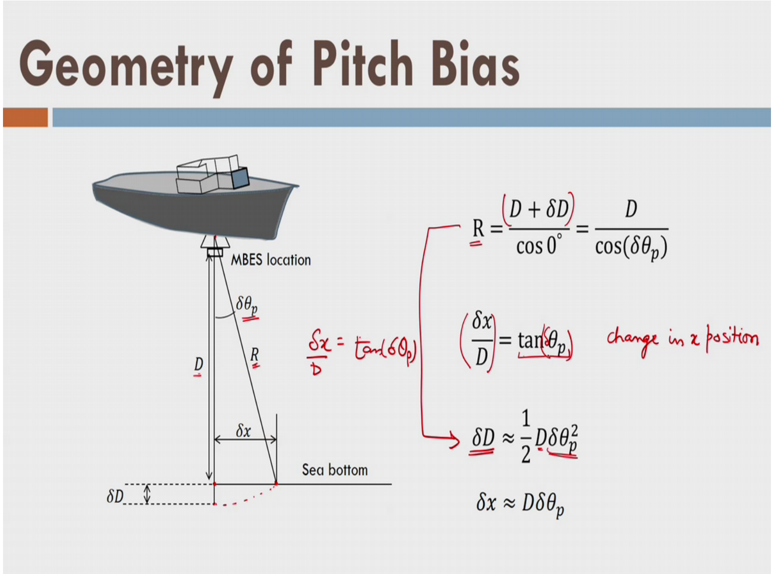

So, let us talk about the error in the pitch what is the pitch here. Let us say this my vessel and vessel moving in the direction of fan here like this the perpendicular to the screen ok. Now, because of the vibration in the sensor because of the vibration in the vessel or because of the vibration caused by the water the vessel is moving like this, right. So, if I say this is my y axis this is my x axis so, right now the pitch is about y axis rotation about y axis, fine.

So, we know that if it is the this thing what will happen this is my vertical pearls, right moving in the vertical direction. So, what will happen because of this motion? It will be doing some kind of error and as a result we know this is the x direction. So, we will have wrong value of the x coordinate. So, what will be the error in the x coordinate? That we assumed earlier as a 0, but there will be some value here now, because of the ambiguity created by the pitch and we call it the pitch bias or the systematic error caused by the pitch.

So, let us look into distinct so, now, here in the figure yeah in the figure this is the range R and this is the depth D ok. Now, because of the range should be measured here ideally in a vertical position however, because of this small error or it could be big error because of this, error in the pitch the point is imaged over there and that are we got the reflection from this point.

Now, we can see that the range is R here ok. Now, from this triangle we can see easily that R is written D plus delta D here this distance from the bottom of the instrument or right divided the cause of the 0 degree, right. You can see it here that if range R is this much like this, what could have been the position here, that we need to write cos 0 because there is no angle between R and D plus delta D. However, right now from this triangle this and this triangle here I can write that R is also equal to D divided by cos of delta theta p.

Now, from this you can easily find out that delta x by D is also equal to tangent of theta p here, all right so, that is one thing. The change in the x position is this ok. What about the delta D? That error in the depth D it will be equal to from this formula we can find out that half of the D into delta theta p square. Here we know that basically from this we can write here at delta x equal to by D equal to tangent of delta theta p here so, right here it is my delta theta p here, fine.

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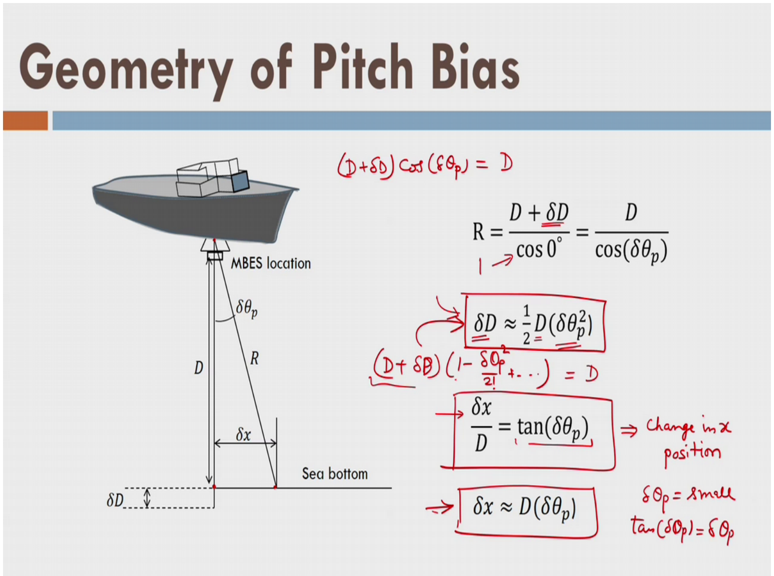

So, from this we can find out that what should be the value of D delta D here because this factor going to be 1 and this factor will be remaining here ok. Now, if you multiply this thing and find out you can find out yourselves that delta D will be equal to the half of the D into delta theta p square ok. Perhaps what you need to do is you need to expand the cause of delta theta p, right in the by the series forms, so 1 minus theta p square by 2 and so on.

So, what may happen there? So, D will be canceling out there with the this D ok. So, if I just write it like this for example, like D plus delta D cos of delta theta p is equal to D, right. Now, if I expand it by the cos series this one, what will happen here? I can write it like this D plus delta p delta D into 1 minus delta theta p square by 2 and so on. We know higher order terms and it is equal to the D.

So, now if I multiplied this term here with this one so I will have delta D and finally, I will get this equation you can write yourself. So, this is the kind of error we should expect in the depth measurement if I have some roll pitch. Now, at the same time we have this from this triangle, this triangle, this triangle and this triangle that this is the equation delta x by D into tangent of theta p.

So, what is the meaning here? That is the change in x position fine ok. So, I can also write it by multiplying D here. And moreover we know that when delta theta p is small tangent of the angle delta theta p will be equal to delta theta p and as a result we can, right an approximation here ok.

So, now we know that what is the change in the x position as well as what is the change in the depth value or what is the exact value of the measured depth D or what is error in the measured depth D forgiven pitch bias ok.

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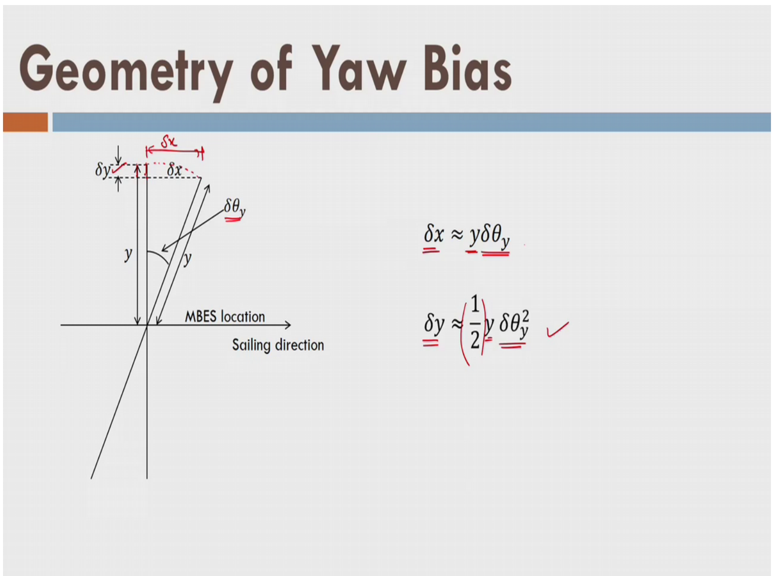

Now, you can see here that the geometry of the yaw bias here it is basically the movement of the vessel in horizontal plane about the z axis like this. So, it is moving like that so, z is not changing x and y are changing, fine. Because of that what happens is here you can see that this position is tracked here or I can see here because of this thing this is the error in the y this portion here and this is the error in the x here from here to here this is your delta x here ok.

Now, we want to measure and we can very simply write it here like this delta x is equal to approximately equal to y into delta theta y here, fine. And delta y is equal to half of the y delta theta y square if I assume this circular curve logic I can derive this equations, fine so that is the idea here, ok.

Now, y is nothing but the position of my pulse with respect to center of the that means, if pulse is interacting like this somewhere ok. And because of this one what will happen? The position of these pulse with respect to y and x will change, but not with respect to z will change. So, depth measurement will be correct, but x and y measurement will be erroneous. That means, in a certain reference frame where I assume that my y is perfectly in the direction of the across track direction and access my along the direction that will not be maintained because of this motion, fine. And that is the effect of yaw voice on the geometry of the measurement, right so, that is idea here ok.

