Coastal Engineering
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Module - 9
Tsunami
Lecture - 1
Tsunami - I

Now, we will get into one of the most important topic, never heard or less heard prior to 2004, at least in this part of the world we call it as nature's fury it is nothing but tsunami 2000, 2004 and it is also very often refer to as the great Indian ocean tsunami.

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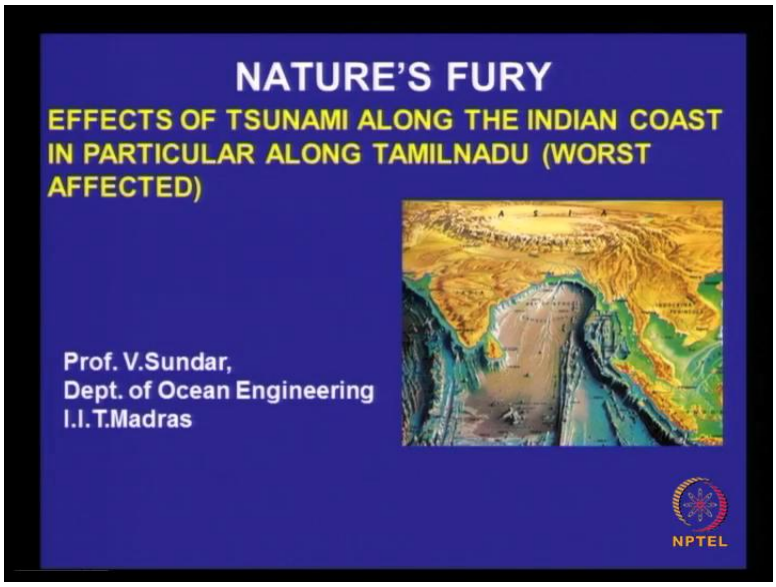

So, for the benefit of most of him many of the informations which I am providing, are available in the net and as this is quite useful to general audience. So, I have taken the liberty of using informations from different sources, be it news papers, magazines, informations from friends, students, faculty, colleagues, internet, different websites, etcetera. So, finally, I will play some record, thanks at the end of the lectures, lecture lecture.

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So, organization of the lecture, waves, tides, current, and tsunami; tsunami definition it is travel past events, cyclone wave and tsunami, what is the difference? Warning systems. Then some of the safety rules and based on imageries I will give some information.

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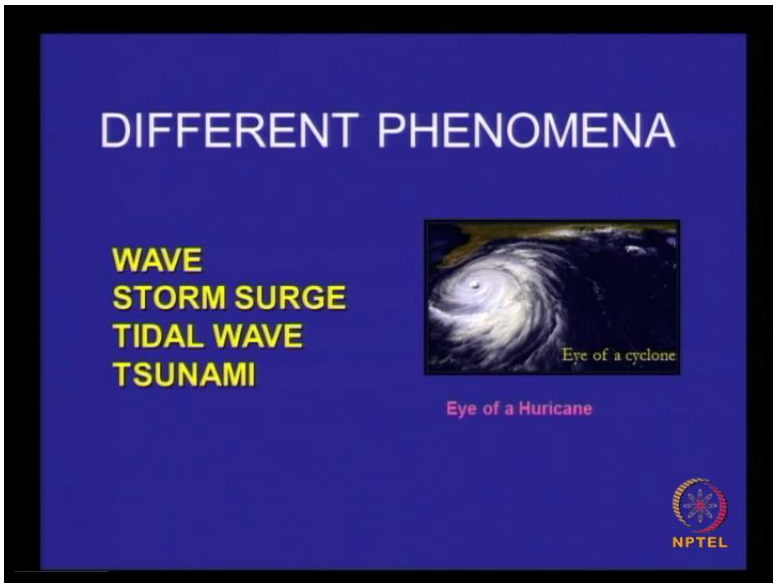

The different phenomena what is a wave? What is a strong surge? What is the tidal wave? What is the tsunami? Here the wave is an oscillatory motion and it is driven by the speed of the wind, wind is acting over the water surface generates a waves in somewhere in the deep ocean.

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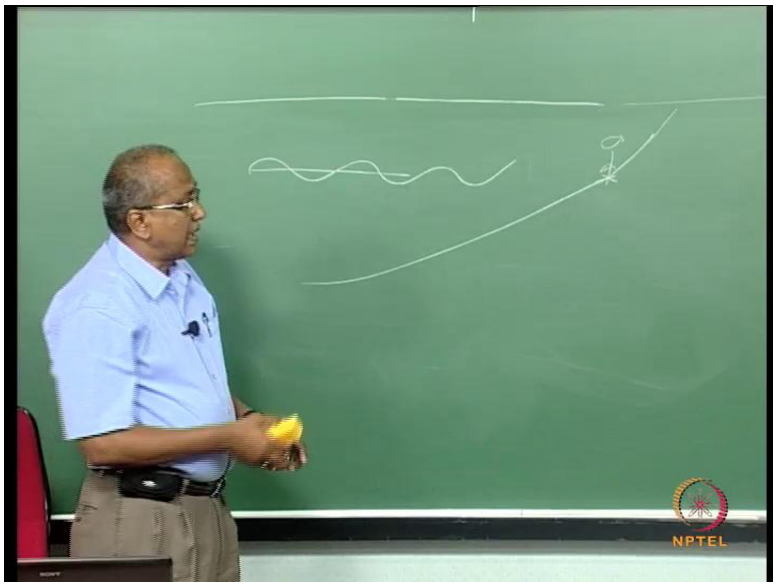

And then you have the waves generated and it propagates, and then it breaks and then you have a horizontal up rush over the beach. This is everyday phenomena and you are very sure that no extreme event is going to happen. If there is an extreme event happens like the one you see there, if there is a low pressure built up in the Bay of Bengal for example, then it is possible for the metrological department to monitor the movement of the low pressure area. And then give you periodic signals or warning saying that they are likely to have a cyclone. Cyclone is associated with heavy wind speeds; and you have a very clear warning that a cyclone is going to hit the coast.

And storm surge is also similar case where in you have the low pressure areas, and you can have a storm and there can be extreme surge taking place near the coastal bed, coastal area. So, during storm surge you can have water levels going up to about 10 meters, we have had enough number of storms surges along the east coast, particularly along the east coast. Tidal wave is again, it is between the attraction between the celestial bodies, and it is quite a huge wave which can rise up to several meters.

But, what is a tsunami, tsunami is you have this, but the water level goes up and the original beach is here, and when the water level goes up you see the waves running over, what are the causes for. So, you see that there is no question of a kind of, you can have a kind of preparedness for this kind of an event, because the height of the tsunami can go even up to about 30 meters. And if you want to have some kind of a barrier for a tsunami

and when the tsunami height can be as high as 30 meters, you cannot raise the wall against yourself.

So, what are the problems, first what are the causes now, this is the basic difference between waves, storm, surge, tides, and tsunami. More about the details, I have given the complete description about the mechanics of ocean waves, my lecture under wave hydrodynamics.

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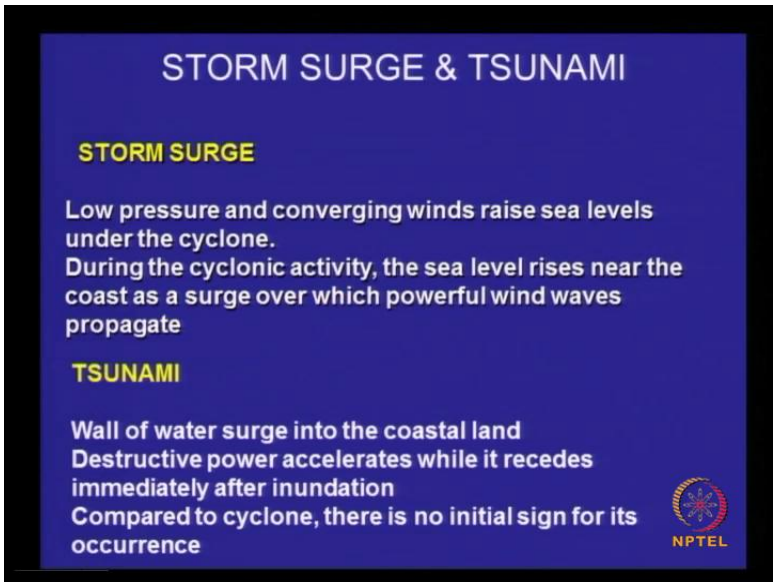

Now, here is some of the information storm surge and tsunami which is more closely related, in this case you have a low pressure converging winds raise sea levels under a cyclone. During a cyclonic activity the sea level rise, near the coast as a surge over which powerful wind base propagate, we have a clear warning, but effect is almost same, but it is not it is not so devastating as in the case of a tsunami. Tsunami is something like a wall of water, just a wall of water, surging into the coastal land destructive power accelerates while it recedes immediately after inundation.

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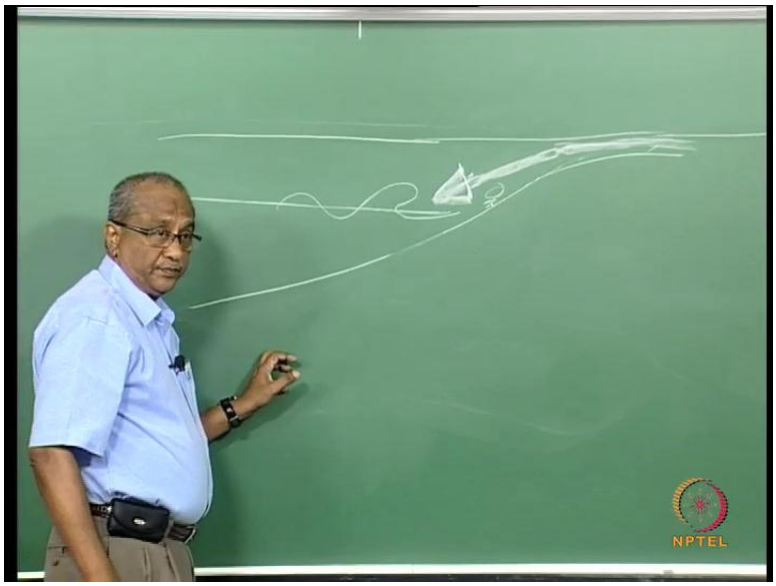

Because, in this picture you are original shore line or some somewhere here, now you have the rise in sea level, I mean the water level and then it has propagated it has propagated for example, it has propagated like this. And it can propagate may be for 1 kilometer or 2 kilometers, it depends on the kind of land over which it is propagating, but then the gradient is actually back to the ocean.

