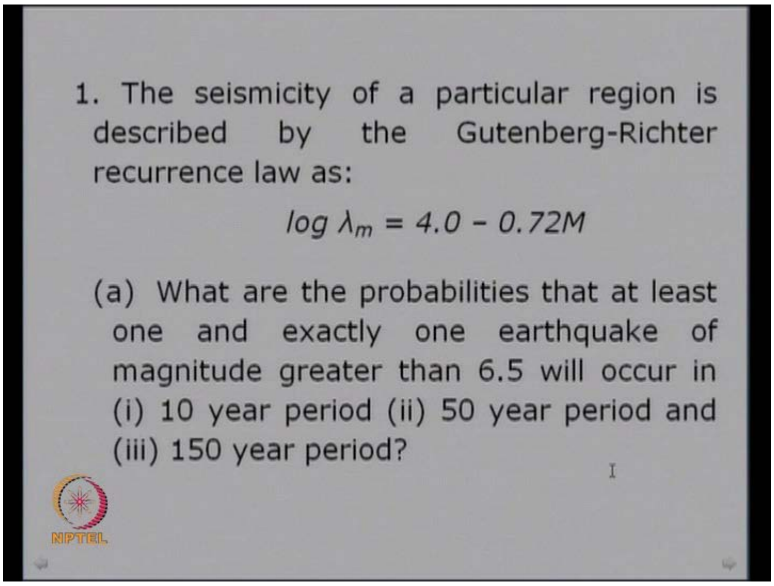
Geotechnical Earthquack Engineering
Prof. Deepankar Choudhury
Department of Civil Engineering
Indian Institute of Technology, Bombay

Module – 9
Lecture - 42
Quiz

Now, today for our NPTEL video course on geotechnical earthquake engineering, let us have a quiz for this course. So, as you can see here, department of civil engineering, Indian Institute of Technology, Bombay, geotechnical earthquake engineering is our course name. We are conducting a quiz today, full marks for this quiz is can be said as 100 and the duration will be one hour, and you need to answer all the questions given in this quiz, there are four questions altogether. You may assume reasonable data if it is required, most of the data are already given, but if you feel that you still need for some more data you can assume it.

Now, for this quiz, it is necessary that you first go through the course content presented for this NPTEL video course on geotechnical earthquake engineering, and mainly the modules and the subtopics covering the probabilistic seismic hazard analysis, then dynamic soil properties and then the ground response analysis and transfer function, those things. So, after completing those particular modules, etcetera, you will be able to answer this quiz, including the basic seismology and seismic waves concept.

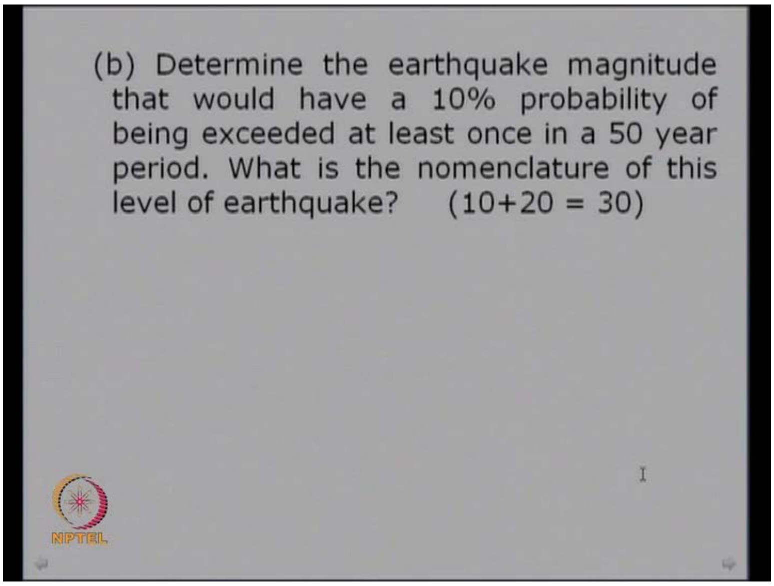
(Refer Slide Time: 02:11)



So, now let us see the first question of this quiz. In the first question it is asked the seismicity of a particular region is described by the Gutenberg-Richter recurrence law, which is given as this equation let us say, log of lambda m equals to 4 minus 0.72M. So, we have already seen earlier in the course content that typical Gutenberg-Richter recurrence law will be represented by this type of equation using these coefficients a and b. So, this is nothing but Gutenberg-Richter equation for a particular region; let us say, the equation came out to be like this.

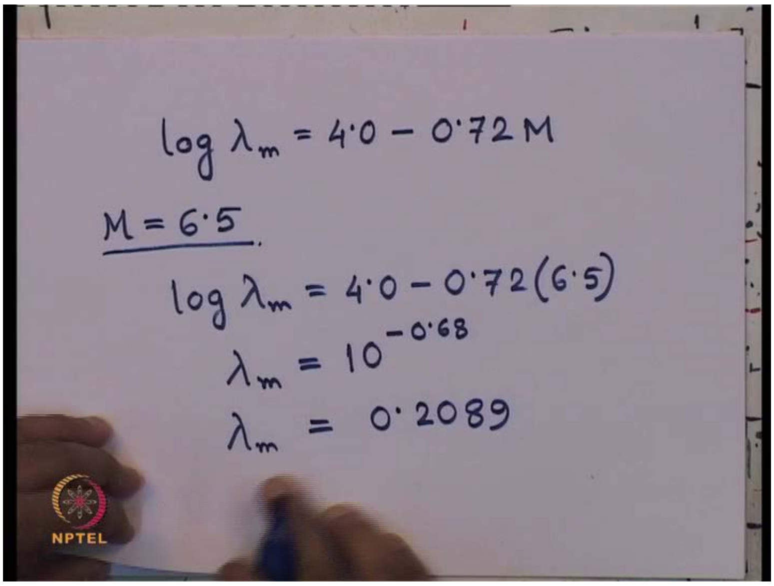
So, what are the questions asked based on this? It is asked, that what are the probabilities, that at least one, that is one question, and exactly one earthquake of magnitude greater than 6.5M, greater than 6.5 will occur in. There are three time scales given, 10 year period, 50 year period and 150 year period. This is the part a of this question.