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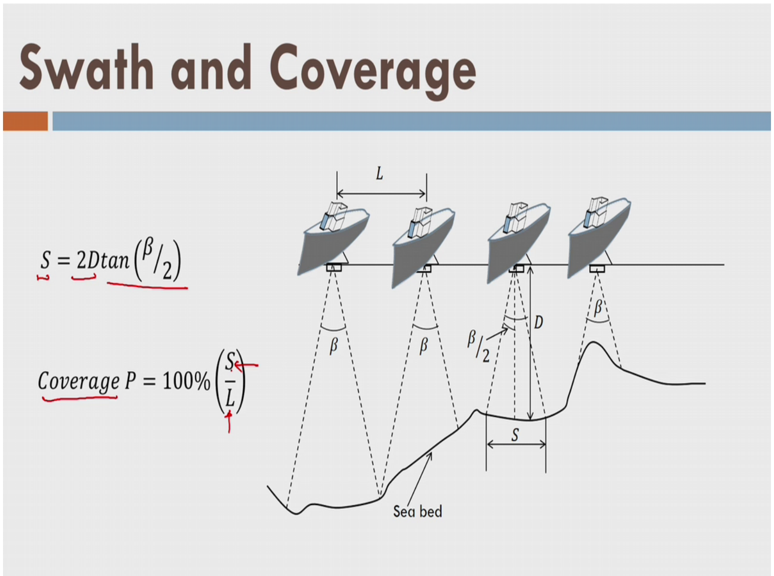

What is the swath?. Remember in case of LiDAR we have defined swath as the number of pulses fired across the field of view. In this case since we are considering the echo sounder that is sending only one pulse at a time and so it sends in one pulse the pulse interacts with the ground surface comes back, so pulse interacts with the seabed surface comes back and it is received by the receiver. After receiving it sense in the next pulse, fine.

So, now, this is the reason that we call the footprint of one pulse is equal to this swath in case of echo sounder having the 1 pulse at a time ok. So, now, we say that frequencies 15 kilohertz that means, in 1 second it is sending 15000 pulses that means, it is expected sent so many pulses. Now, what happens is when pulse goes comes back second pulse thrown it comes back and third pulse and so on. So, this operation happened 15000 times in 1 second, for a given depth let us say like depth is it is possible to perform this one.

Now, you can imagine that if depth increases what will happen the time of travel will be more and automatically the frequency of my firing pulses will be less just like LiDAR, right. So, these concepts are simple, moreover as we said that if my frequency if lower automatically if I increase the wavelength correspondingly what will happen, the higher the wavelength the higher the travel distance in the what will be there. So, it is kind of again I explained to the tradeoff and now you know the reason why the frequency has to be lower if the depth is more fine ok.

So, now the swath of one foot print or the size of the one footprint in case of echo sounder that sense only 1 pulse at a time is given by this 2D this is my depth into tangent of beta by 2 which is very obvious from here. So, it is my swath that is nothing but the footprint of the one sound pulse and we want to cover the whole seabed remember in case of order one survey or especial order survey in case of a special order survey we said that not a single point of the seabed should be left uncovered ok. So, what can we do here?

So, let us look into this aspect of the coverage ok. What is the coverage? Let us say if there is one position of my vessel where it has sent one pulse and it has covered some footprint or the data of the depth ok. Now, let us see that after completing this operation on the one line it turns back and it goes like this, so in that after turning back it is again covering another line of data. So, this is my line spacing here ok so, it is basically covering the data in the longitudinal fashion where these are me footprints created by the each lazar pulse each sound pulse ok.

Similarly in the previous line it has covered pulses like this and both lines are like parallel so, this is the line spacing. Now, I want to ensure that between two lines of this data collection there should not be any area left uncovered ok. So, what can I see here that this length should be covered by the at least two footprints or they should be some overlap between the footprints of the adjacent two lines, fine.

So, now we can see here that the coverage is defined as the ratio of this line spacing to this swath ok. So, if it is 100 percent coverage that means, the swath of the two adjacent lines should be touching each other, fine or you can say the footprint should be touching each other or they should be some overlap so, overlap is also there ok.

So, now we can see here that there are two lines of data acquisition which are each line is covering some sound pulses or the footprints caused by each sound pulse now you can see this length between the two lines has to be covered by these pulses or the footprints ok. So, if there are two footprints one is created at this data equation line and another is created and or this on this data equation line ok.

So, if these two pulses are touching each other all the two footprints of the pulses are touching each other. What will happen? It is 100 percent coverage between the two data acquisition lines or the range lines if you remember, fine. Now, if this slight overlap also there is nothing bad in the sense because of the overlap and ensuring that yes there is no idea left uncovered, fine. So, that is the idea here and that is why we define the coverage as the ratio of this swath divided by the line spacing and if it is 100 percent, fine that it is absolutely, fine for special order service, right so, that is the idea here ok.

So, you should take an example here let us see that alpha is equal to that is tilt of the bed is equal to 10 degree, beta is equal to 20 degrees. So, and depth is equal to 100 meter that is a vertical depth ok. So, what will be the delta D here? That is given by this formula here 100 into tangent of 10 degrees into tangent of 20 y 2 which is again 10 degrees here, fine and you will get it here 3.1 meter, right. Do it yourself and try to find out ok.

So, what is the delta D here? Delta D is nothing but the ambiguity in the measurement of the depth ok. That means, if I measure the 100 meter depth I will have an ambiguity of 3 meter or inaccuracy of 3 meter or 3.1 meter well that is the idea here ok.Now, there are some recommendations for the measurement or for the use of the echo sounders basically we decide the frequency of the eco sounder. Now, this frequency is decided according to the depth remember higher the depth lower has to be the frequency. Why, because the pulse each pulse will travel more time will take more time to travel for the larger depth compared to the smaller depth.

And so it takes more time for the return and so I can fire less number of pulses in a sequential firing manner, fine sequential firing means one pulse is fired once it is received next pulse is fired. So, in 1 second I can fire some limited number of pulses only ok. So, if that increases I will fire less number of pulses naturally, fine.

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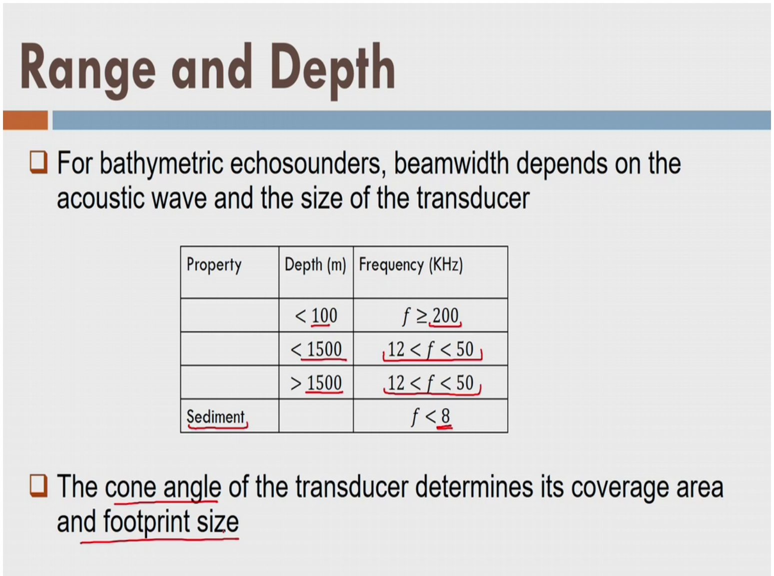

And that is the reason here some guidelines are given, if the depth is less than 100 meters we generally go for the frequency more than or equal to 200 kilohertz and if the depth is somewhere in this range we will go for the 12 to 50 kilo hertz. And then if depth is more is still this range is same moreover if there are some sediments so, sediment penetration is also required and sediment penetration is also is possible only at the high wavelength or low frequency. And that is why we recommend that if there are sediments present on the seabed let us go for the very low frequency that is 8 kilohertz or even smaller fine ok.

The cone angle as we told determines the coverage area and the footprint size is fine we have discuss this part ok. So, now, we have said that as we are considering the characteristics of my eco sounder what we should consider more. The eco sounder assume some kind of speed of the sound or the velocity of the sound that means we have assumed 1500 meters per second ok. In fact, this speed of the sound is also affected by a lot of factors.