So, this comes back, so much of mass of water coming back that has tremendous destructive power. The most of the destruction most of the destruction took place when it was returning back, and in this case there is absolutely no initial warning no initial warning, so it can happen any time.

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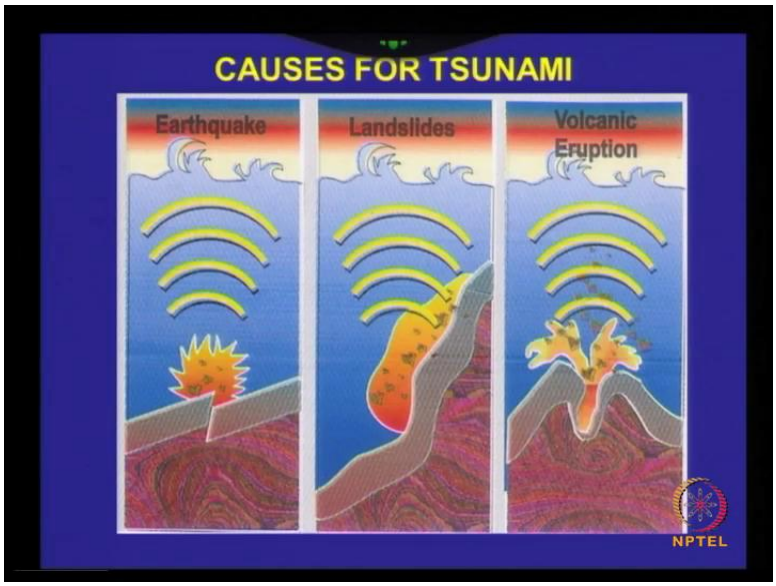

So, causes for tsunami that is natural causes, natural causes of tsunami are due to an earthquake, due to landslides, due to volcanic eruption inside the ocean. So, you inside the ocean, you see the sea bed and beneath the sea bed, it is all like plates which will be seeing, so you have something like land, something like rock material. And if you have a huge landslide inside the ocean, the entire water medium gets disturbed.

And similarly, if you assume that some of this structures beneath the ocean, if they move one one below the other, then you might have a tsunami being caused. So, either an earth quake or a landslide or a volcanic eruption these are the main causes for the.

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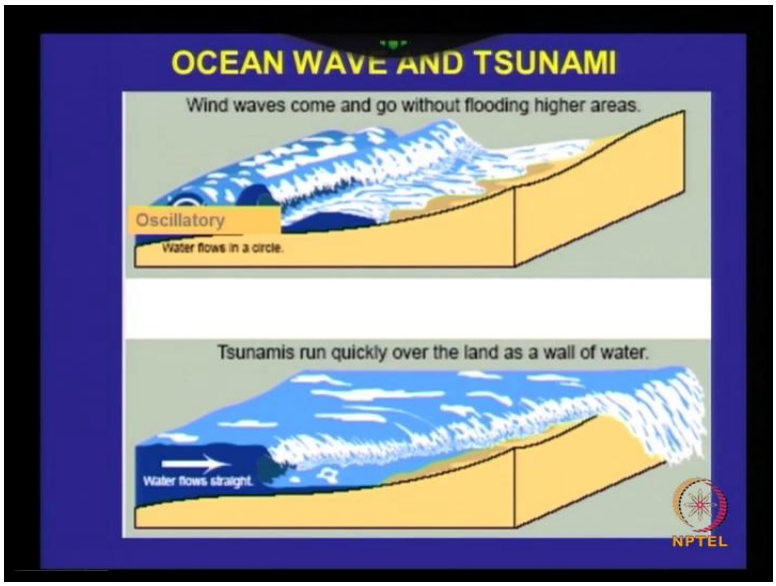

Now, you see the wind waves come and go without flooding higher areas, if there are some there may be some extreme events in the waves also, there may be some local phenomena. A local phenomenon can occur, where you can have an extreme flooding locally for a short duration, but tsunami is not like that, it run quickly over the land as a wall of water.

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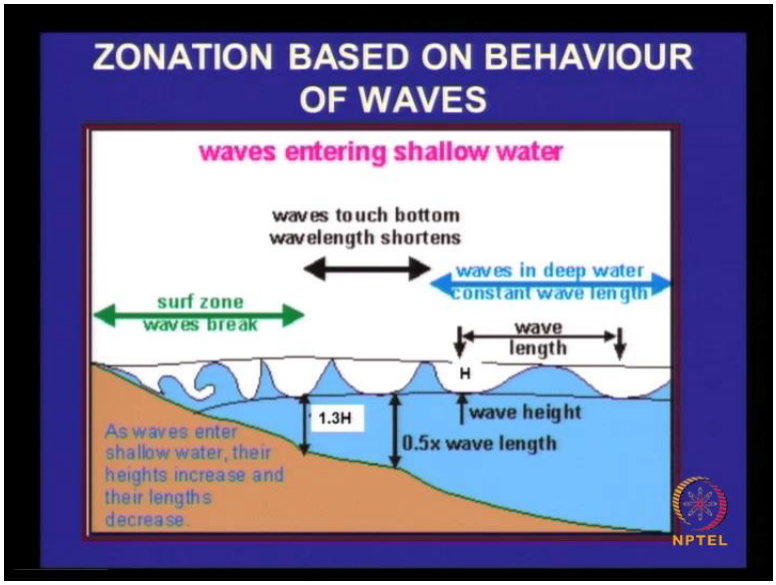

Now, zonation based on, now we look at the zonation based on the behavior of the ocean waves, waves enter the shallow waters, waves touching the bottom, wave length shortens

from a waves move in from deep water, constant wave length, so this is how it moves. Then when it is about 0.5 times the wave length, you see that the steepening of the waves take place, and somewhere around this place the waves breaks when it is approximately 1.3 times the wave height. And then you see the gentle up rush of the water, so the physics of the behavior of the ocean wave is well understood.

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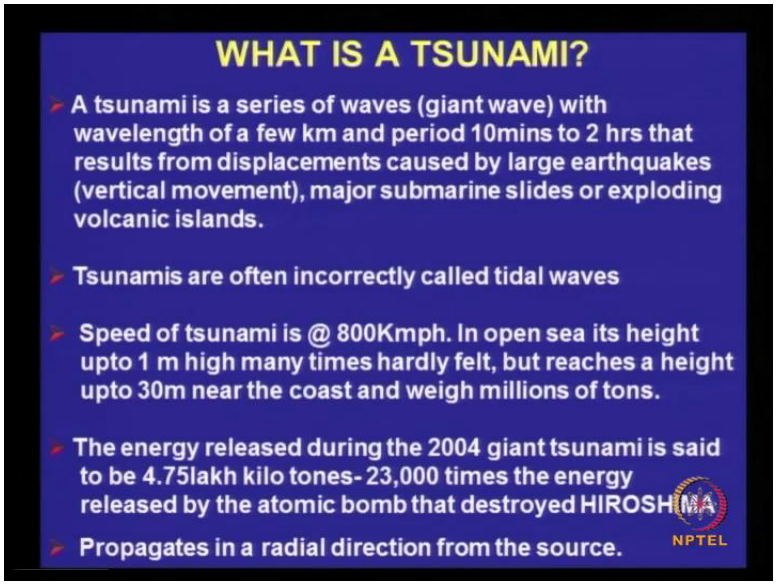

Now, we move on to a tsunami, a tsunami is a series of waves or is termed as giant waves with wave lengths of few kilometers. And period 10 minutes to 2 hours that results in from displacements caused by large earthquakes that is vertical movements, this is very important, major submarines slides are exploding volcanic islands.

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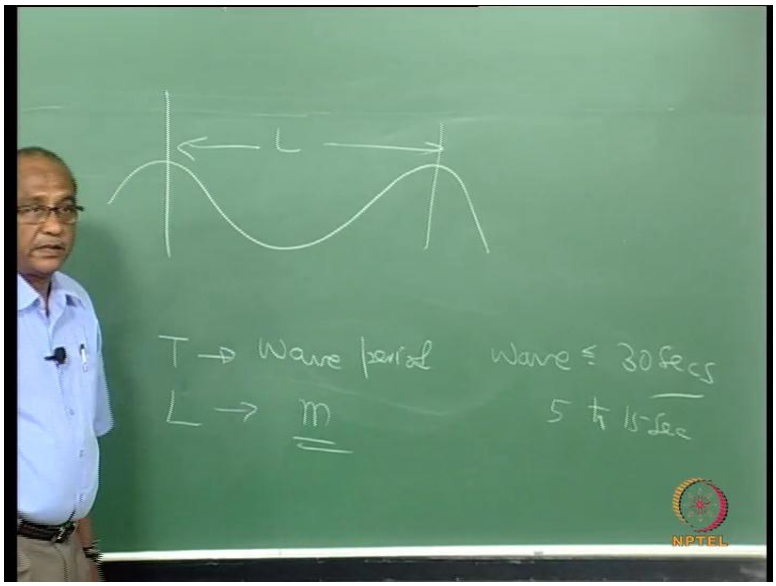

So, one thing very important aspect is that, when you have a wave tsunami is also a wave, when you have a wave you see that this is wave length, and time taken for moving or traveling for the wave, to travel one wave length is the wave period. So, this wave period in the case of a wave is mostly less than 30 seconds, most of the time it would vary between 5 and 5 to say 15 seconds, occasionally you will have period greater than 15 seconds, and the wave length is only of order of meters.