(Refer Slide Time: 03:32)



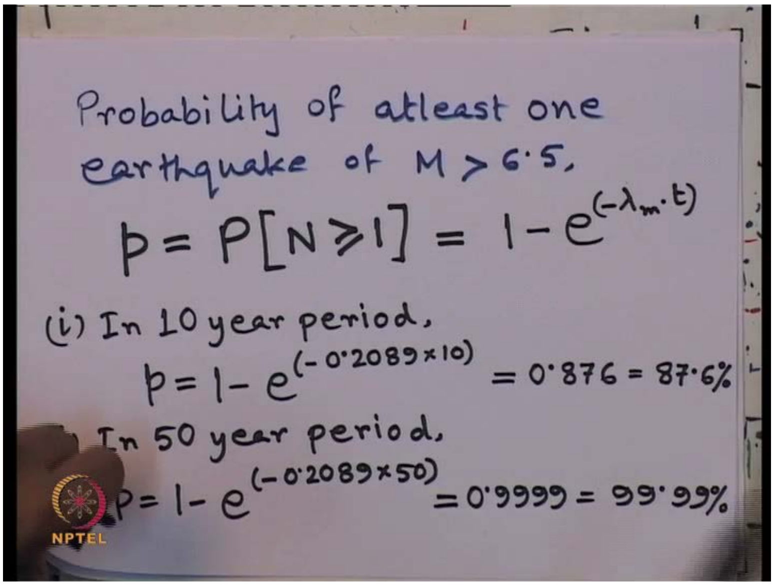
And the next part, part b of this question asks, determine the earthquake magnitude, that would have a 10 percent probability of being exceeded at least once in a 50 year period And then it is asked, what is the nomenclature of this level of earthquake, that is, when 10 percent of probability being exceeded at least 1 in 50 year period. The total marks for this entire question is 30 marks, the subdivision is like this, 20 marks for this portion and 10 marks for the next portion. So, now let us see how the solution we can make.

(Refer Slide Time: 04:27)



So, the Gutenberg-Richter recurrence law is given as log of lambda m equals to 4 minus 0.72 M, that equation is given to us. Now, what is the magnitude value given? M equals to 6.5, that is we have to find out the lambda M value for magnitude of 6.5, right. So, if we put in this equation what you will get, 4 minus 0.72 times 6.5 which will give us the lambda m value as 10 to the power minus 0.68. Hence, lambda m will be equals to 0.2089. So, once you obtain this value of lambda m, later on we need to use this value for computing the probabilities.

(Refer Slide Time: 05:42)

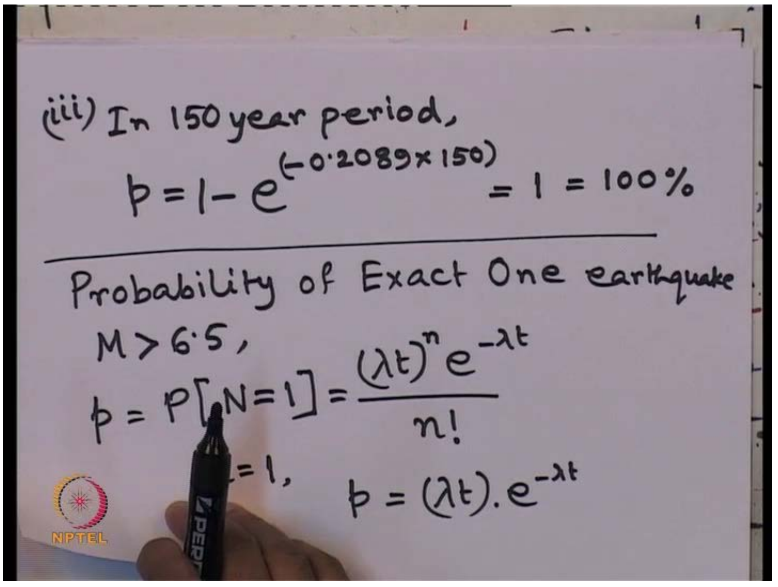


So, next one is mentioned as, that probability of atleast one earthquake of M greater than 6.5, so what will be that? So, in this case, as we all know, earlier we have made the derivation, so this P is nothing but P of number of events greater than equal to 1 is nothing but atleast 1. So far that we, now using Poisson distribution equation is 1 minus e to the power minus lambda m times t, that is the expression already we have learnt in our course.

So, what are the three different time scales given? First one is, in 10 year period what will be the value of this probability? 1 minus e to the power minus of, what is the value of lambda m, just now we calculated, that is, 0.2089 and t is 10 years. So, simplifying this, calculating this how much we are getting? We are getting 0.876, which is nothing but equals to 87.6 percent, in percentage if we express this probability. So, in 10 year period there is 87.6 percent chance in that locality where atleast one earthquake of magnitude greater 6.5 will occur, clear.

Next one is in 50 year period. In the same way you can use e to the power minus 0.2089 into 50. On simplification you will get 0.9999, so it is nothing but 99.99 percent. So, the probability of occurring this magnitude greater than 6.5 atleast one in this region in 50 year period is almost 100 percent, close to 100 percent, right. And then there is no need to calculate for 150 year because in 50 year itself we got it almost 100 percent atleast, it will occur once, but still for the sake of completeness let us do that.

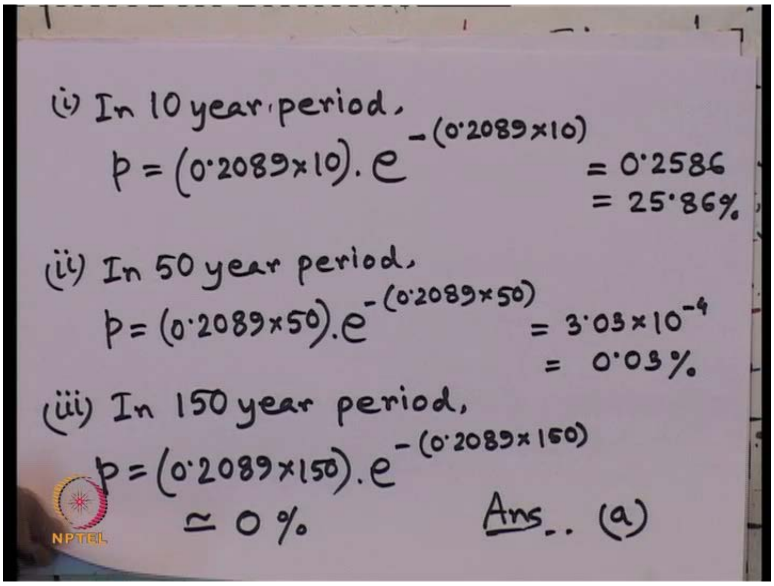
(Refer Slide Time: 09:13)



So, in 150 year period this P will be 1 minus e to the power minus of 0.2089 times, t is 150, that is one, that means, 100 percent. That means, it will always occur in 150 year time span one, atleast one earthquake greater than 6.5 magnitude in that locality where this Gutenberg-Richter equation is given over there.