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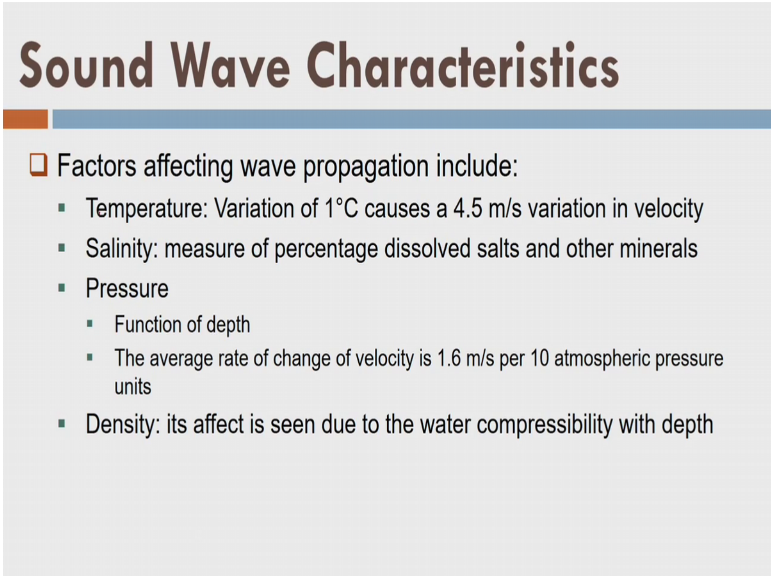

The first factor is the temperature of the water ok. So, basically the variation of 1 degree centigrade causes a change in this 4.5 meter per second variation in the speed of the value or sound or the velocity of the sound salinity the measure of percentage dissolved salts and other minerals ok.

So, salinity also changes the speed of the sound in the water. Then pressure as we know that from sea pressure itself is function of depth and the average rate of change of velocity is 1.6 meter per second per 10 atmospheric pressure units. That means, if pressure is change by 10 atmospheric units as we go deeper into the depth what will happen the speed of the sound waves will also changed by 1.6 meter per second per 10 unit of atmospheric pressure, fine. Again the density, it is effective seen due to the water compressibility with that ok.

What will happen? Water will be compressed at the lower depths or we can say as we go to the greater depth we will have more compressibility and because of that the speed of the song will increase there, but at the lower depth the speed of the sound is lower. Now, all these are effects of the physics they are coming these concepts are coming from the physics you can talk you can learn more about the physics of the sound and you will come to know all these properties, fine.

But in general our echo sounder assumes one particular value ok. In order to take care of these factors what we need to do? You need to calibrate your echo sounder for given situation. That means, if you go to the seabed or if you go to the seacoast the treatment of the sound wave or the speed of the sound wave will be different compared to a river because, river might not be having that much of salinity might be have different temperature, might be having different pressure because it has different depth and so on.

So, all these things we have to take care or rather we should calibrate our instrument first for a given situation. So, it depends the quality of survey or quality of depth measurement of the by echo sounder depends or our calibration, fine. The calibration means we try to find out what are the possible systematic errors and we will try to remove those. So, that our observations are subjected to only the random errors that we try to minimize through our statistical processes, fine. Well, systematic errors has to be removed systematic errors have to be removed first by the calibration process ok.

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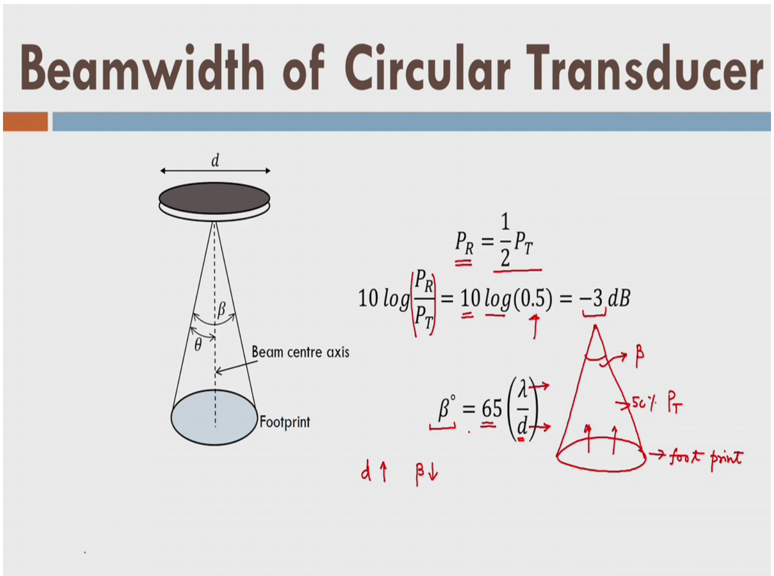

Now, let us consider the beam width of the circular transducer like this, it is my transducer here and there is a depth D. So, it is my cone and so it is footprint, fine, this is my beam width beta. Now, this is the d that is a diameter of the aperture of my circular transducer, fine so, this is my beta bite 2 or theta angle what we call.

So, you can see here that the logic of my working here is if the returned power is half of the transmitted power, fine. So, then I will consider that the signal has been received the received P R if it is 50 percent of my transmitted one pulse power and I will say that yes signal has been received or that the data has been recorded or the depth has been detected, fine.

So, now, using the same logic what we defined in case of radar or LiDAR and this in the same logic of 50 percent so if I take the ratio of P R by pt which is equal to 0.5 here and then if I take the log base stand and multiply it by 10 I call it the decibel and it is minus 3 decibel, right. The question is there how can we improvise the performance ok. If the received signal power is more than 50 percent absolutely, fine but there is some limitation.

So, basically beta is defined for the footprint or the depth, where I am getting let us say this is size of footprint here and if from this footprint if I am getting the return signal power which is more than 50 percent of P T. So, according to that point if we define the angle that is formed at the transducer point of where this is my point of firing pulses so, this angle is called beta and this is the way we define the beta ok.

Now, if you see here that beta is given by some other limitations and that is 65 times lambda by D. So, basically it depends only not only on the wavelengths of my pulse but also the D which is aperture or the diameter of my transducer ok. Now, one can argue that and the footprint size can be reduced or the accuracy or the ambiguity of the footprint can be reduced by reducing the beta ok. So, what could be possible solution here? The first solution is if I increase the d which is the diameter of the transducer I can reduce the beta and I can improve the efficiency of the instrument.

Now, the issue is very simple here. Issues simple the moment increase started increasing diameter of the food transducer what will happen it is size will start increasing and then with this is a limitation that means, we have limited load to carry on the vessel and that is why the size of the instrument is always limited. And that is the reason the beta has some limitations, fine. Similarly by reducing the lambda can also be reduced to a certain extent only, right and the remove remember if I increase, reduce the lambda value what will happen the depth of penetration will be less ok.

So, there is always a limit here. And that is why we designed some instrument which can fire the sound pulses at different different frequency or different different wavelength or so they will be having different values of the footprints, fine so, that is the idea here ok.

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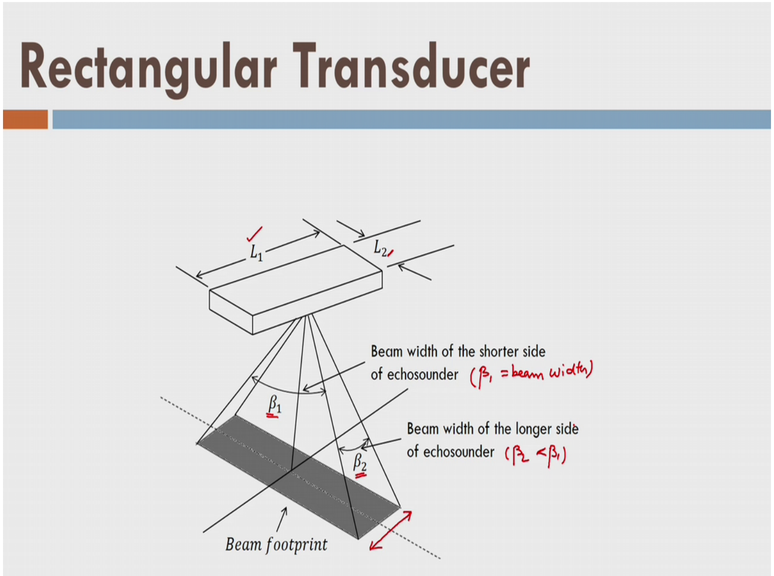

Now, in case of we have also have the rectangular transducers here because in case of rectangular transducers my footprint will be created like this of two dimension now, the circular one, right. So, now, you can see here it has two types of beam width one is along the beam width of the shorter side of echo sounder which means this is my shorter side L 2. So, along that we have beta one beam width, right and similarly we have the beam width of the longer side of the echo sounder. So, it is my longer side so, I have beta 2 here which is less than beta 1 fine ok.