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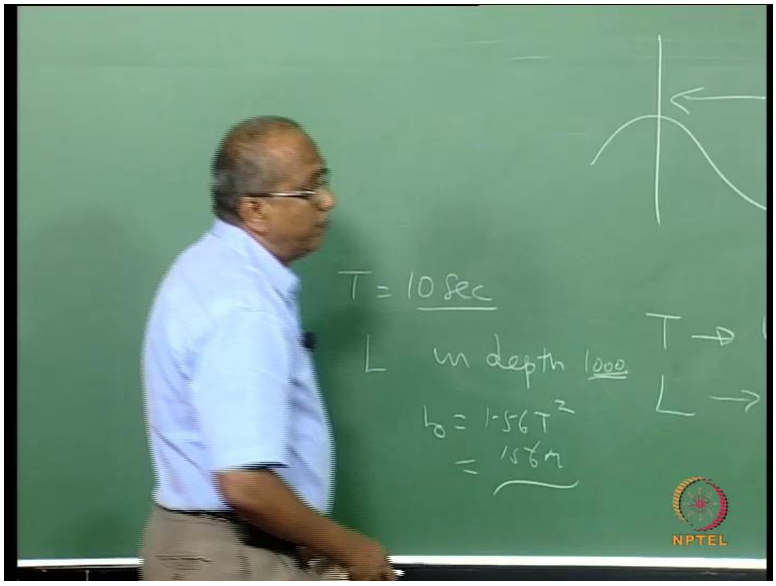

So, for example, if I have a wave period of 10 seconds, what is the wave length in a water depth of, in a depth of say 1000 meters, l naught is equal to 1.56 into T square, so how much it is 156 meters, is that clear. But, in the case of a tsunami, it will not be in terms of meters, it will be in terms of kilometers. So, tsunamis are often incorrectly called as tidal waves, the speed of the tsunami is about 8000 kilometer, it can be about 8000 kilometer 800 kilometer square hour that is equivalent to that of a jumbo jet.

And in open sea it is height is up only about 1 meter, and it is hardly felt, so during a tsunami if you are in deep waters better remain in deep water, do not come to coast. And when it reaches the coast, it can go up to about 30 meters and it can way, it is weight can be millions of tons. 2004 giant tsunami is said to be 4.75 lack kilo tons that is 23000 times, the energy that was released by the atomic bomb that destroy the entire Hiroshima.

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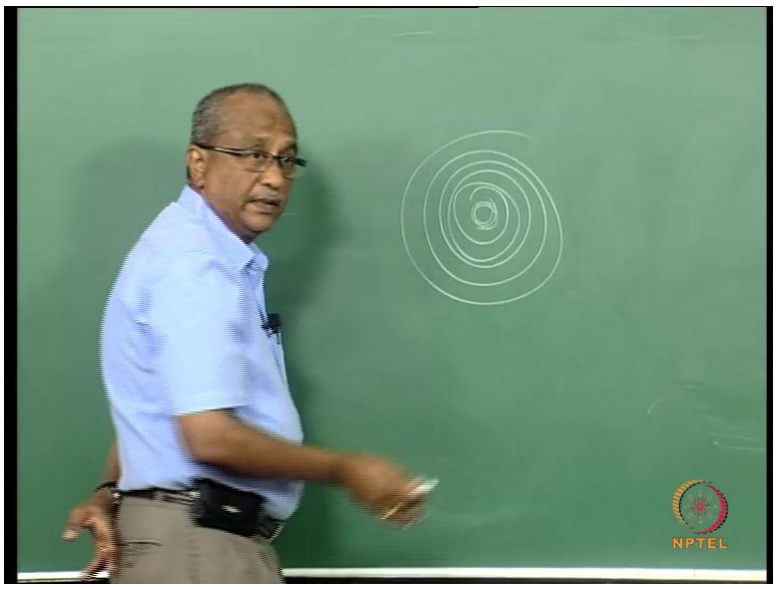

It propagates radially, anywhere it propagates radially and it can travel for 100s and 100s of kilometers without any problem.

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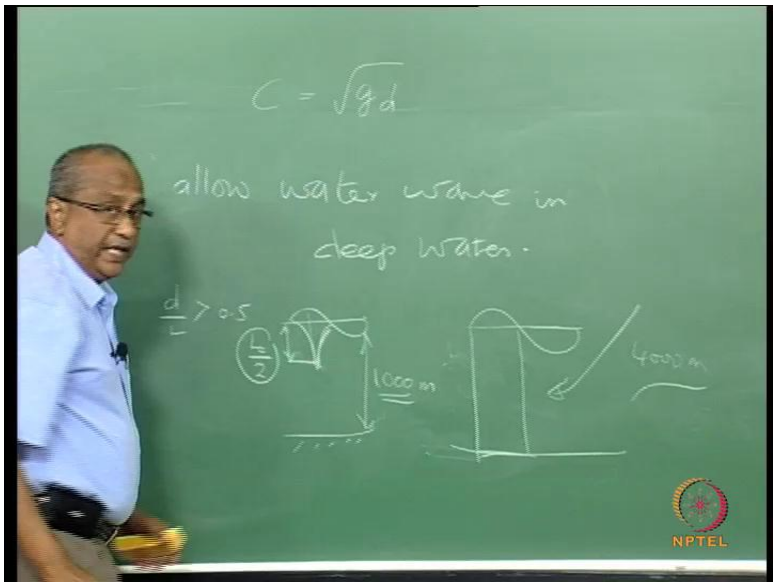

Basically, it is a shallow water wave in deep waters, particularly this tsunami, what does that mean shallow water wave, so as per the wave mechanics, when d by L is point, is greater than 0.05, you have the disturbance of the felt only up to a distance which is L naught by 2 and L naught is only in terms of meters. So, when a wave is propagating the effect on the sea bed is not felt at all, say for the instant for example, if the water depth is greater than 1000 meters, it is not felt at all.

But, in the case a tsunami, water will be felt because here d by L is less than 0.05, because water depth is although it is greater, the wave length is in terms of kilometers. So, hence this will be felt, the effect of waves will be felt all the way up to the water depth, even if the water depth is 4000 meters, so that is the major difference.

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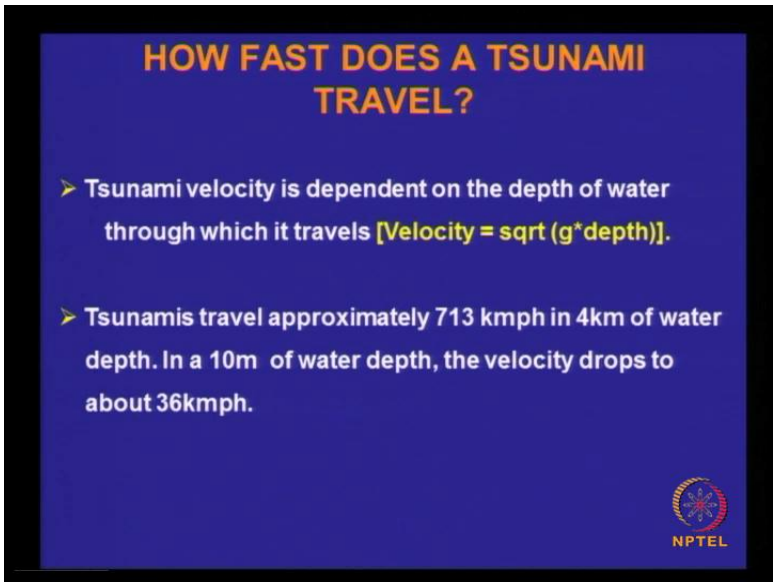

How fast does a tsunami travel, since it is behaving as a shallow water, the speed of a shallow water is given by root of g d, so which comes around 8000 kilometers or 700 kilometers in the case of 4 kilometers water depth. I am when I say 4 kilometers water depth, I am referring to the Indian ocean in the Indian ocean tsunami of 2004 that occurred in a water depth of 4 kilometers, is that clear, and that is why I am using the 4 4 kilometers of water. So, the speed of the wave is 700 kilometers per hour, and then you can imagine how it would have traveled.

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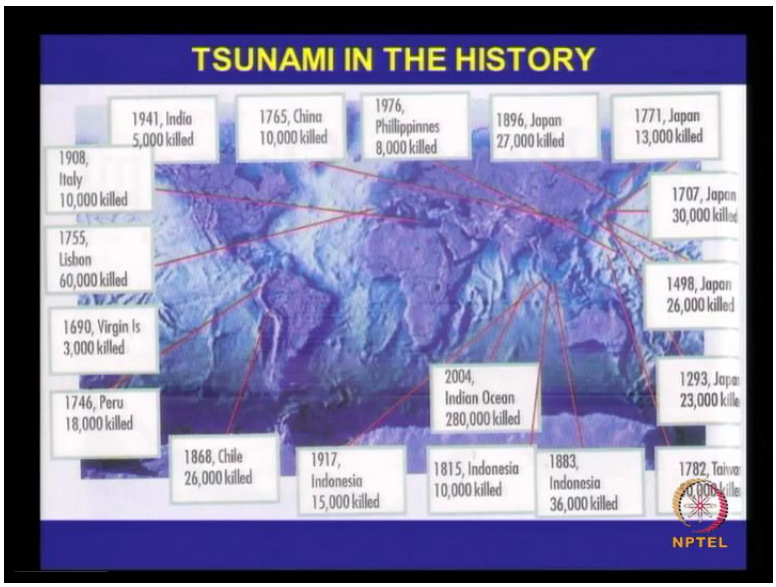

Tsunami in the history, you have lot of information in this slide, so 2004 people killed are around 280000. So, if you look at the whole history, this is the worst, this was the one of the worst tsunami; and that is the reason why I choose to talk about this tsunami what were the effect etcetera.