Next part is the probability of exact one earthquake. So, earlier one was atleast one and in this case we are telling exact one, only one earthquake will occur, which will have magnitude greater than 6.5 in that region. So, in this case, the probability equation for an event N equals to 1, that will be if we use that same Poisson distribution as we know. What is the lambda t to the power n? e to the power minus lambda t by n factorial. Now, using n equals to 1 what you will get? So, P you will get lambda t times e to the power minus lamda t, that is the expression, clear. So, if now we put the value of lambda here, lambda m already we have calculated for this zone and for different period t if we put, we will get the corresponding probability of exact one earthquake of magnitude greater than 6.5 in that region. What we are getting in this case let us see.

(Refer Slide Time: 11:39)



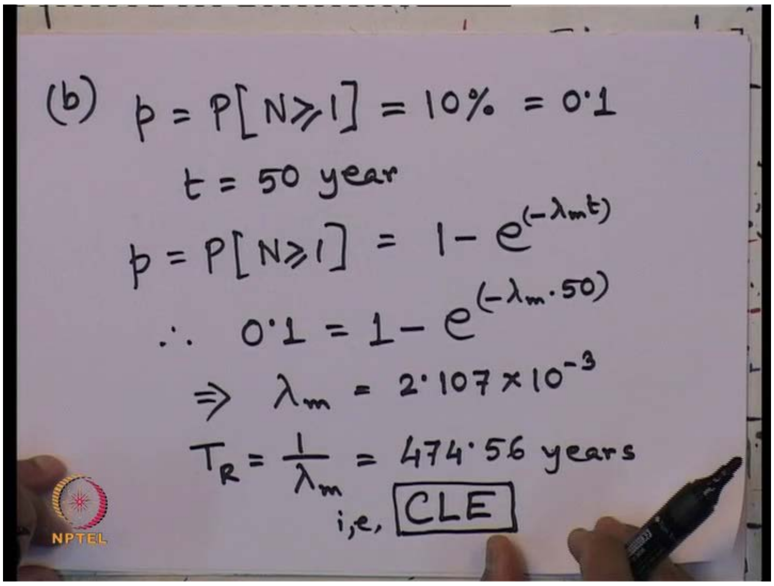
So, the first one in 10 year period, the value of P will be lambda value is 0.2089 and t is 10 times e to the power minus of lambda t, 0.2089 into 10, that gives us the value of 0.2586, which in percent we can write 25.86 percent. That means, in 10 year period, in that locality, one earthquake magnitude of 6.5 will occur with a probability of 25.86 percent.

Next one, in 50 year period, in the same way we can calculate, 0.2089 is the lambda value, t is 50, e to the power minus 0.2089 into 50, that gives us the value of 3.03 into 10 to the power minus 4, which gives us 0.03 percent. That means, exactly one earthquake in 50 year period occurring of 6.5 is coming this one. And that, what does it mean? In inverse way it is correct for the other, that there will be not exact one, there will be more than that, is it clear?

So, in 150 year period, let us see what will be the value of this? P will be, lambda is again, this t is this, e to the power minus 0.2089 into 150, that comes out to be almost close to 0 percent. That means, there is no chance of having exactly one earthquake in that region of magnitude M greater than 6.5 over a period of 150 years. There will be more than that, never it will be more than 1, clear. So, with this we have completed the answer of part a, which carries 20 marks. Now, let us move here.

Let us look at the slide now, we will move to next part, part b, which says, determine the earthquake magnitude, that would have a 10 percent probability of being exceeded at least once in a 50 year period. So, this is a kind of reverse problem of part a. Can you see earlier magnitude was given 6.5, and it was asked that what will be the probability, now probability is given. So, this is more true. When we are going to do for any design, that is upto which level of magnitude you are going to design for your structure, as I have discussed earlier.

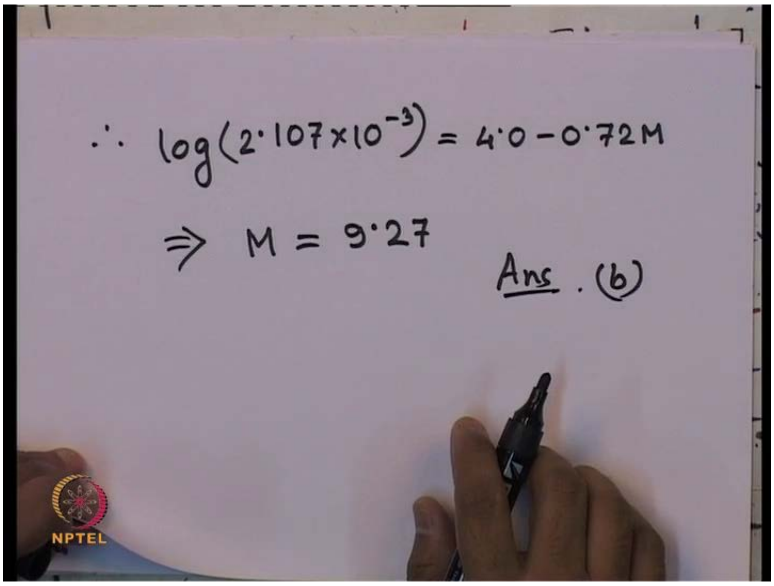
(Refer Slide Time: 15:48)



So, the part b of this first question what will be the solution? So, in this case this P is given for an event, that atleast 1 is 10 percent, that probability is given to us, which is 0.1 and t is given as 50 year time span. Now, the expression of p for this condition of atleast one event, we already know this from the Poisson's distribution, it is given by this expression, that is known to us. So, in this case this value is given, therefore here it is 0.1 equals to 1 minus e to the power minus lambda m times 50. So, we need to find out this lambda m for from here because t is 50 probability is 10 percent. Fine, so which gives us on simplification the value of lambda m comes out to be 2.107 into 10 to the power minus 3. So, what will be the value of return period? Return period T R will be equals to 1 by lambda m, so inverse of this is coming out to be 474.56, that many years.

Now, it is asked, you can see the question here, what is the nomenclature of this level of earthquake, that is, 10 percent of probability in 50 years time exceeded atleast 1. So, that we got in the theory also, we learnt it is about 475 years of return period, right, that same thing we got here as well, so that 475 years of return of earthquake. What we say the classification will be? So, here the answer will be, it is classified as contingency level earthquake. So, this is, that is, its classification will be CLE, that will be one of the answer of this part b, that is, the nomenclature of this earthquake is contingency level earthquake where return period is 475 years. And what is the magnitude?