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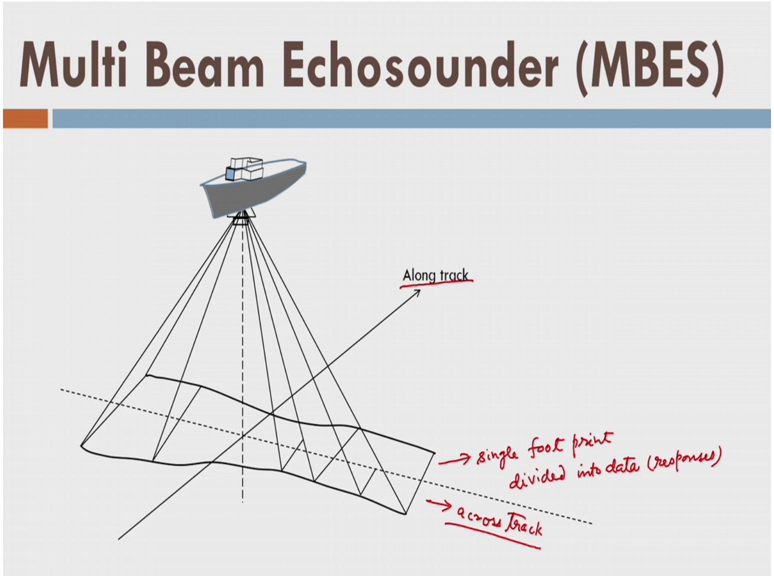

So, let us talk about the multi beam echo sounder. What is multi beam eco sounder? Ok. Remember we have said that if there is a single beam echo sounder what we call SBES it will be sending these sound pulses vertical direction once one at a time. So, it has some limited capability in terms of frequency that is number of pulses fired in 1 second.

Now, what can we do here? We have an another treatment or another possibility. That means, if I look a larger area and from that large area the complete footprint is coming and now I am dividing that one footprint into multiple pulses or multiple responses. So, each response I will call one pulse or one return ok. So, now, if I know that from which area in the footprint of particular responses coming I can say that is a scan angle or that is the angle of deviations from the vertical and at that angle and getting so into depth, right. So, that is idea about the multi beam echo sounder.

In case of multi beam echo sounder this is a single footprint, right that is acquired by 1 pulse and that is divided into data or I can say responses, fine. To decimal along track direction here and that is the acrostic here, right so, footprint is creating in the acoustic direction, right.

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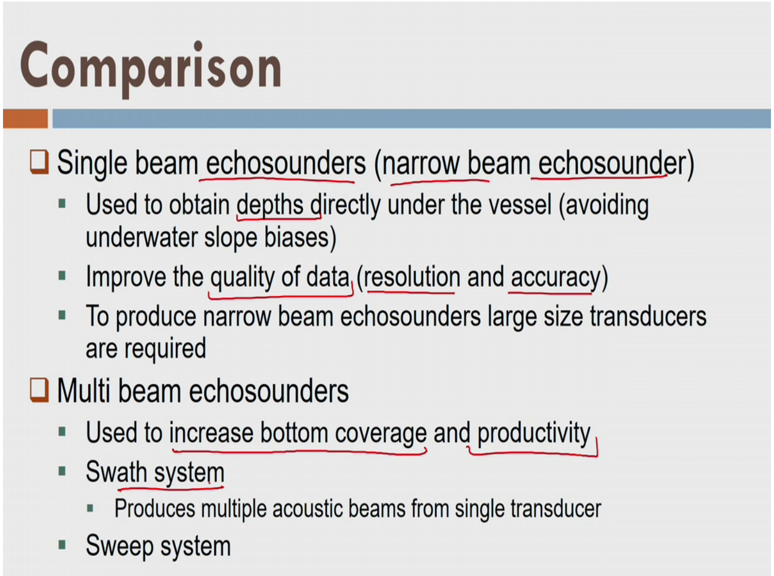

Now, let us compare the single beam echo sounder and the multi beam echo sounder. The single beam echo sounders they have the narrow beam echo sounders and hence they have low ambiguity or I can say that lower ambiguity of the one footprint size, fine. So, it is basically some advantage also that means, we can directly obtain we know that we are going to obtain the depth of my water depth or a sea bed just below the vessel ok.

So, it is having higher quality of data because of the higher resolution and higher accuracy. Remember in case swath tilt we said that because of the tilt of my echo sounder what will happen, I will have more ambiguity because footprint size will be more and but I will be reporting my depth or the range and the center footprint. So, that is kind of ambiguity we started introducing as we have the tilt angle. So, naturally in case of multi beam echo sounder what happens? The some of the pulses are some of the responses are coming from tilted positions or the from the tilted directions, right and those will have more error compared to the center one or the another one ok.

So, now then we have in case of multi beam echo sounder I have higher coverage. So, the I have higher productivity or rather I will take less time if I use multi beam eco sounder. Then we have two types, system one is called swath system that means, it is acrostic skimming or the whisk broom scanning and at the same time we have sweep system that means, there is a system here which is having multiple sensors or receivers and then it is sweeping along the vessel like this.

So, this my along truck direction and the instrument is like that it is sweeping along with that like a sweep what we call [FL], right. All the sweeper remove the some kind of garbage it sweeps the some kind of stick or some broom on the surface. The same way this is stripping. So, now, let us look into the NBES characteristics or multi beam eco sounder characteristics.

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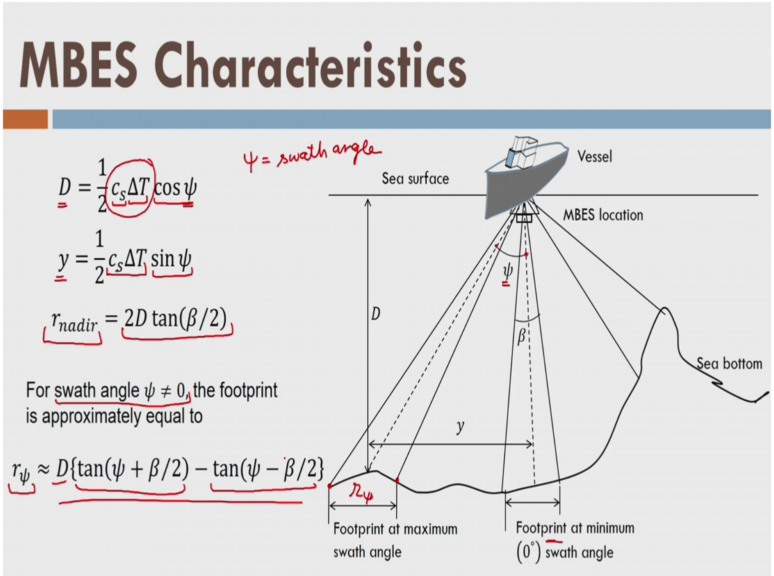

So, the depth is given by at angle of tilt let us say this is this here. Now, I am taking the this another direction so, some this center of nadir direction to this is my psi angle. So, at this psi angle the depth is given by this where it is my travel time delta T and cos of psi, fine because this is the depths here you can see and the we measure the range and range is this quantity ok.

Similarly, the position that is y position across that position is given by this where this is my range half times sine of psi ok. So, what is about x position? This is my z here D, y is also given across attract. The x is assume to a 0 at a given position or we have to measure the x along the line of data acquisition.

Now, the size of footprint at the nadir we have already know for this pulse will be this much, right ok. At the same time is my swath angle which is phi is not equal to 0, so this psi is called swath angle, right. Remember in case of LiDAR we call it the half field of view here we call it swath angle, fine. So, now the footprint R phi which is R phi here R sigh here sorry it is given by D times tangent of psi beta plus beta by 2 and beta minus 2.

We can find out that I am trying to measure this point to this point distance and so this is written like this.

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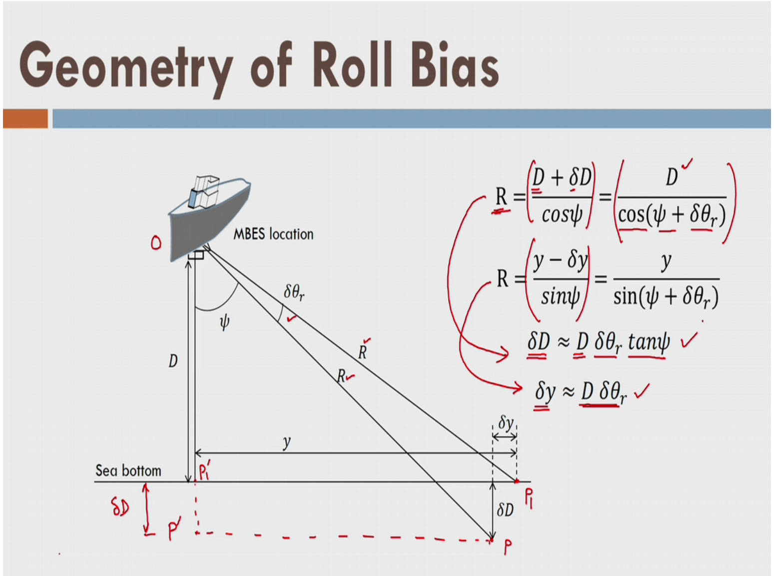

Now, let us say there are some errors, errors means some systematic errors and how to remove those systematic errors very very important aspect ok. So, now we have the role bias that means, what is the role if my vessel is going like this and this is the line of data acquisition perpendicular to the screen here and the vessel is moving like this kind of thing, it is called rolling. So, this is called the rolling phenomenon, right. So, now we know that my vessel is rolling and it is rolling by some amount called delta theta R fine, right. R for role and delta theta R it is doing like this, because of that what happens is if my eco sounder is like that it is also doing like this, fine.