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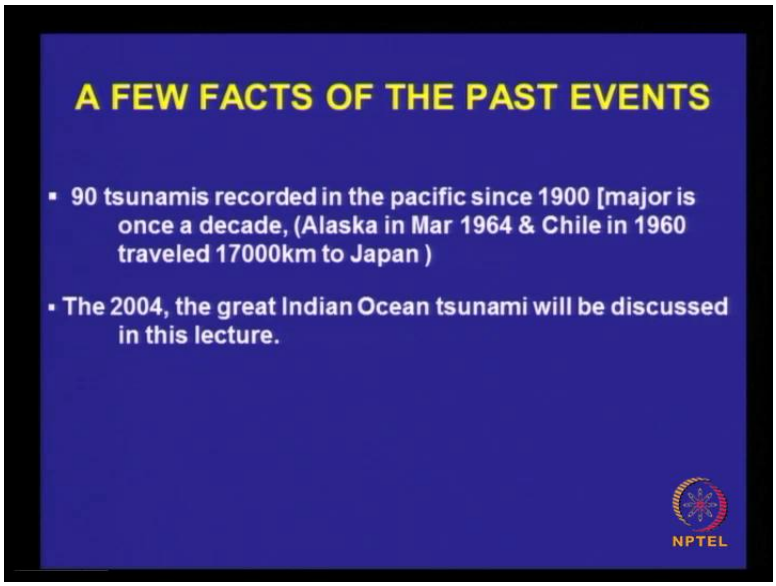

Few facts of the past events 90 tsunamis have been recorded in the pacific, since 1900 major once in decade, Alaska in March 2000 1964, and in Chile in 1960 travelled 17000 kilometers to Japan. That is chilly, you know where it is south America, so it has travelled all the way to Japan over a distance of 17000 kilometers, the 2004 great Indian will be discussed in this lecture.

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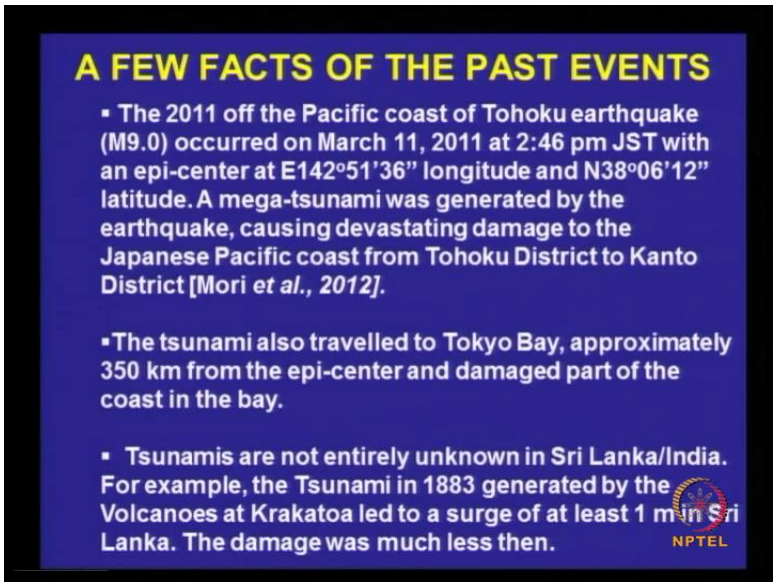

Before that, a few facts of the past events again, the 2011 of the Pacific coast Tohoku earthquake that is on the rector, it was 9 that occurred on March, 11th 2011 at 2.46 pm, Japanese standard time with an epicenter at the latitude and longitude are given. A mega tsunami was generated by the earthquake causing divested damage to the Japanese Pacific coast, from Tohoku district to Kanto district.

A lot of informations are available about this tsunami are in the net, on this is also really very, very devastating, after the Indian Ocean tsunami, this was again a major tsunami. Tsunami also travel to Tokyo Bay approximately 350 kilometer from the epicenter and damage part of the coast in the Bay, tsunamis are not entirely unknown in Sri Lanka or Indian, we had forgotten about tsunami prior to 2004. For example, the tsunami that occurred in 1883 generated by volcanoes at Krakatoa Islands, that is led to a surge of at least 1 meter in Sri Lanka, but the damage was not that much.

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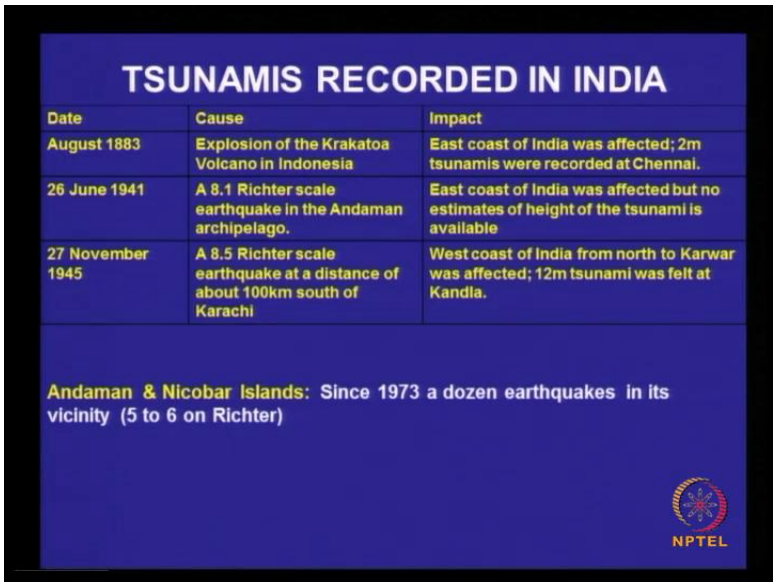

Tsunamis recorded in India, 1883 explosion of Krakatoa volcano that is again in Indonesia, East coast of India was affected 2 meters of tsunami were recorded in Chennai. 1941 on a rector on a rector of a 8.1 earthquake in Andaman's, East coast of India was affected, but no estimates of the tsunami heights is available, then 1945 on a rector of a 8.5 earthquake at a distance of about 100 kilometer South of Karachi that is we are referring to Arabian sea.

West coast of India, most from North to Karwar, north of Karwar was affected, so 12 meters tsunami was felt at Kandla, 12 meter of tsunami. So, Andaman and Nicobar Island since 73, a dozen of earthquakes in it is vicinity, but mostly ranging between 5 to 6 on the rector. So, this rector even 0.1 really matters in terms of devastation, so in fact, hours in the case of ocean, our 2004 tsunami it was initially said the strength was 8.9.

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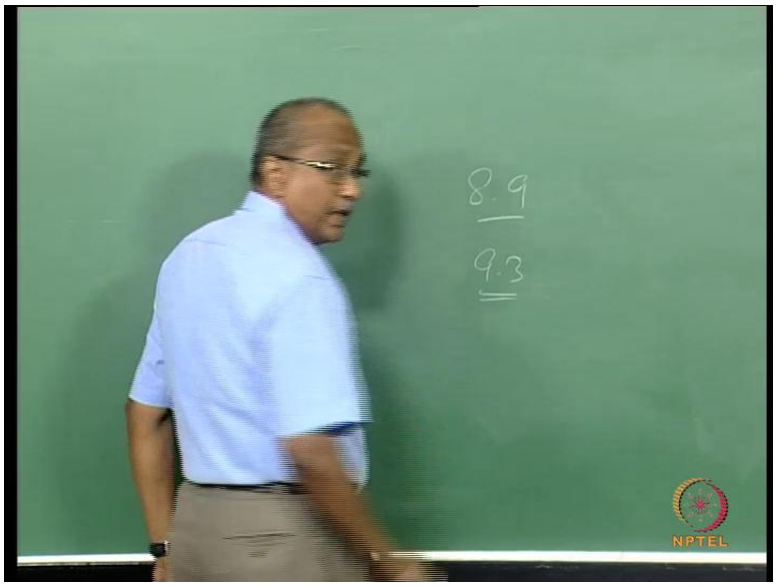

Later it was fixed as 9.3, every single decimal point really matters, when you look at it is strength.

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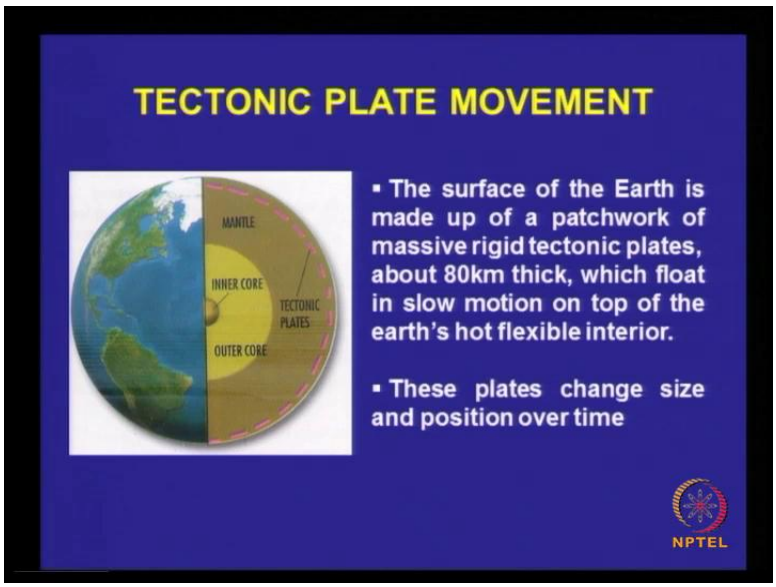

Before we go into the tsunami, because tsunami due to the earthquake is happening below the earth, so let us look at, I will not go into the in details, but if you are interested you can go into the all the details of the tectonic plate movements, etcetera. The surface of the earth is made of a patchwork of massive rigid tectonic plates, saw something like plates that is the surface of the earth, of about 80 kilometer thick which floats in slow

motions, you do not feel that; on top of the earth's hot flexible interior, these plates change in shape or charge in size and position over time.