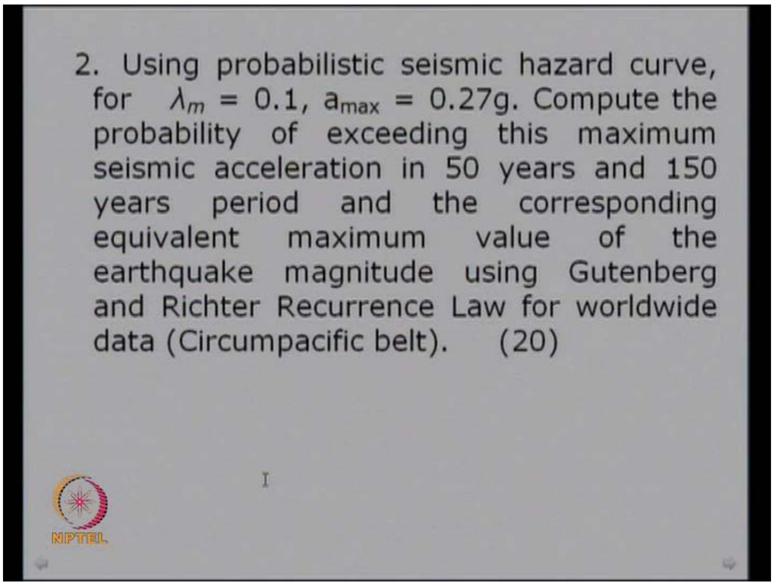
(Refer Slide Time: 18:44)



So, therefore, the magnitude when you are calculating for this region you have to go back to, now let us see here, we have to go back to that region, what is this? Gutenberg-Richter recurrence law, because in this case lambda m you have obtained, you need to find out for which magnitude it is correct.

So, log of lambda m, how much we have calculated? It is 2.107 into 10 to the power minus 3 is our lambda m value, equals to 4 minus 0.72M, fine. So, if you simplify this what we are getting? The M value works out to be 9.27, fine. So, that is what it shows, that atleast one earthquake of magnitude 9.27 will occur with 10 percent of probability in 50 years period and return period of 475 year in that locality, fine. So, this is the magnitude. So, that is the answer of part b for this first question, which carries total 10 marks. So, in total, the question number 1 carries 30 marks.

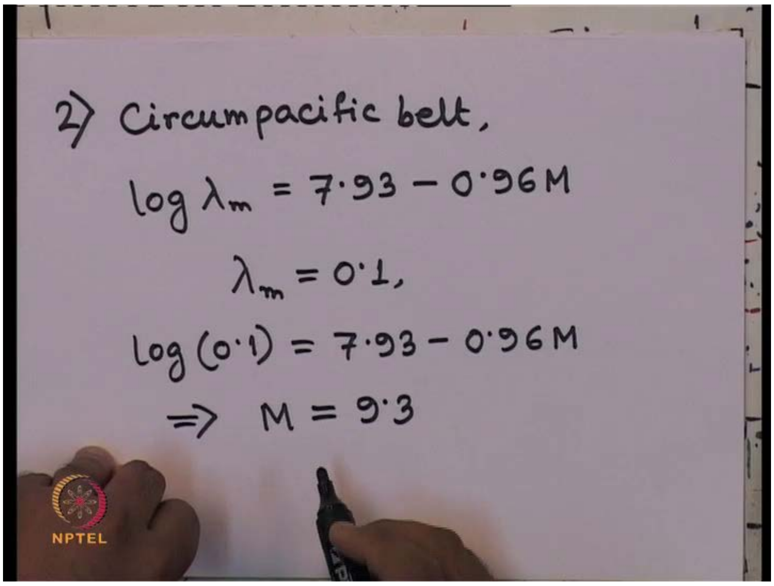
(Refer Slide Time: 20:23)



So, now, let us move to second problem, let us read this problem first. It is said here, that using probabilistic seismic hazard curve, psha curve, for a lambda m value of 0.1, a max value is obtained as 0.27g. So, these two are here, are input data for a particular probabilistic seismic hazard curve. Suppose if you have arrived and obtained some probabilistic seismic curve for a region from your results of that psha curve you got this value, let us say lambda m equals to 0.1 and a max value, maximum acceleration value is 0.27 g. So, how to make use of that curve for your design?

That is what it is mentioned here, that compute the probability of exceeding this maximum seismic acceleration in 50 years time and in 150 years time and the corresponding equivalent maximum value of the earthquake magnitude using Gutenberg-Richter recurrence law for the worldwide data using for circumpacific belt. Already we know about this recurrence law for, which was proposed by Gutenberg-Richter in circumpacific belt. So, the total marks for this question carries 20 marks. Let us see how to solve this problem.

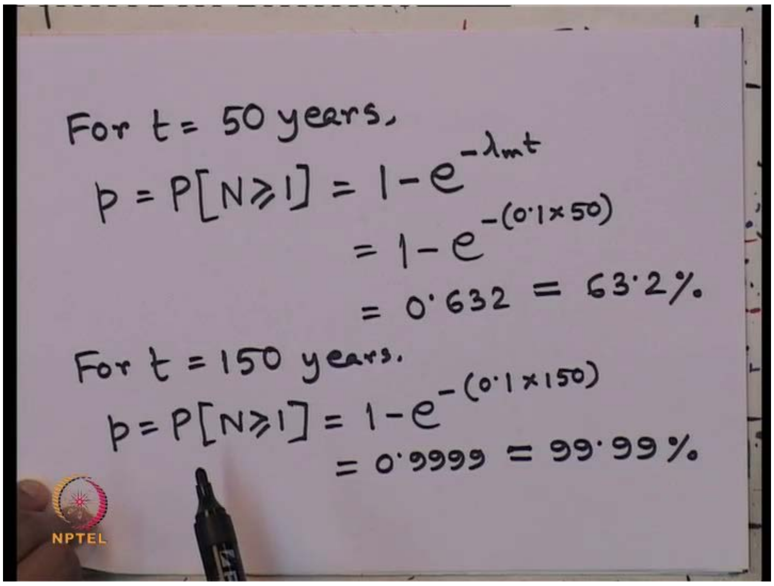
(Refer Slide Time: 22:07)



So, first let us write down what is the Gutenberg-Richter equation for circumpacific belt. So, for problem number 2 for circumpacific belt using worldwide data the equation is given by log of lambda m equals to 7.93 minus 0.96 M, this we have discussed in our theory class already. So, in our problem it is given, that for your region, from psha curve you got lambda m value of 0.1, that is given, so what will be the m value, that we need to obtain? So, log of 0.1 equals to 7.93 minus 0.96 of M. By solving this we get, M value comes out to be 9.3, that is the first part of the answer.

Now, with this magnitude next question is, in 50 years period and in 150 years period what is the probability of exceeding this value? Let us look at here, that what is the probability of exceeding this maximum magnitude in 50 years and 150 years period. Corresponding to this equivalent maximum value of earthquake magnitude, this is the corresponding equivalent value of earthquake magnitude of what we have calculated in m equals to 9.3, fine.