And let us say at certain position my delta theta R is like this and so I am measuring the depth or the range in this direction instead of vertical direction, fine. And that is introducing the error in my estimate. So, let us see what is this estimate of the error? At the same time I would like to say you one thing that bias is my systematic error which means I know what is the value of my delta theta R or what is the values my role and so I want to calculate what is the value of the ambiguity or the error in my estimate of the depth or range, fine.

Now, we can see here in the range is R that means, because of the theta error which should I should measure the this range for this point. However, because of the error here

I am this point is measured. So, now, this is my range R here and earlier it should be range R, right ok. Now, you can see from this triangle the first angle which I draw here, ok you can see here that this distance is nothing but if you take this triangle let us say point P, let us say point O somewhere here and point P dash ok.

So, if you take the triangle P, P dash, O I can write here that D plus delta D which is this distance this is my delta D and that is nothing but the ambiguity in the depth ok. So, this is the depth measured plus ambiguity. So, I can do if I divide by this cos psi angle, what will happen? I can get this quantity D divided by cos of psi plus and it is equal to this quantity from this triangle, right let us say point P 1 here and so I have P 1 dash here fine.

Now, from this triangle P 1, P 1 dash and O, I can write the D this distance this depth divided by cos of psi plus theta R equal to range only, right. So, range is given by this by 2 from two triangles. Now, I can also write in the form of y which is nothing but y minus delta y so, from this triangle I am writing. So, from triangle P, P dash O I am writing this term and this term I am writing from the triangle P 1, P 1 dash and O, right.

So, here two triangles are giving the distance and now I can write what is the ambiguity in my depth that is given by D delta theta r tangent of psi. Here if you solve this one you will get this one. Similarly, what is the ambiguity in the acrostic direction that is given by this one? So, you take how to take some approximation and you can find out these correct derivations, fine. So, let us the effect of my roll biased.

Similarly, we have the effect of pitch bias and the law bias will see long what is the meaning here ok. Now, let us look into the pitch bias ok. What is the pitch here? Let us assume again that the vehicle is moving in this direction across the screen and now this is a vehicle ok. Vehicle might be doing this also, fine because of the water velocity or whatever reason, right.

So, this phenomena is called the pitching, right the way we speak and the pitch so that is why we are moving like this. So, similarly the vessel is also moving like this and that is creating some ambiguity in my position of the footprint So, let us look into that ok.

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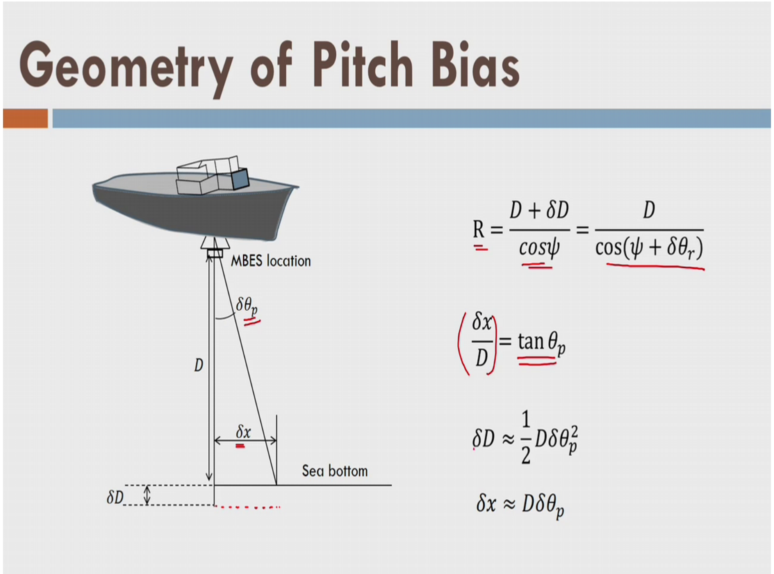

So, I can see here that it is going to create the ambiguity in the x position y because the x is measured along the direction of movement of vessel this is my y here and this is the depth here, right. So, he you can see here that because of this movement what will happen? That pulse will be moving like this and it is going to create some ambiguity along the track or along the flight along the line of data acquisition and that is why since we are measuring the x along the line of data acquisition, I will have error in the delta x or in the x value of my position of footprint, fine.

So, now it is shown here very clearly that if there is a pitch bias of delta theta p it is creating delta x here that is ambiguity in x position and again using the same logic you see here that D plus delta D if I use this triangle here. So, I can write this thing here cos psi and again the same thing here, you can see here that delta x by D is given by tangent of theta p here ok.

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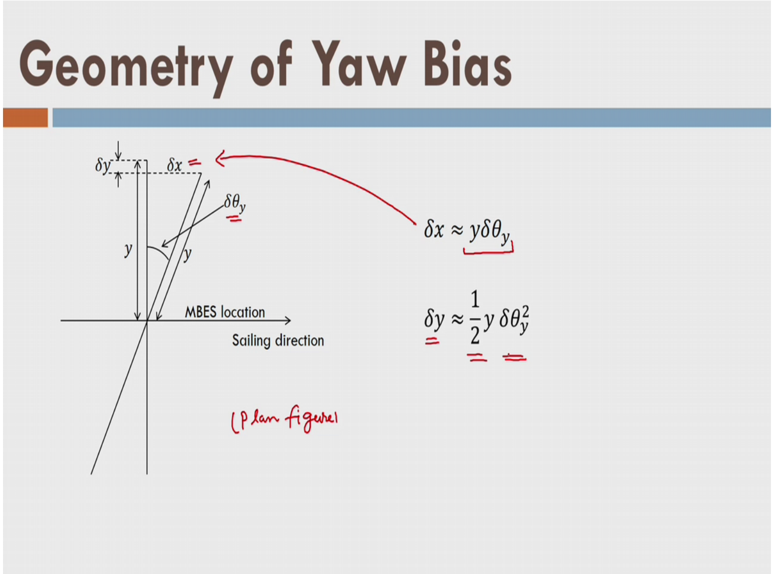

Now, if I take the approximation here. Now, let us look into the geometry of yaw bias. What is yaw?. Let us assume that again this vehicle is going like this and it is doing this kind of motion, fine. That means, with respect to the vertical axis it is moving like this and as the result it is creating the ambiguity in both x and y position, but not at the depth because in the depth is still measured like this and vehicle is doing like this. So, what will happen? It will only create the ambiguity in x and y positions, fine. So, now you can see here that the y position is like this and it is my plan figure here it is not showing the depth it is only plan figure, fine.

So, now, you can see here that because of the delta theta y here I have the error delta x here, fine and that is nothing but yaw. So, delta x is basically given by the y delta theta y here fine, you can see here that delta is x is nothing but equal to this quantity. So, now, what is my delta y here? That is the ambiguity in the y here and that is given by half y delta theta y square fine ok.

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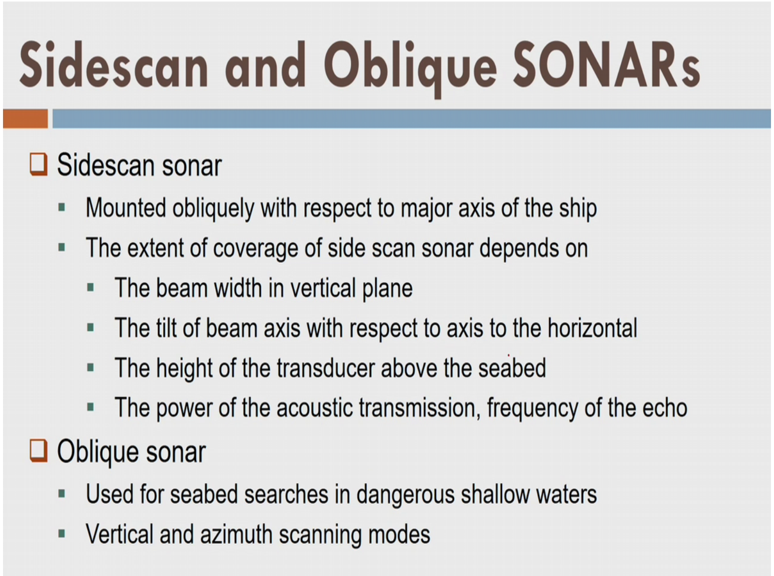

Now, let us look into the various configurations of my sonar instrument or the sound navigation and ranging, fine. So, acoustic systems as also called sonar because their using sound and so word came sound navigation and ranging, fine it is called sonar ok. Now, we have some arrangements called sidescan and oblique. What happens is now, let us assume that we have some echo sounder which could be vertical or which could be a swath system, right fine.