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So, when you this is what is called as the ring of fire, these are all some of the back ground material, this is the ring of fire, so you see that this is Australia and this is where we are, this is the location which we are talking about. So, cycling the Pacific ocean on the bottom of the sea bed, lies a series of volcanic arcs and deep ocean trenches, called as ring of fire. And this region has a highest occurrence of earth quakes and volcanoes, this region is called as circum-Pacific seismic belt is a source to over 75 percent of world active, and dormant volcanoes that is about volcanoes.

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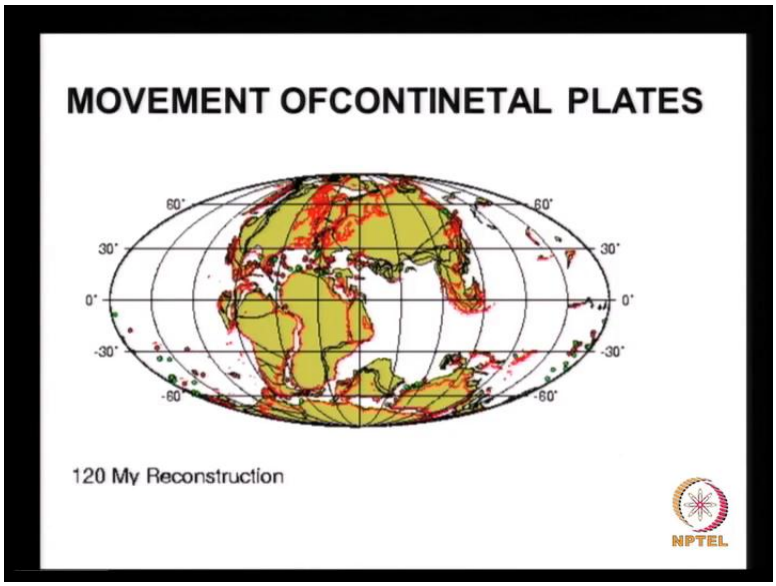

Now, when we look at the movement of the continental plates, you look at all this continents it is believed that millions and millions years back, all the continents were together, and then as years rolled on they started splitting from one another. Now, when you look at this thing, if you put everything, if you remove everything and put it together, you can get a single piece, so exactly you see that India will just go on slip into that. And wherever you have islands those are the places where you have possibilities of earthquakes for example, Andaman, Indonesia, Japan, and you go into Hawaiian Islands.

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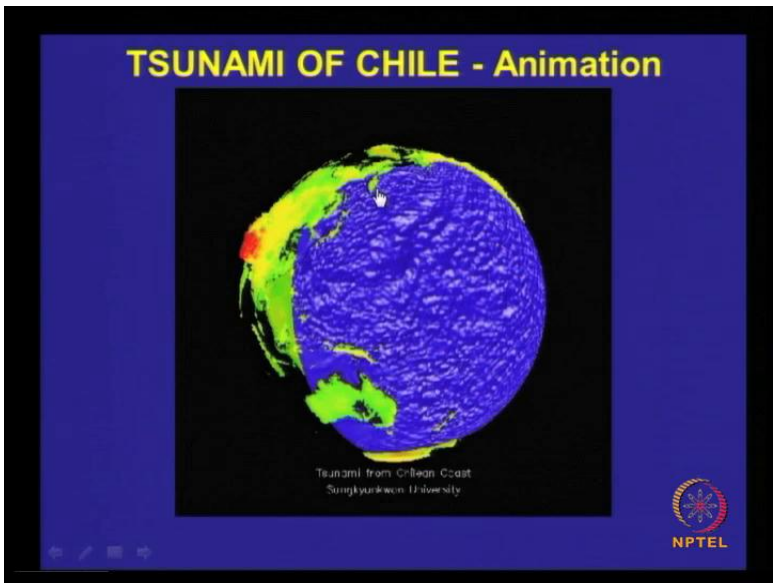

So, the I said about the Chile tsunami, you see that Chile is somewhere here, a tsunami that was generated here, moved all the way to Japan, it has traveled about 17000 kilometers, and this is the animation which you saw is based on a numerical simulation. And after this tsunami of 2004, this has become very, very interesting area wherein, so many institutes are involved in the numerical tsunami, simulation. Why this numerical simulation is is important, because when you know that there is a fault, because you can easily say this is the area, where you can have there is a possibility of having a earthquake.

Indonesia is borne for earthquake; we know that this is the area where you are likely to have earthquakes, a earthquake of different intensities, so as an exercise I can simulate and a strength of the exact characteristic, some more or less exact characteristics of the earthquake that has occurred during the 2004 tsunami. And then allow the waves the disturbance felt on this surface of the ocean, and then allows the waves to propagate, and then check what are all the areas that are likely to get inundated.

Not only that you can also find out the time of arrival, suppose it has occurred in a some say 2 pm, how much time it will take to reach India along Chennai or along Kerala, will it ever reach Kerala. Something happens in Andaman area is there any possibility for you to see some, it is effects somewhere near Kerala or will it be felt even near Bangalore, not Bangalore along the Karnataka coast. Certainly it will have it is effect along the East coast, because it is directly opened, so you can have once you have simulated a numerical model, you can keep on trying with different kinds of scenario, instead of a rector scale of 8.9.

If I have a rector scale, I just increase it to 8.95 or may be 9; you will see the difference in the pattern of inundation. So, this is the a kind of a (( )) of exercise to also get yourself prepared you understand, so such simulations are very, very important.

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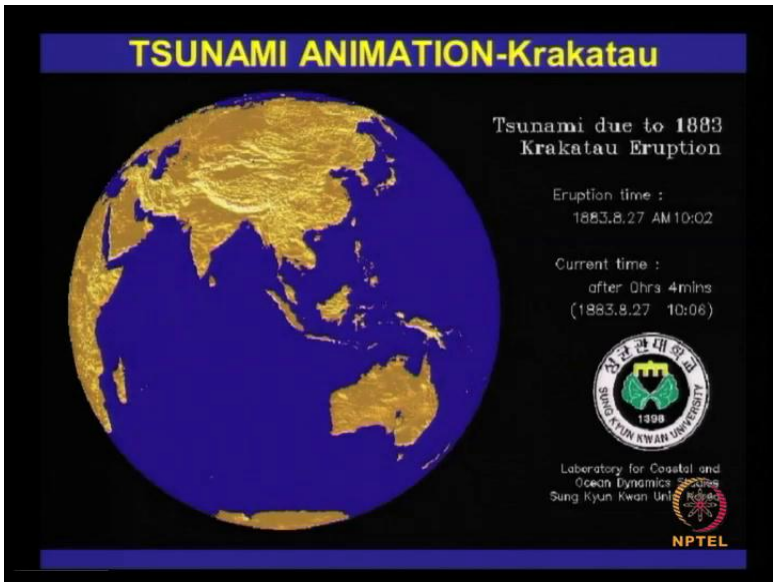

Now, you look at this is the Krakatoa island that occurred in 1883 that is in Japan, where this was a volcano eruptions, so you see that it has travelled, it will slowly travel all the way to Sri Lanka. So, when you if you have a numerical simulation that shows this, you can this helps you in to in preparing the vulnerability map, or the inundation map or preparedness map or whatever you would like to call.

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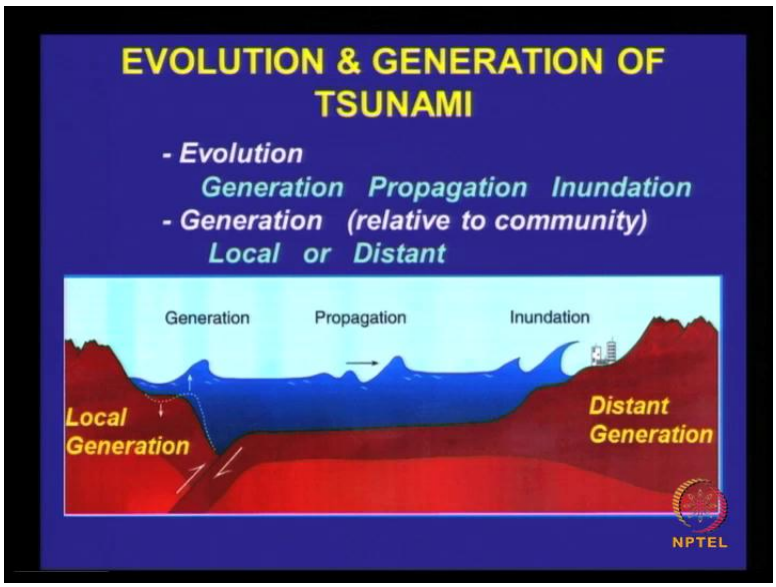

So, when you talk about a tsunami, the tsunami happens somewhere here an earthquake, so if there are plates which are in compression, beneath the sea bed. And when they are

disturbed during the earthquake, the plates move either this way or this way or this way, when there is a movement of the plates, naturally it is something like a wave maker you know. So, it disturbs, so much of energy is released into the fluid medium, so when it is released into the fluid medium you will have the source, at the source the disturbance of displacement of the water surface.

So, the displacement of the water surface will take place here, then you have the radial motion and then you have the propagation, and then you have the inundation, because the waves are not going to break. So, if you assume that this stretch of the land is not like this, then you do not have a much of a fear, but you assume that your beach is a flat one something like this, something like a. If you if you if you are living along a coast where the beach slope is flat under normal wave action, you are not going to have any problems, but in the case of the tsunami you see that submerges of the entire area can take place. That is why flat beaches are good for beaches for recreation, but very dangerous in the case of a tsunami.

So, what we need to do is, in the case of numerical modeling, numerical models modulus try to work on how to truly represent the source term at this location, that is how do you represent the disturbance, how big is the disturbance, the magnitude of the disturbance, it is very difficult to define. Once that is defined and once the disturbance at this location is established, then we have a number of numerical models which can take care of the propagation, and also the inundation. Once this information is known, you can I am make your plans for the mitigation measures.