(Refer Slide Time: 23:51)

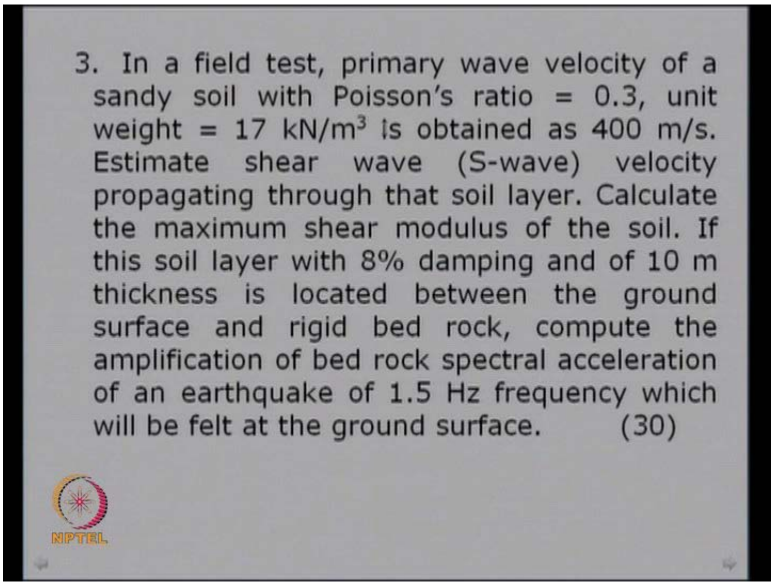


Now next part is for t equals to 50 years. In the similar way, as we have solved for problem number 1, that is, at least one event will occur, the equation using Poisson's distribution is given by this. We all know, here lambda m is already given to us, 0.1 and t, it is 50 years, so how much it is coming? 0.632, which is nothing but 63.2 percent, whereas for t equals to 150 years it will be number of events greater than equal to 1, will give us 1 minus e to the power minus of 0.1 into 150. On simplification we get 0.9999, which is nothing but 99.99 percent or you can say 100 percent even. That is, at least one magnitude of that 9.3 will occur in 150 years in that region where this circumpacific belt equation of Gutenberg-Richter is valid, but remember this is unbounded Gutenberg-Richter equation.

So, that is why this magnitude of 9.3, which is very much on the higher side, should not be directly taken or blindly taken. It should be modified with respect to the upper bound of the Gutenberg-Richter or bounded Gutenberg-Richter analysis, which is not done for this circumpacific belt.

So, this is the extra observation, like when we are solving any problem it is not for only academic purpose or for the sake of problem solving, we should infer the results from out of it, how to make use of it in practice. So, in practice if somebody uses this value of 9.3 it is not justified. You should use the bounded Gutenberg-Richter equation in this case, as we have seen over here, fine. So, that is the answer for this problem number 2, which carries 20 marks.

(Refer Slide Time: 26:39)

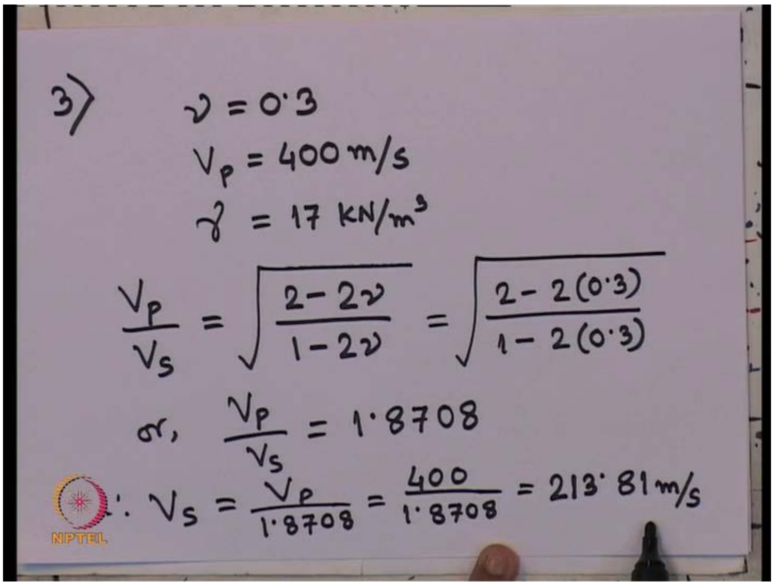


Let us move to next problem, problem number 3. So, for problem 3 let us look here, what is asked. In a field test, primary wave velocity of a sandy soil with Poisson's ratio value of 0.3 and unit weight of 17 kilo-Newton per meter cube is obtained as 400 meter per second, which is quite common, like you can do any kind of field test, like seismic cross-hole, seismic downhole, seismic uphole, SSW, MSW, all this test. Suppose if you know, that it is a sandy soil with this basic parameters like Poisson's ratio value is 0.3 and unit weight is 17 kilo-Newton per meter cube and P wave has been obtained, remember primary wave or P wave has been obtained, which is 400 meter per second.

Now, what is asked, estimate the shear wave, that is, S wave velocity propogating through that soil layer. That means nothing but we have to convert this primary wave velocity to shear wave velocity using the relationship between them, using the material property. As we know primary wave and shear wave velocity, they are related through the Poisson's ratio value, so that we have to use. Calculate the maximum shear modulus of the soil. Once you know the shear wave velocity, obviously we can calculate the shear modulus, that is first part of the problem.

Next part, it says, if this soil layer with 8 percent damping and of 10 meter thickness is located between the ground surface and rigid bedrock, compute the amplification of bedrock spectral acceleration of an earthquake of 1.5 hertz frequency, which will be felt at the ground surface. So, total marks carries for this question is 30.

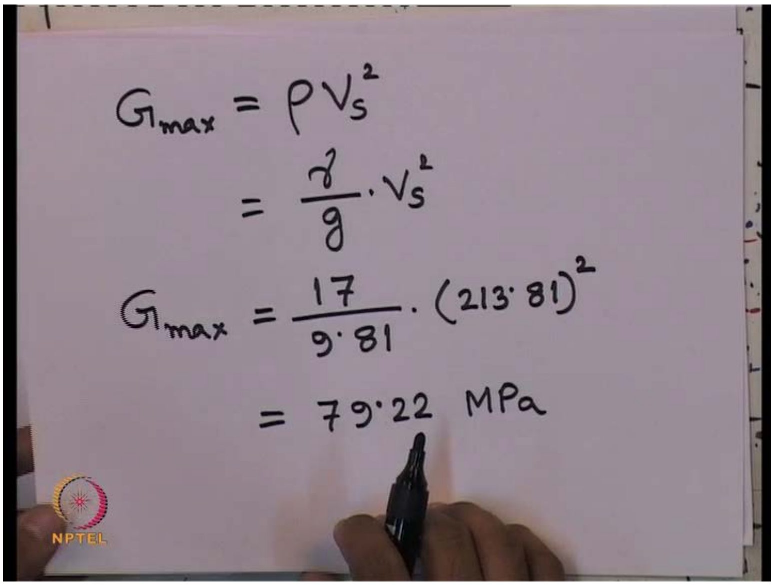
(Refer Slide Time: 28:50)



So, let us see how to solve this problem. So, problem number 3, the solution will be like this. So, Poisson's ratio is given as 0.3, V p, primary wave velocity is measured as 400 meter per second, gamma unit weight is given as 17 kilo-Newton per meter cube. So, what is the relation between V p by V s? V p by V s, that is, primary wave velocity to shear wave velocity ratio, we know it is given by 2 minus 2 mu by 1 minus 2 mu. That means, if you put the value of Poisson's ratio here, which is given to us, you will get for this soil what is the ratio of V p by V s. So, V p by V s is coming out to be 1.8708.