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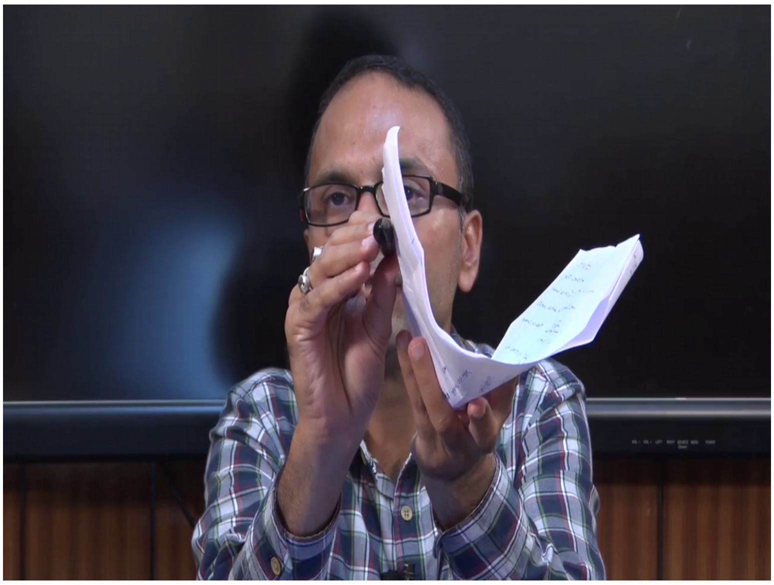

If we look at the other system where if I have a vessel like this; this my vessel for example, so if I mount the sounding instrument on this side. What will happen? It will be doing the sounding from here ok. So, basically vessel is moving like this and the side beam system is can the area like this and that is a advantage I need not go into the area with vessel ok.

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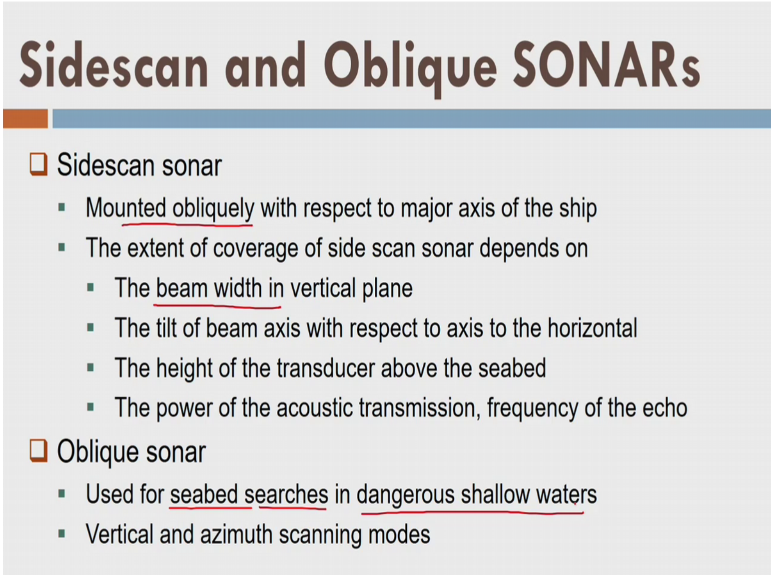

So, what happens is it is the sounder is mounted obliquely with respect to the major axis of the ship there. So, the extent of the coverage of sight depends on the beam widths in the vertical plane. That means, what is the beam width here in this plane which is vertical plane here, fine the tilt of the beam axis. So, what is the tilt here basically?

So, look that this is the higher the tilt higher the coverage, lower the tilt lower the coverage. The height of the transducer, so my transducer is basically mounted here ok. So, if this height also matters because it is going to increase the height from the seabed and that is why higher the height higher the coverage and the power of the acoustic transmission on the frequency of the echo that we have already said ok.

In case of oblique sonar, what is the oblique sonar? If you see here that oblique sonar is simple idea, I am having a system which is multi beam eco sounder but the preference is to create the higher swath angle. And as a result what happens from this place itself it is looking at way large ranges and very large areas covered here ok. So, I am very near to the let us say some area and I am trying to cover this one, fine.

So, basically the oblique sonar is used so, do these searches in the dangerous shallow waters, right if water is very dangerous I do not want to go here but I want to do some kind of detection some search and not the measurement ok. Let us say there is some kind of accident happens and it is preferred not to go there what will happen I will use this kind of system oblique system where and I will be sending some sound pulses, right to that area and if that thing detects something in that area that will it is kind of success of the mission, fine. So, it is having vertical and azimuth a scanning modes.

That means this my vertical has and that is also azimuth mode this for example, this vessel here. So, it is doing some kind of azimuth scanning here and it is having vertical scanning here like this, this is a motion of the vessel.

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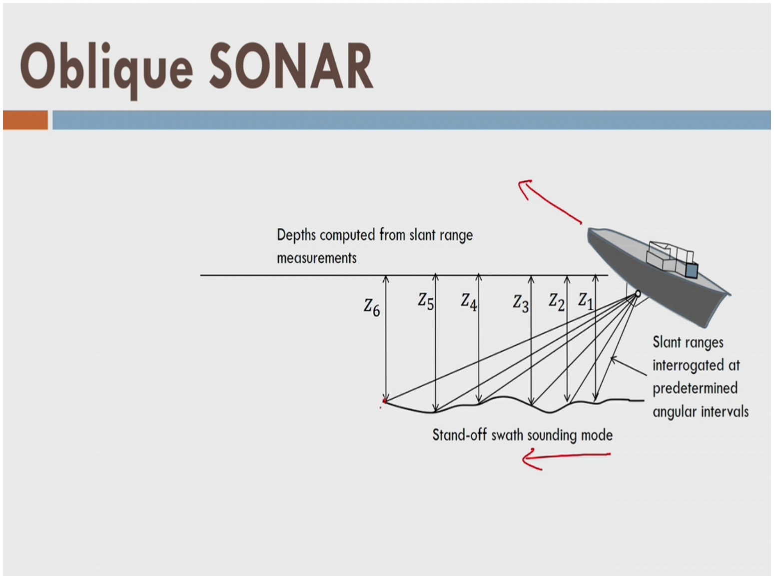

So, this is the figure shown here. You can see that vessel is moving in this direction and in the acrostic direction it is sending pulses up to very large range, right and it is trying to measure the depth like this.

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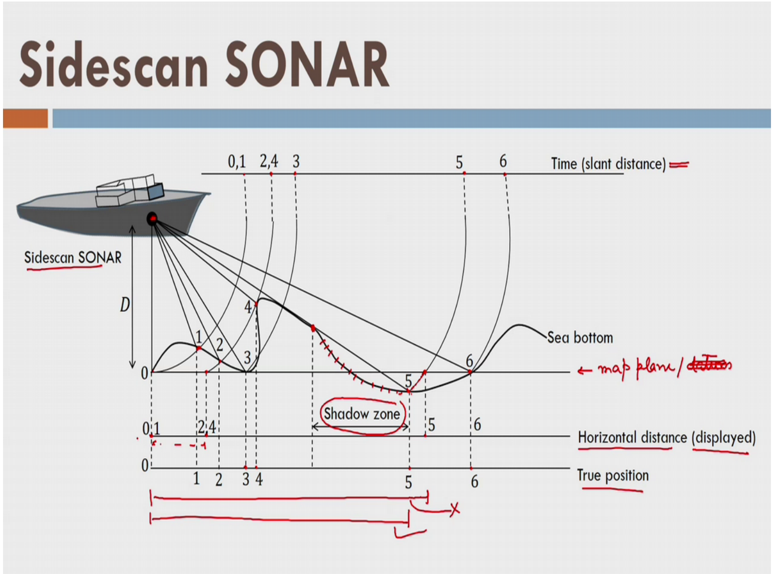

Now, this is a sounds try this can sonar is here ok. You can see here that from this side it is mounted on this side of the vessel and it is trying to find out ok. One ambiguity should note here that what happens is this is my slant range order distances measured according to time. So, the point 0 is measured here because of the wave front you can see this is a wave front and now it is interesting with this point one also and as a result point 1 and point 0 are reported at one time or one timestamp or the distance between the point 0 and 1 is not recorded.

At the same time the two point 2 and point 4 are also recorded in terms of time at one point ok again point 3 here and so on you can see. So, now, the point 5 which is at having little lower depth from the datum this is my basically the map plane or I can say datum here. So, with respect to this point if this point is coming here it is mapped here on the time scale and this point is mapped here on time scale.