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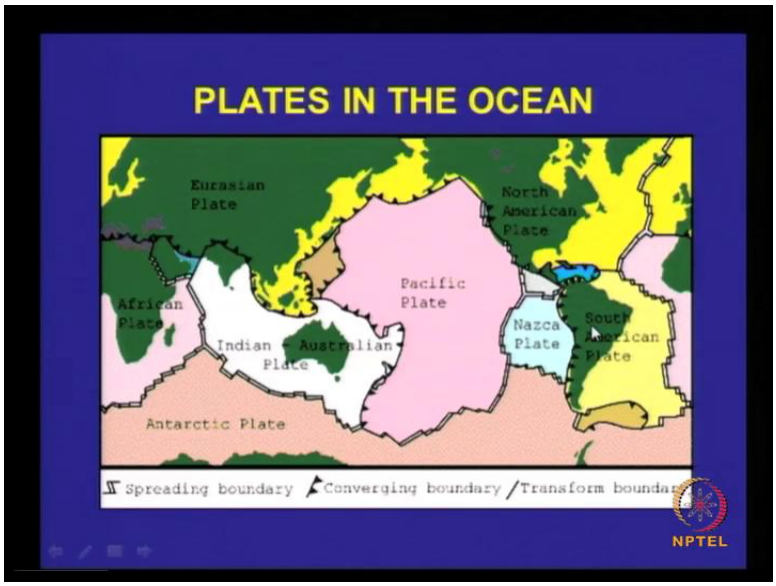

So, when you look at the plates in the ocean, you see that this is the Indian plate, this is the Australian plate, and this is the Pacific plate, and here the Burma plate, Eurasian plate is here, and this actually the Burma plate. So, you have a lot of plates beneath this ocean surface beneath the sea bed, where there are boundaries which are like these plates are in compression, it is a sticking very close to each other. Like here, if you see these are all converging boundaries, they are under great tension.

If one plate slips over the other plate, so this is one plate and this is another plate, suppose this plate moves below, then it results in the earthquake and you have the possibility of generation of the tsunami. So, what we will have, we need to see is this Eurasian plate or the Indian plate which slipped, which went below the Eurasian plate or micro Burma micro plate, this is Burma micro plate. The whole thing is the Eurasian plate, this is exactly where you had the problem of this plate going below the other plate.

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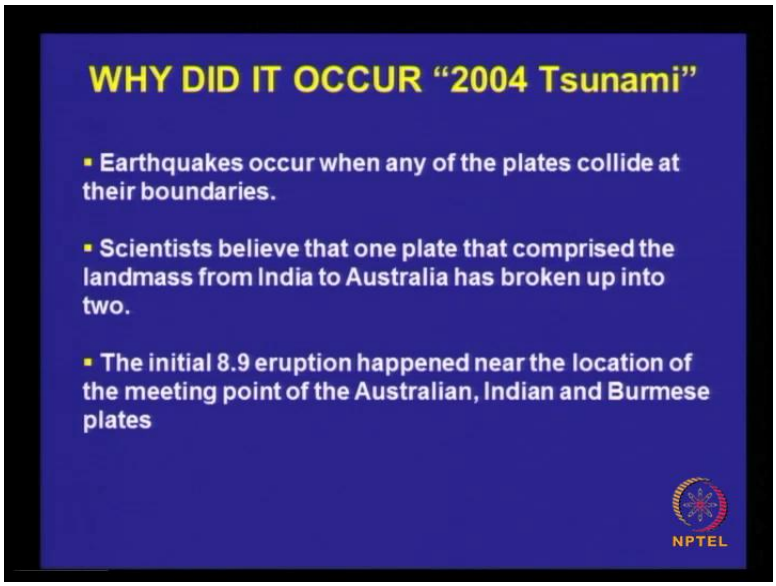

Why did the occurrence of 2004 tsunami take place, the earthquakes occur when any of the plates collide at their boundaries, scientist believe that one plate that comprise the land mass from India to Australia has broken into two parts. And the initial eruption was 8.9, happened near the location of the meeting point of the Australian Indian plate, that is this plate and this is the Burma plate, so this is the point.

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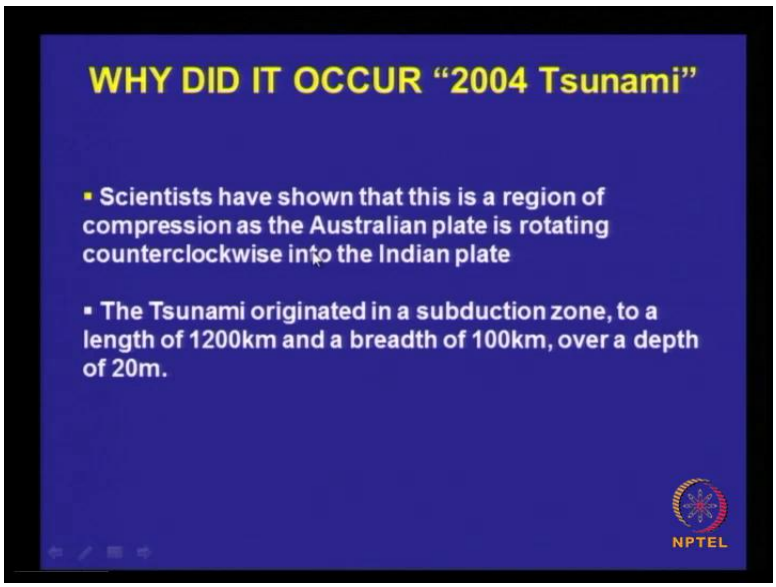

Scientist have shown that this is a region of compression, as the Australian plate is rotating counter clockwise into the Indian plate, tsunami originated in this seduction zone

that is between the Indian plate and the Burma plate. So, tsunami originated in the seduction zone, the overall length of 1200 kilometers width of 100 kilometers, and over a depth of 20 kilometers 20 meters sorry.

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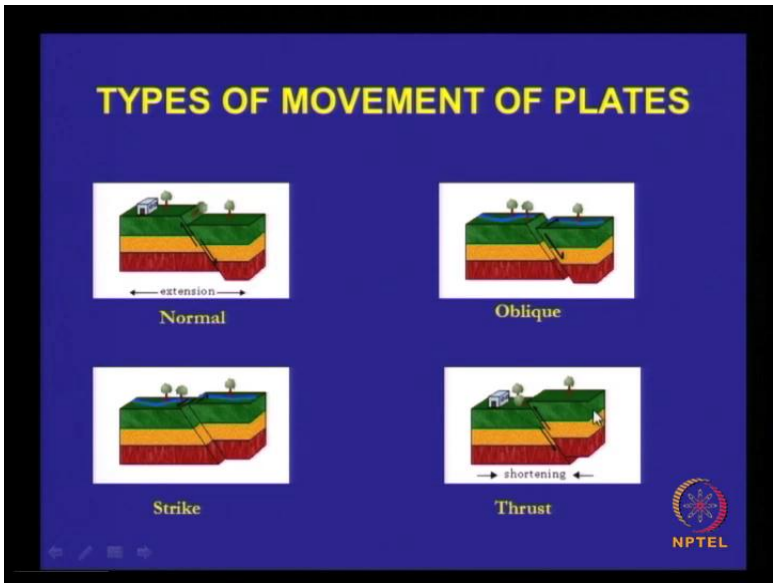

So, the types of the movements of the plates are shown here, you have a normal that is one is going out, the other is strike, strike is the lateral movement and oblique is like this and then you have the thrust.

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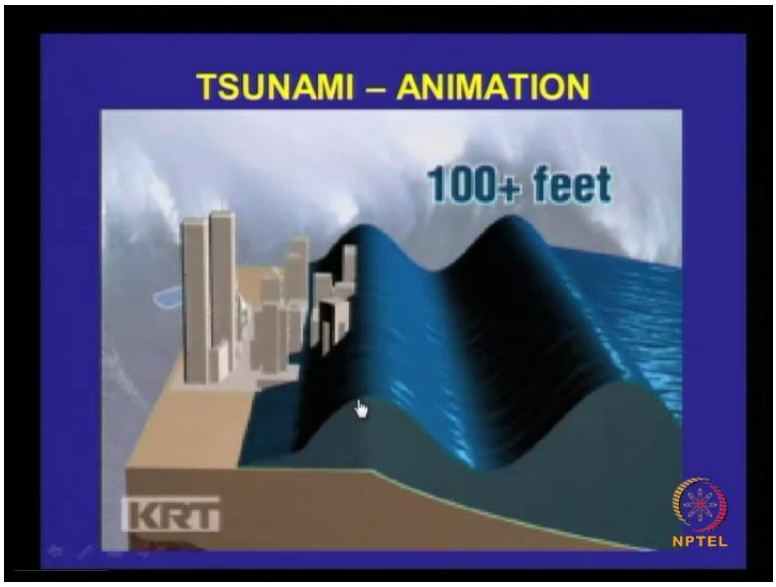

So, when you have one plate seduction, taking place over the other, then you see energy is released from the ocean surface from the bottom and then the waves start to move in radial directions. So, once they start moving in the radial direction, it will move keep on moving and it will bring lot of problems to the coast, so that is in plan. Now, if you look at this you see that the eruption has taken place here, and then you see the waves slowly moving very fast moving and then it reaches you look at the amplitude of the waves, it magnifies when it comes to the, very close to the coast.