Now, V p is given to us, so we can automatically obtain V s, should be equal to V p by 1.8708, which is 400 by 1.8708, which gives us the value as 213.81 meter per second. This unit is important. As we know shear wave velocity should be less than primary wave velocity, we are getting that and it is related through the Poisson's ratio of the material. So, this is the shear wave velocity of that soil, fine. So, that is the answer of first part of this question 3.

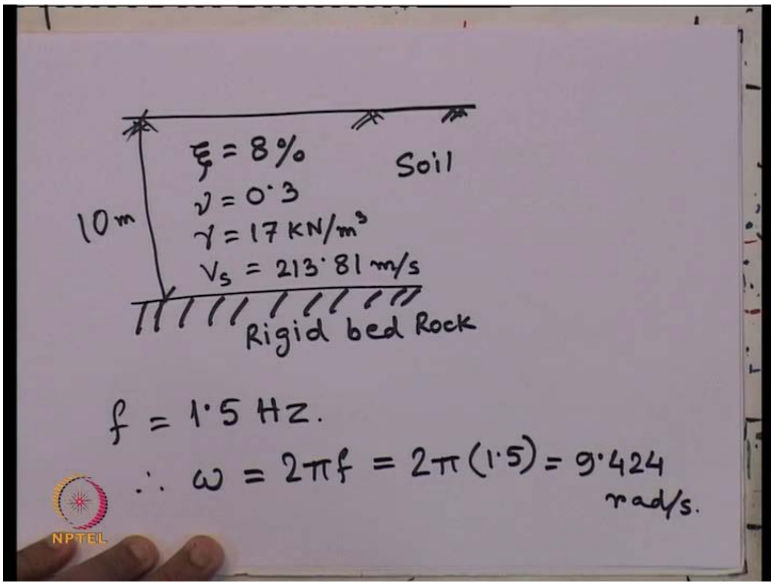
(Refer Slide Time: 30:49)



Now, the next part is asked, what is the G max value, that is, maximum shear modulus G max is given by the equation rho V s square, rho is the density of the material. So, we can write down it, gamma by G into V s square. Therefore, what value of G max we will get? If you calculate and cross check this value, gamma is given as 17 kilo-Newton per meter cube, G is given, as we know, acceleration due to gravity 9.81 and V s, how much we obtained, 213.81 meter per second square, so this much square. So, by solving we are getting it as 79.22 mpa, megaPascal. So, that is the value of G max, which is the answer of second part of this question 3.

Now, let us come to this part, which is related to the amplification, soil amplification using the transfer function.

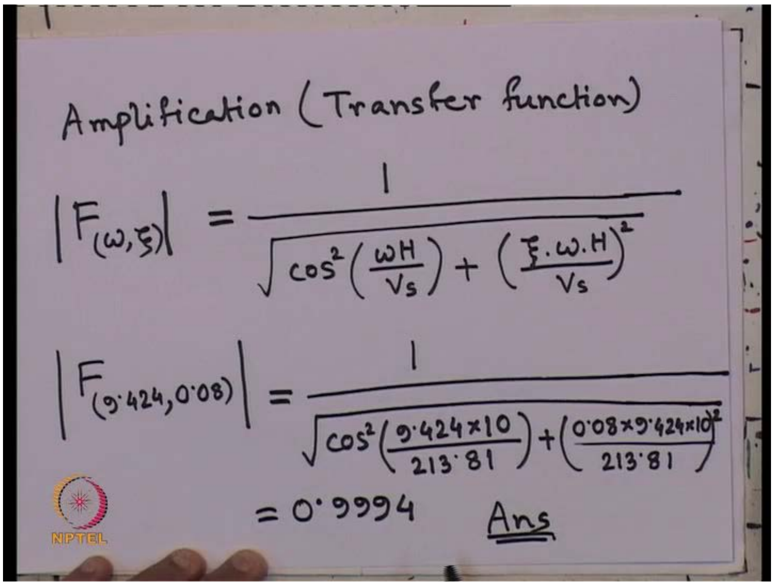
(Refer Slide Time: 32:18)



So, it says, if the soil layer with 8 percent damping and of 10 meter thickness, so let us first draw the situation. This is the ground surface, we have a soil of 10 meter thick and what is the value of this damping ratio of this layer, is 8 percent; for this soil layer value of this damping ratio is 8 percent, that is given. Thickness of that layer is this and here, it is given as below 10 meter depth, it is rigid bedrock, so rigid bedrock. And this is a soil layer, which has the other parameters already we have obtained or it is given, like Poisson's ratio is 0.3, gamma value is 17 kilo-Newton per meter cube and V s value we have calculated, that is, 213.81 meter per second.

So, knowing these things what we can write? It is mentioned what is the frequency of earthquake excitation, that is 1.5 Hertz, can you see here? So, if frequency of earthquake is given as 1.5 Hertz, which is very common range of frequency of earthquake as I have already discussed, if we convert it to circular frequency of earthquake, omega will be 2 pie f. So, 2 pie 1.5 will be equals to 9.424 radian per second, fine, that is the omega of this.

(Refer Slide Time: 34:38)

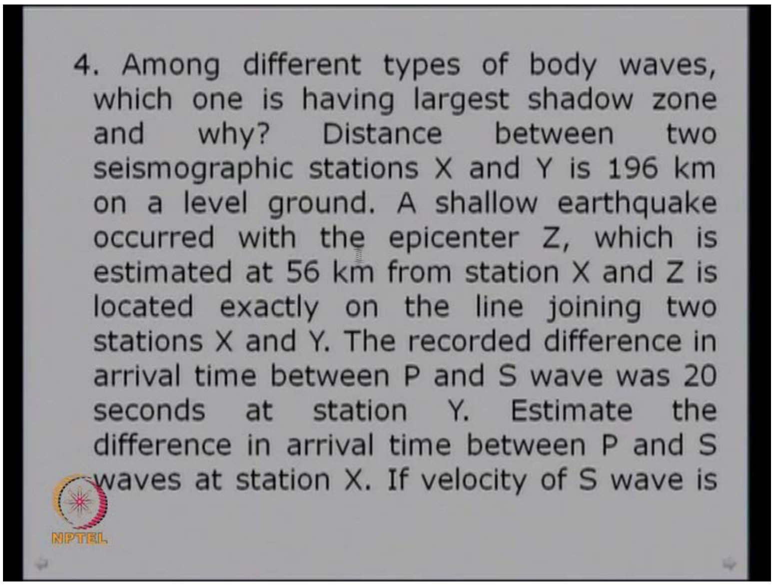


Now, what is this transfer function? So, amplification, amplification, which is nothing but that transfer function. If we refer to our theory class of this associated problem, this we need to find out, if at some omega and some value of damping ratio eta mod of that, we need to find out what was the equation given for this condition, that is, a soil layer and below that there is the condition we should use. This is the uniform soil layer followed by a rigid bedrock, that condition and it is a damped soil, so that equation we should use.