Now, if you see that this is my true position that means, if I draw the real map of the sea surface point 6 should come here, point 5 should come here, point 4 should come here, point 3 should come here and so on. But what is the horizontal distance that has been displayed or recorded. You see 4 point 6 which is exactly at the map plane or datum or we can say the plane which the data is recorded, right better not to, right datum here call it map plane ok.

So, what happens is point 6 is here, but point 5 is reported here because on the map plane if I draw the wave front it is coming here. So, it is recorded here on the horizontal distance. So, the horizontal distance from point 5 is reported from 0 to 5 this distance like this distance ok. However, this is the wrong distance the correct distance is this distance fine ok.

Now, you can see here that this is the shadow yawn which means because of the sound pulse as interacted here beyond this point it will not go or if it all it goes to point 5. So, the whole zone is my shadow zone where we do not have any data from here we do not have any data. That means, from this point to point 5 we do not have any data so, it is call shadow zone.

Now, coming to the point 4; point 4 is again mapped here because the pulse has interacted with the terrain here, fine. So, now, in case of this my true position but point 4 is reported here at point 2 because point 4 and 2 are lying on the same footprint. So, point both point 2 and 4 are recorded at this distance which means this distance from 0. You can see here similarly point one and point 0 are recorded here in terms of time as well as horizontal distance because, the horizontal distance is evaluated with the help of time only as well as the slant range is also calculated with the time only.

So, I can say that time is nothing but the direct reflection of such slant range and some way we can also calculate the horizontal position, right. So, that is idea you can see in case of side scale sonar. Now, we have some interferometric logic also here; that means, I can also measure the phase of the return signal and I can find out the estimate of depth and other variables so, let us look into this thing.

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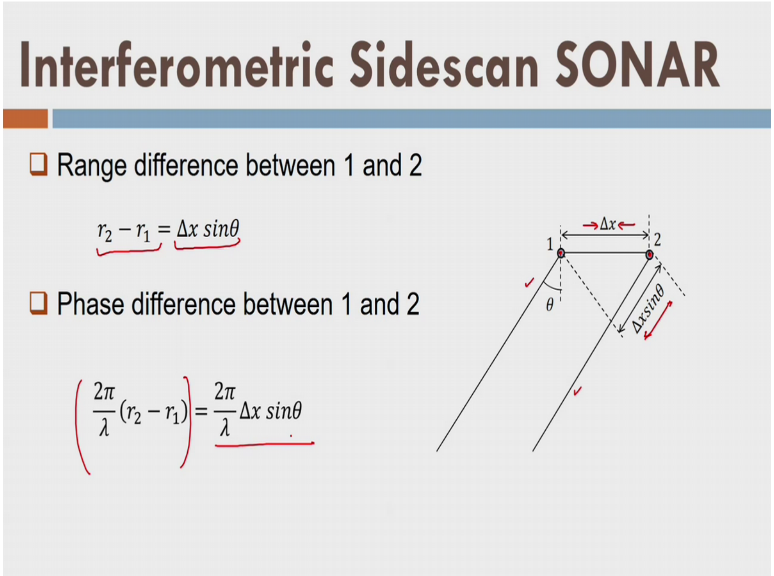

Let us say there is one pulse which is having an incident angle of theta and there is another pulse having the same incident angle. Now, it is pulse number 2 is reaching here, pulse number 1 is reaching here and there is a horizontal distance of my delta x here, fine. So, now, you can see here that this is the difference of my range, fine so, r 2 minus r 1 is this one.

And now if I convert into the phase I can find out the phase measurement like this ok. So, phase difference between 1 and 2 so, using the phase difference I can also estimate the variables like depth and distance between the points and so on. Now, once you measure from the echo sounder we should put some corrections ok. So, before finishing this lecture we should consider those things also.

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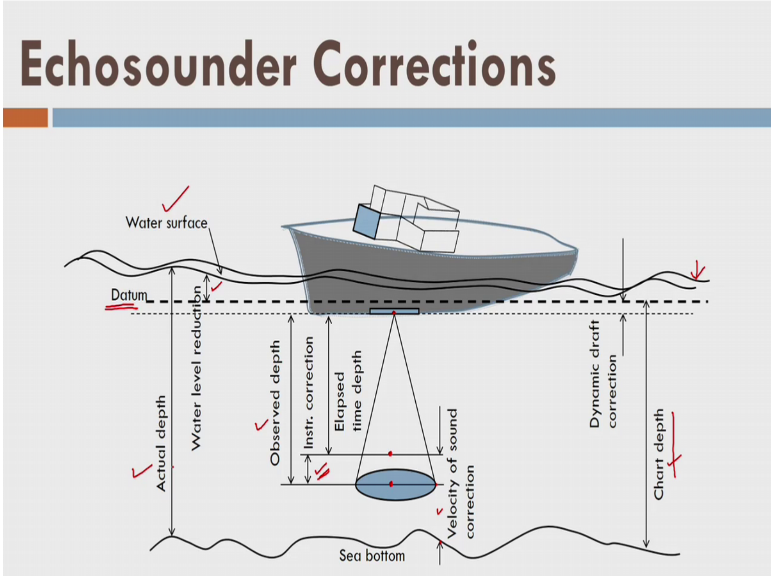

So, let us see this is my real water surface here, fine will be shown here ok. This is the datum; datum means we have done some kind of 19 year study and we find out this is my MSL or some kind of datum, right. So, I expect that my sea vessels should be placed at the datum and my measurement should be done from the datum ok. However, because of some reason or weight of the vessel what happens? Vessel sinks down a bit.

So, I have some correction called draft correction over here, fine. Now, you can also see that water surface because of the tide is above the datum. So, datum is a kind of average level so, the water surface is above the datum today at this movement ok. At the same time the vessel is slightly below the datum or rather my instrument which is measuring the pulses which is throwing the pulses it is slightly below the datum ok.

Now, what happens is what we call this correction as my the difference between the water level and the datum is called the water level reduction or the tidal correction because of tide today water level is above the datum possibly it could be below datum also on some other day. So, this correction could be positive and negative, fine.

Now, you see that the instrument which is situated here has measured this depth or rather I can say that it has a really measured this depth but it is reporting this depth why? Because, the time we have received the time difference from this it is according to this point and this is my instrument error. So, any error or any ambiguity in my measurement of the instrument it is reflected here fine ok. So, this is my correct observe that is this much. So, if I correct my that range or the depth that is measured by the instrument by the instrument correction my systematic error whatever then I will get the correct observe depth.

Now, I can see here that because of the error in the velocity of the sound that means, because of the ambient conditions of my c are different than what I thought. So, I assumed that there could be speed of 1500 meter per second of sound however, speed of something different. And as a result what happens I am thinking that I am measuring over there, but I am measuring in fact, here at this level of footprint. So, now, this collection has to be there from there to there and that is called the velocity of the sound correction, right.

Now, this is my draft correction so, you can see that the charge depth is this depth here which is from the datum to the sea bed. And on the other hand my actual depth is this which should be corrected for the all these factors, fine. So, if you want to measure the actual depth you should consider all these factors at the same time if you want charge depth you should consider the depth from the datum. So, after completing echos on the operations let us look into the possible of airborne LiDAR survey for the bathymetric or for the hydrographic surveys ok.

Here we can see there are some lasers which can penetrate through the water ok. What happens is once we have a laser scanner is mounted on the aircraft and aircraft is flown over the sea surface or the water surface ok. So, then a pulse is thrown towards the water surface at known scan angle ok. What happens is partly the pulse is reflected from the water surface and the remaining part of the pulse goes or the effects through the water, fine. So, after passing through the water surface that reflected pulse will be interacting with the seabed and again it is reflected back towards the sensor.

So, sensor basically measures two responses, one is reflected from the water surface and one is reflected from the seabed and then it finds out the tan difference of the two measurements and this time difference is converted into the depth difference or the range difference of water body, fine.