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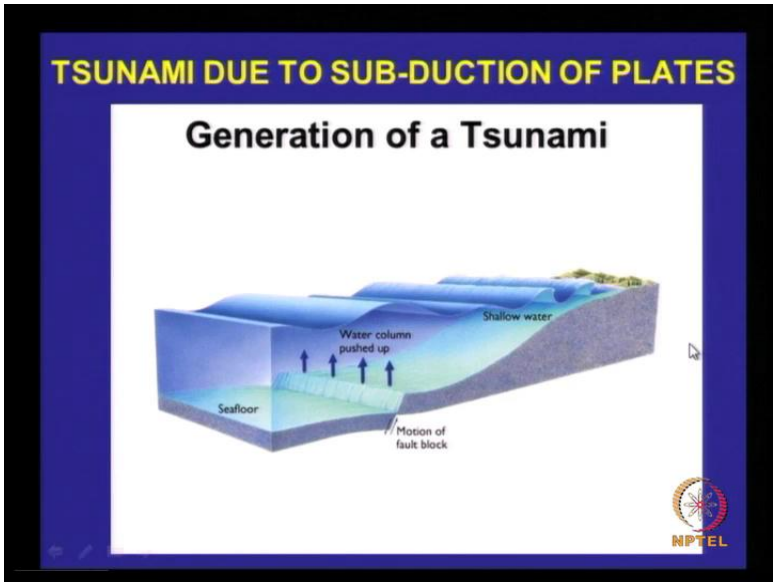

So, this two animations show you how this tsunamis are generated, and tsunami due to seduction of plates, so this is where you have the seduction taking place one moving below the other. And then water call up pushing up, and then you have the shallow waters and the building up of wave and in the energy, and then the propagation of the tsunami into the mapped.

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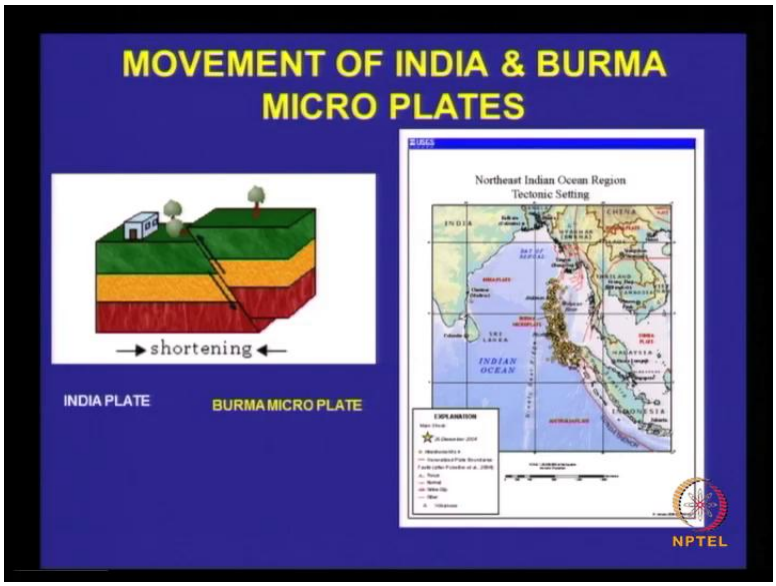

So, movement this is what happened in the case of this location, this was the area where it happened, so this is the Indian plate, this is the Indian plate and this is the Burma micro plate. And now this is trying to move as we have seen in the other animation what happened, so when it moves you have sudden release of, so once there is an earthquake like this there can be a of number of a numbers of shocks at very short intervals. And once a wave is, once a this kind of a incident happens you can have a tsunami in the morning, and again in the evening you can another wave, giant wave coming.

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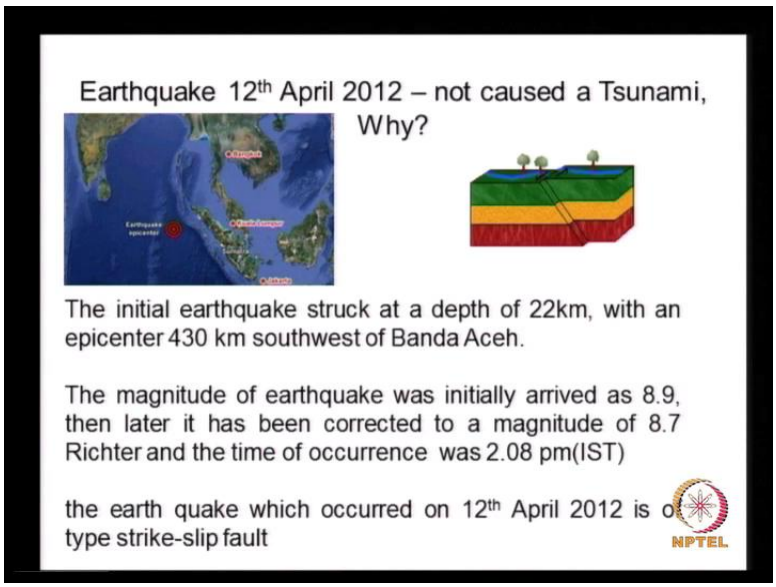

So, but this means the case 12th April, very recently you would have heard about the tsunami I mean the earthquake, so there also warning given that was on April 12th the initial and today is 15 April, today is 3 days back. The initial earthquake struck at a depth of 22 kilometer with an epicenter of 430 kilometer of Southwest of Banda Aceh, so Banda Aceh is the location where the 2004 tsunami also occurred.

So, the magnitude of the earthquake was initially arrived at 8.9, almost the same as that we had in 2004, then later it has been corrected to a magnitude of 8.7 whereas, in 2004 it was 9.3, later corrected. On the time of occurrence was at 230 IST, whereas 2004 it was in the morning, the earthquake which occurred on April is of type strike, so it is only a lateral movement.

So, lateral movement of this plate will not cause any earthquakes any tsunami, so there was observably no tsunami, and no fear, and no damage, there was an initial warning given and then taken away by evening. So, this explains why the April 12th tsunami, I mean earthquake did not cause any tsunami.

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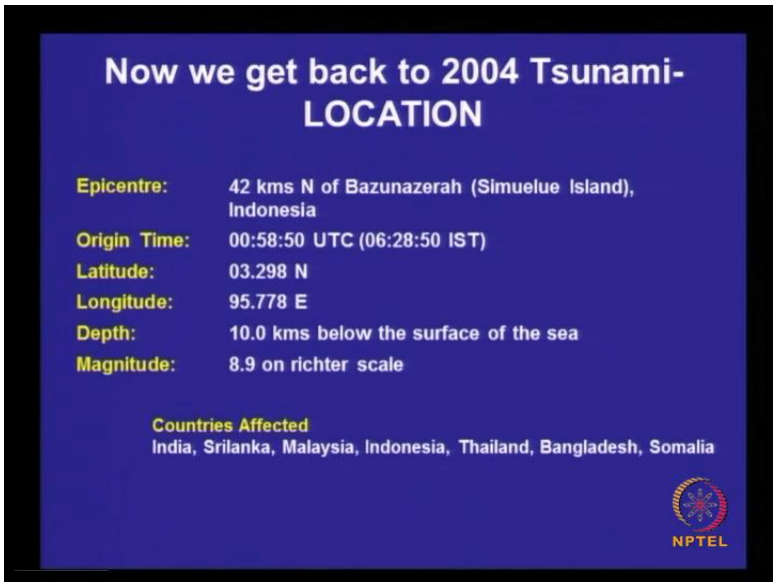

Now, we go back to 2004 tsunami, so it occurred the epicenter was 42 kilometers in Indonesia, and the time of arrival is time of occurrence is given there the latitude and longitude, and the depth 10 kilometers below the surface of the sea. Then you had the magnitude, but the water depth is 4 kilometers, then initially on the rector was 8.9 and

then the countries affected are India, Sri Lanka, Malaysia, Indonesia, Bangladesh, Somalia.

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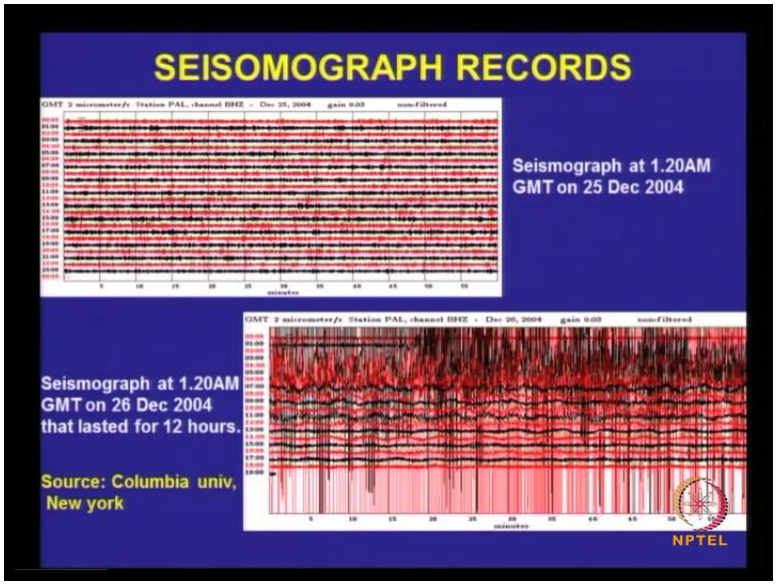

So, in the case of tsunami only postmortem is really possible, preparedness you can prepare yourself for the tsunami, but only what is gone drawn, but postmortem really helps. So, this is the seismograph taken at 1.20 AM on December 25 th, and this is the seismograph after the catastrophic has taken place, you look at the disturbance taken place though the seismograph.

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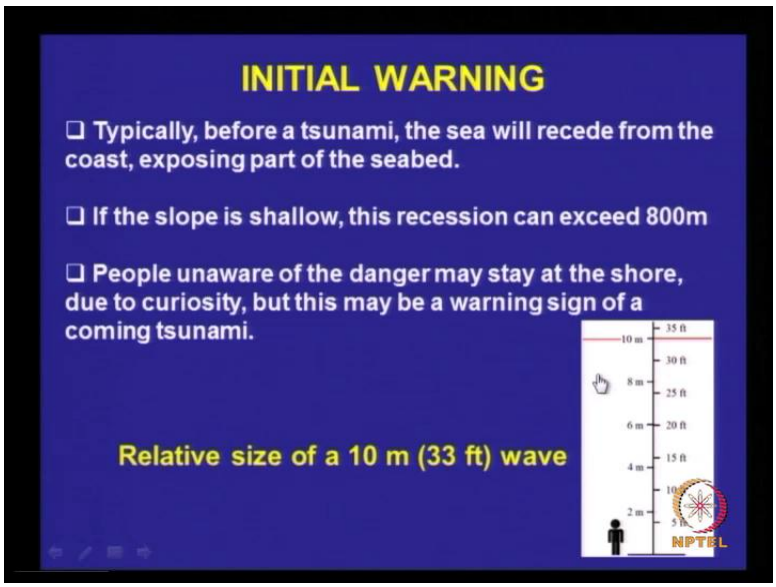

Initial warning, initial warning before a tsunami the sea will received from the coast exposing part of the sea bed. If the slope is shallow this recession can exceed 800 meters or even a kilometer, people unaware of the danger may stay at the shore due to curiosity, but this may be a warning sign of a coming tsunami, relative size of a human being with that of a tsunami. So, what happen during the tsunami is, many of the people being a Sunday they were near the beach, and when the water level receded that is when saw the water going into the ocean.