So, F transfer function is a function of frequency of earthquake excitation and the damping ratio of the material, it is given as 1 by root over cosine square omega H by V s plus eta omega H by V s whole square. Now, what is H? As we know, in this case H is nothing but this thickness of the soil layer, fine. So, knowing this what we can find out in our case? F of omega is, in our case it is 9.424 and this value of damping ratio is 8 percent means, 0.08, right, 8 percent. So far that the transfer function will be 1 by root over cosine square, you can check this, 9.424 into H is 10, this V s value is 213.81 plus this damping ratio is 0.08, omega is 9.424 and H is 10 by, V s is 213.81, that whole square, this is under root and that is the denominator. Now, if you simplify, what is this value gives us? 0.9994, what does it mean? This is the answer, you got the answer, fine, but what is the practical use of it, let me discuss now the practicality of this value.

Let us look at it what it says, that compute the amplification of this bedrock spectral acceleration of an earthquake, which is coming with frequency of 1.5 Hertz, what will be felt at the ground surface? So, in this case we found for this soil layer with this given engineering properties and dynamic soil properties, etcetera, there is hardly any amplification of this earthquake frequency of 1.5. Remember, this is only true for all this given values of omega equals to or frequency of 1.5 Hertz only. If we are talking about some other frequency, say low frequency earthquake, high frequency earthquake, we will get different values of amplification. So, this is for a particular frequency of earthquake we are getting it, that almost no amplification. Transfer function 1 means, from bedrock to ground surface there is no amplification of this earthquake motion. So, with this the problem number 3 is complete, which carries 30 marks.

(Refer Slide Time: 39:24)



Now, let us move to the next problem, that is, problem number 4 for this quiz, which is the last problem of this quiz. It says, among different types of body waves, which one is having largest shadow zone and why? So, what are the body waves?

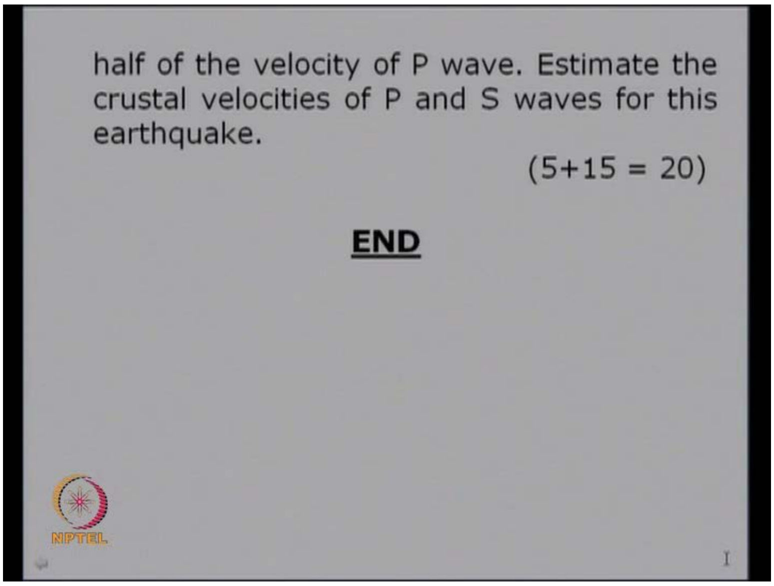
If we want to give the answer here directly instead of writing, body waves are nothing but two types, as we have already discussed in our theory. One is, primary wave or P wave, another is shear wave or S wave. Now, among this two, which one is having largest shadow zone? Of course, the shear wave or S wave will have largest shadow zone, that is the answer of this first part, but it is asked why, so you need to explain it.

So, you have to mention, because the earth's interior is composed of crust followed by mantle followed by core and out of that inner core and outer core, outer core is a molten fluid material not a solid material and we know, that shear wave cannot travel through fluid media, it can only travel in solid media. So, whenever any earthquake occurs at any point of, in the earth, the waves get generated, yet it starts travelling and passing through all this different layers of earth's interior.

So, as soon as the shear wave comes in the boundary of this outer core and mantle, the speed or the velocity of that shear wave drops down to 0. That means, it cannot further get transferred to next layer, but P wave can transfer because P wave can travel in all media, that is, whether it is a solid media, whether it is a fluidic media. So, that is why, in molten outer core of earth P wave can travel, but S wave cannot travel. That is the reason why, the shadow zone is much longer for S wave. So, that reason has to be given for this question over here, which is asked here.

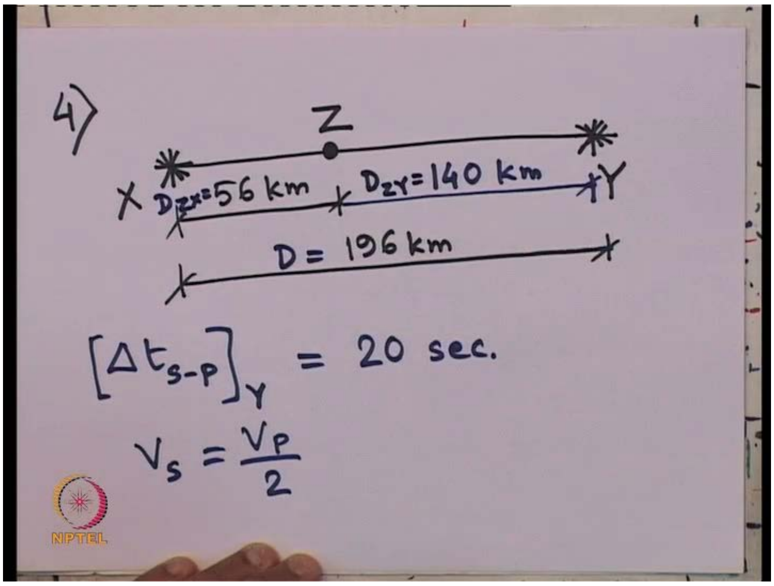
Now, next part is the numerical problem. It asked, distance between two seismographic stations X and Y is known, 196 kilometer on a level ground. This is the practical problem, which can be used for epicentral location and the velocity determination for crustal velocity of P and S wave, how, let us see. So, a shallow earthquake occurred with the epicenter location at Z. Another point, which is estimated at 56 kilometer from the station X and Z is located exactly on the line, which joins this two seismographic stations X and Y, fine. This recorded difference in arrival time between this P and S wave was 20 seconds at station Y. So, at station Y the arrival time difference between P wave and S wave is 20 second. What is asked, estimate the difference in arrival time between the P wave and S wave at station X. So, you can cross check that way, right by using this mathematical relation you can find out whether actually the recorded arrival time difference of P wave and S wave at X station is matching or not.