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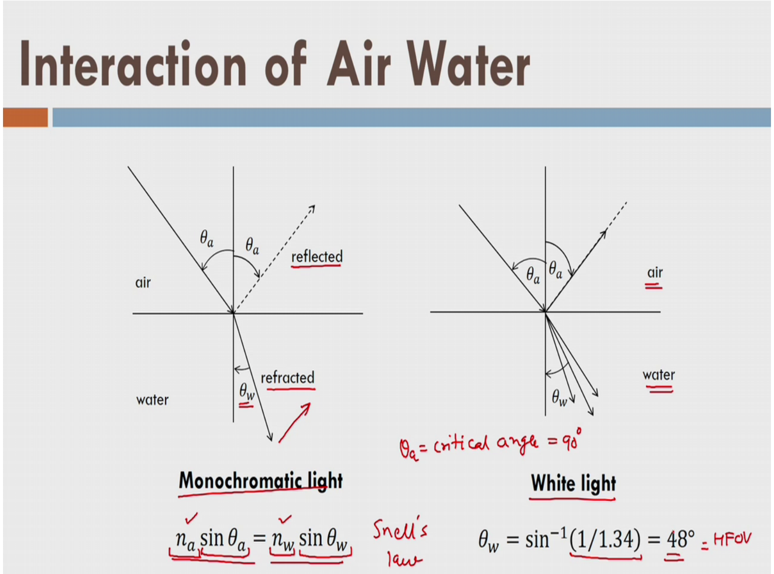

So, now, you can see this operation over here. So, this is the one thing here that this is my reflected component here and finally, this is refracted component and that will be reflected back from the seabed and the sensor will be measuring the both responses, fine. So, in case of monochromatic light and in case of white light we can see the difference here. So, monochromatic light is my laser and the white light is this. So, what happens is in case of air and water interaction here? You see that the white light comes this way and it goes into this thing and it reflects at certain level.

Now, you can see here at the same time, the same phenomena is happening with the laser pulse also ok. So, what is happening here, this is n a is my refractive index of the air and this is sine theta that incidence angle of the pulse in the air and it is the refractive index of water and that is the incidence angle in the water the theta w and that is nothing but this Snell's law if you remember, right.

Now, if theta a is taken to be critical angle which is nothing but 90 degree ok. What happens here and a and we know what is value and a and n w for the laser pulse so, you know this value here. So, we find out that theta w or the incidence angle or the half field of view of my LiDAR system could be maximum 48 degrees here, fine. So, this is indicated over there this is my half scan angle and that is maximum angle possible in case of use of the laser sensor for the air bond surveys of the hydrographic survey, right.

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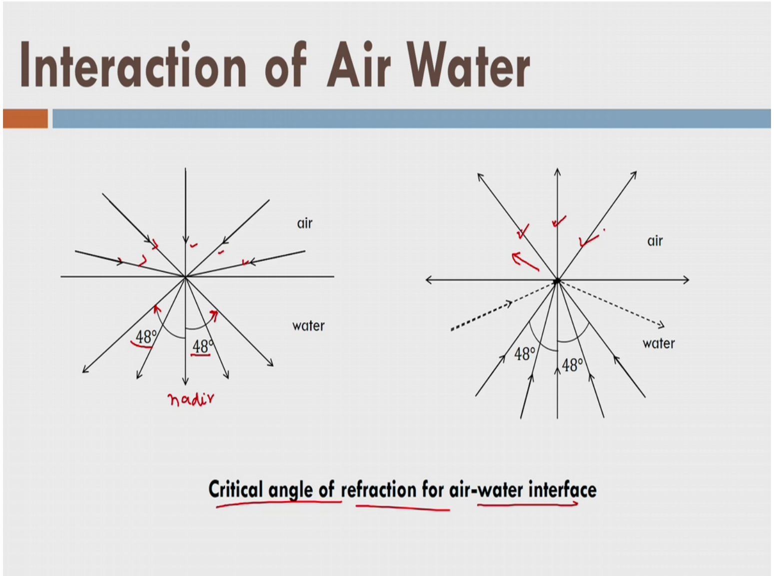

So, here the critical angle of the refraction for the air water interface has been shown here. Now, what happens is that all these pulses are coming here like this and then they are entering into the water with maximum angle of 48 degrees from the nadir here ok. Again the responses are reflected back and again they are converted coming from this 48 degree angle and again going back to the sensor and that is shown here like this, fine. So, that is the idea here ok.

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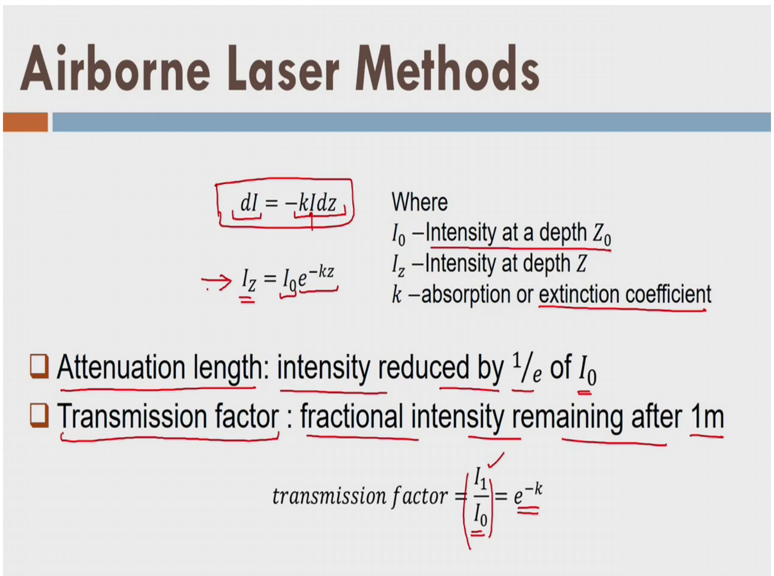

What about the intensity measurement? Now, how do you measure the depth? So, let us say this follows some rule like this the loss of the intensity of the laser pulse is given by this. So, where k is my extension coefficients or and then I is the intensity of the laser pulse at certain depth Z. So, this is the rule that governs the loss of the laser pulse intensity. Now, if I integrate this equation I will get this one that intensity at depth Z is given by I 0, which is that intensity at depth Z 0 some reference depth into e to power minus k z fine ok.

Now, we define something called attenuation length that is the intensity reduced by 1 by e of I 0. So, if I put I 0 by e here I can find out what is the depth Z, right ok. And then finally, the transmission factor and that is the fractional intensity remaining after 1 meter ok. What is the purpose of this thing? So, if I take this intensity at one meter of the water depth and that is my reference depth value than I can find out the value of k and that is a purpose of defining this transmission factor here. So, this is the way we measure it.

Now, by this rule if I find out that at one by e level I create some footprint and that is of best foot print I want to measure. What will happen I can find out the maximum depth that I should measure or I should believe on although the depth will be much higher but I should believe the data up to that depth only ok.

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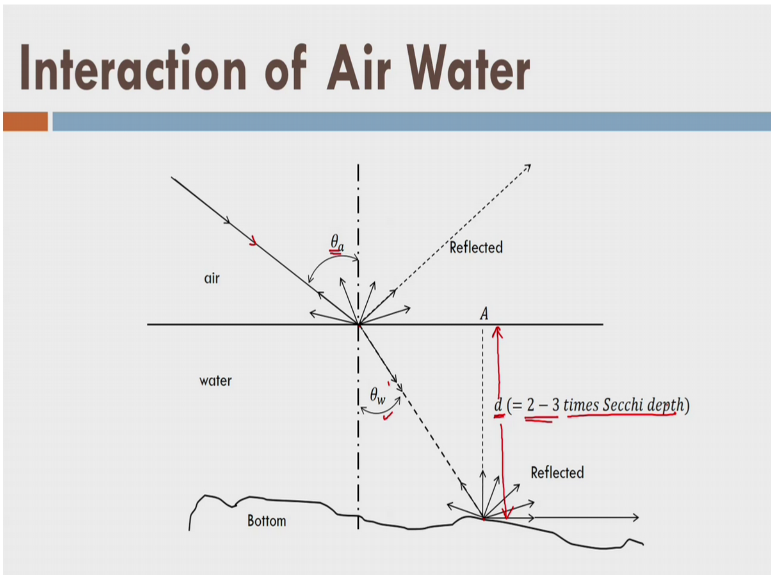

Now, finally, if you see here this is the interaction what is happening here in the air the pulse is coming here ok, it is reflected back in all directions at theta angle it is coming and it is reflected back in all directions. The partly laser pulse is also reflecting into the water and again it is going here and again it is reflected back, right.

And now this depth d which is from here to here it is 2 to 3 times of Secchi depth. What is Secchi depth? If I take a disc which is black and white, right and now if I keep on immersing into the water a certain depth it will be invisible or it is no more visible and that depth is called Secchi depth. So, it is found that laser can measure up to 2 to 3 times Secchi depth, right. So, let us I random physical limit we should have in our understanding, that laser pulse or the laser system for the hydrographic surveys can be used up to that depth only.

So, in this lecture we have seen that the methods of the depth measurement by electronic way or by the modern methods, fine. So, there we complete our hydrographic surveys where we have learned all 3 lectures in detail about the hydrographic survey. The 1st lecture was about the fundamental aspects, 2nd was about the field procedure, and the 3rd one that we covered today is all about the modern instruments like echo sounders, multi-beam echo sounders, side scan sonars, oblique sonars and the air bond laser sensor for hydro graphic surveys. So, we will finish this lecture here.

Thank you.