People thought because we have never being heard, we have never heard of tsunami for so many decades, suddenly you see the major portion of the sea bed getting exposed. So, out of curiosity people went on to the sea bed, just looked at the fish catch and other things, and then not realizing that that is going to be their tragic end, and many people lost the life, because due to that.

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So, initial warning, this is how it looks the retrieving of the water level and then you see the approach of the giant waves, you can have a two or three in series attacking the coast, not leaving much of time for you to escape.

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So, this as I said postmortem is very useful, so shore line receding in Sri Lanka during the, so you see just a coastal areas like Sri Lanka as seen in this satellite, now almost no warning of approaching tsunami, it was looking like a normal stuff. But, prior to the tsunami you see what happened, greater portion of the sea beach was exposed, and you see on the bottom most, tsunami has attach the coast.

And you can find out how much how much of distance how much distance is have gone inside the land, and what could be this one, that this things, this how height has gone you need to verify with the local signature studies. You need to do the survey and find out how much how much height tsunami you had at different locations.

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So, this is another picture at some other location, where it shows that the retrieving has taken place about, receiving has taken place about a 350 meters, this is showing the flooding areas.

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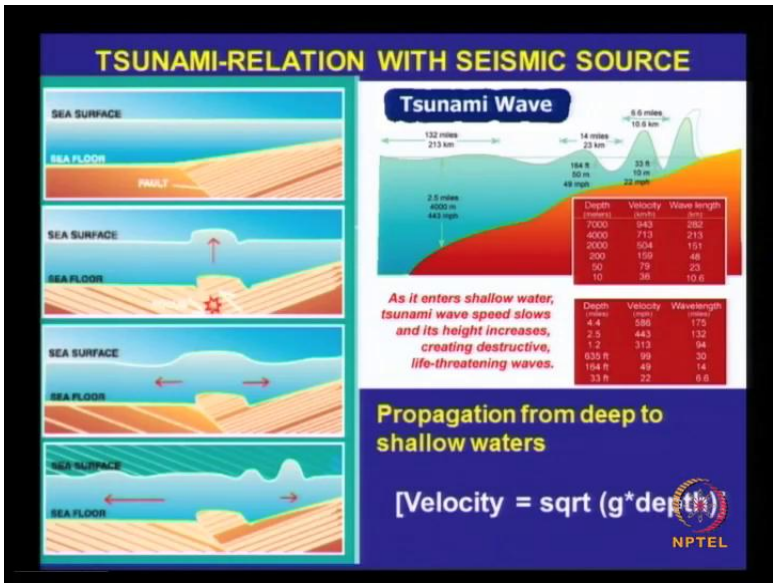

So, when you look at this tsunami wave, this was this has occurred in around a 4000 meters, at that point of time it was around 2.3 213 kilometer of wave length, and then this shows the reduction in the wave length as it propagates towards the coast. And where in the height is also shown here, and along with the, so these are the heights, these

are the depths the velocities are shown here velocities are shown here and your wave length are given here. So, this gives you an impression concerning the speed, wave length, depth, etcetera, and how it behaves in the deep waters, as well as in the shallow waters.

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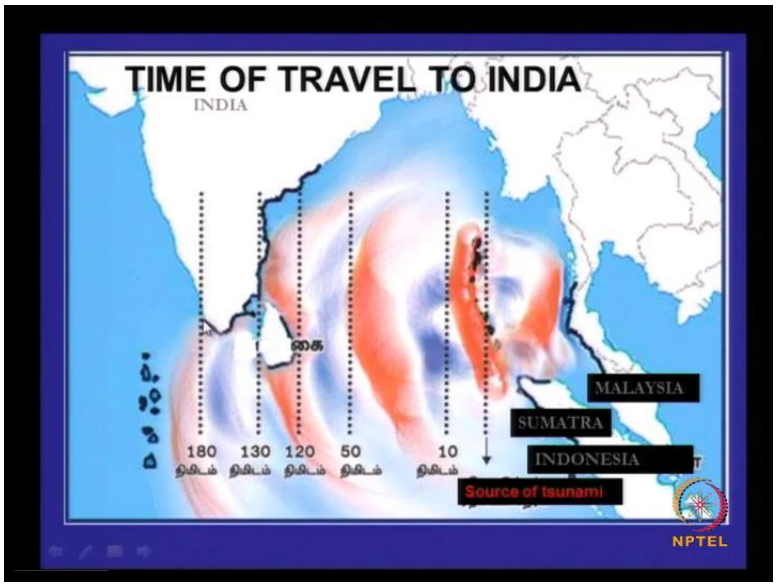

So, tsunami travel it has taken about 2 hours to reach Kolkata to Kerala, so for example, it reaches Chennai the West coast East coast of India about there is 16 minutes earlier about a 15 minutes earlier, but we it was it took not more than 10 minutes, when you compare from this location of Sri Lanka and Chennai just 10 minutes. But, we had something like 50 minutes, but we did not really know that it is going to have, it is affect along the India, Kerala coast, but now we know why it has affected the Kerala coast also we are very clear about that.

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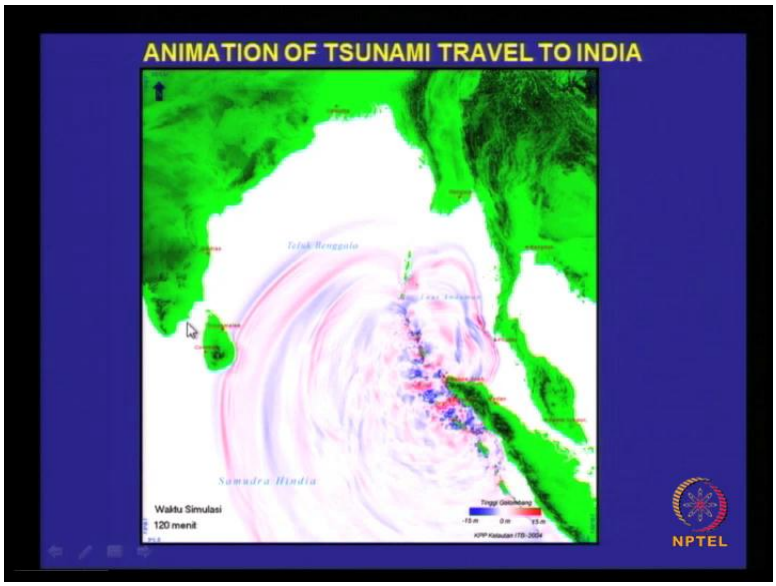

See for example, this was the first animation that was available on the net prepared by the NOAA NOAA, so you see that at this particular location, once it hits Sri Lanka you have the diffraction of waves taking place and it goes, and this is mainly, because of the diffraction. This is the area which has not affected at all, because it is under the shelter of Sri Lanka, the major area that was effected is all the way from here to here, the South all this area, and you did have some problems along the Andra coast also; but not much, but this area was very badly affected.

So, we had at that point of time we had a lot of discussion with a, particularly by a team from university of, Oregon state university from US, as well as the another university Seoul one professor Choe was there, and he is a specialist in tsunami indication measures. So, we had a group joining together, and we have done a lot of signature studies, immediately after the tsunami to find out how much distance it has gone, how high it has gone, etcetera. And this paper is available in the journal of water waves, Ocean engineering division of ASCE, so if you are interested, you can just have a look at it.

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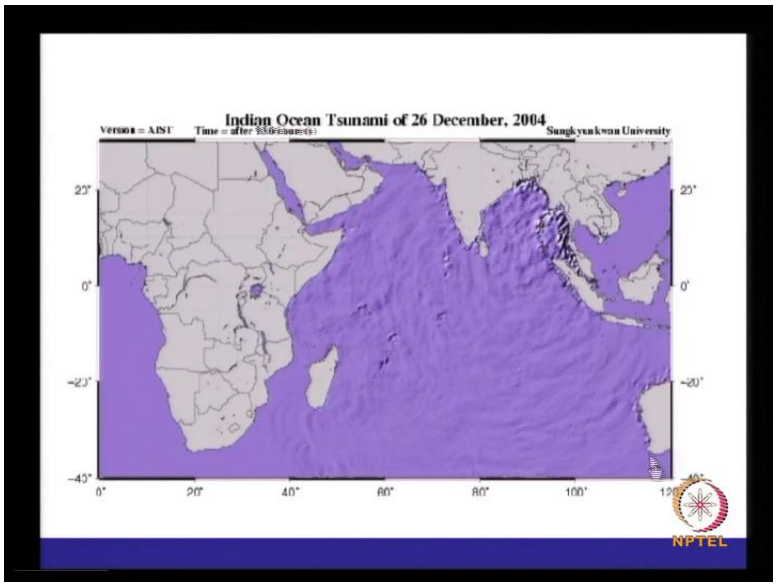

So, this was the this was the animation given by professor Choe, from Sun Ke (()) university of Korea, where in it this shows how what are all the countries that were affected. So, this tsunami was as travelled even to Australia, Madagascar, so it did have some affected all over the entire basin was really disturbed, I will stop.