(Refer Slide Time: 43:39)



If the velocity of S wave is half of the velocity of P wave, that is what we considered, also crustal wave velocity of S wave is typically half of that P wave, estimate the crustal velocities of P wave and S wave for this earthquake. And total marks carries 5 plus 15, 20 marks. 5 already I have answered, 15 is for this numerical problem. So, now let us solve this problem.

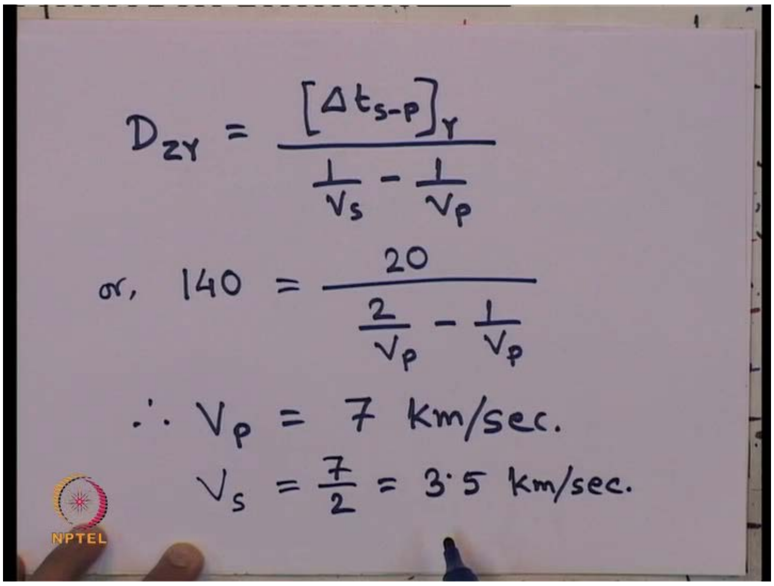
(Refer Slide Time: 44:14)



Now, the solution of this problem number 4, the numerical part I am solving is said on level ground, line joining these two stations. Let us say, these two are the stations, this is let us say station X, this is station Y, seismographic stations, where the seismograph are available and on this line it is said the location of epicenter is Z. What are the distances given is, this distance is given from X to Z as 56 kilometer and the distance between this two seismographic station is also given to us, it is 196 kilometer. So, automatically we can calculate this distance, that is distance between the epicenter and this Y station, which comes out to be 140 kilometer.

Now, what is given to us? The delta t between that S and P wave at station Y, it is 20 seconds, that is given. Another thing is given, that V s equals to V p by 2, that is, shear wave velocity is half of primary wave velocity. And what is the distance versus time and velocity relationship? This distance D is 196 kilometer, between, between X and Z is 56 kilometer. So, let us say, this is D of ZX; distance between Z and Y is, let us say D of ZY, which is 140 kilometer.

(Refer Slide Time: 46:32)

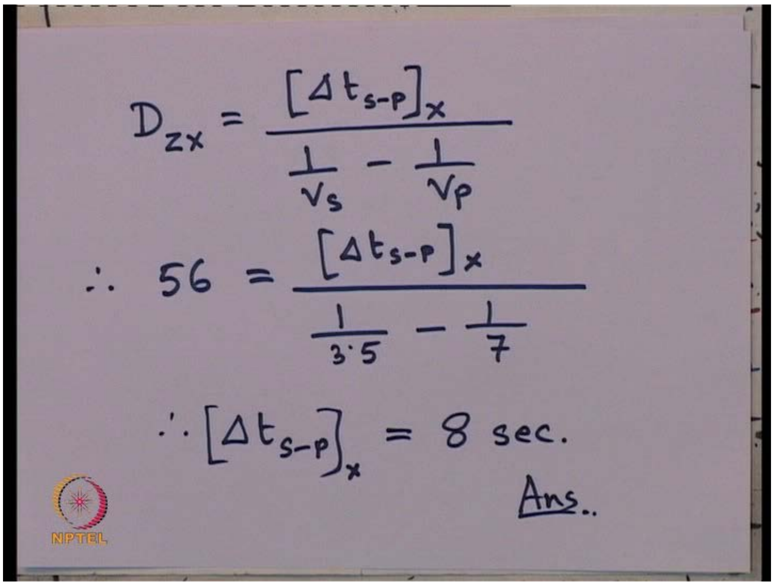


What we know? We know, that D of this ZY is nothing but delta t of S minus P at station Y, because we are considering from epicenter by 1 by V s minus 1 by V p. This equation already we have established in our theory class, that time difference between arrival of S and P wave divided by 1 by V s minus 1 by V p. So, using this we can write down what is the value of this 1 D ZY, it is 140 kilometer. What is this value of time? This is 20 second. Now, V s is nothing but V p by 2, so 2 by V p minus 1 by V p.

So, only unknown here is V p. So, therefore, V p, by solving this if you calculate this how much it is coming? It is coming out to be 7 kilometer per second. Remember about the unit, because this is in kilometer, this is in second, so kilometer per second, fine. So, if V p is 7 kilometer per second what should be the value of V s? This is 7 by 2, which is 3.5 kilometer per second and this is the crustal velocities we obtained.

Another thing it has been asked to find out, let us look at the question, estimate the time difference of arrival between P and S wave at the station X, that also we need to find out.

(Refer Slide Time: 48:36)



So, to do that the next part is, D of ZX is nothing but delta t S minus P at station X. So, this one we have to find out by 1 by V s minus 1 by V p. Therefore, how much is this D ZX? That is 56 kilometer, it is already given.

We need to find out this time of arrival between S wave and P wave at station X. V s value is already calculated, 3.5 kilometer per second; V p value is 7 kilometer per second. So, everything is known, only this one has to be find out. This is in kilometer, this is kilometer per second, so we will get this in second. Therefore, by solving this if you calculate it how much we are getting. So, delta t S minus P at station X is coming out to be 8 seconds. So, that is the answer of this question number 4, fine.

So, let us look here. So, we have estimated the crustal velocity P and S wave of this earthquake also the time interval between the S and P wave at X station X. So, with this we have come to the end of this quiz. So, by answering this total 100 marks in one hour, we can complete.