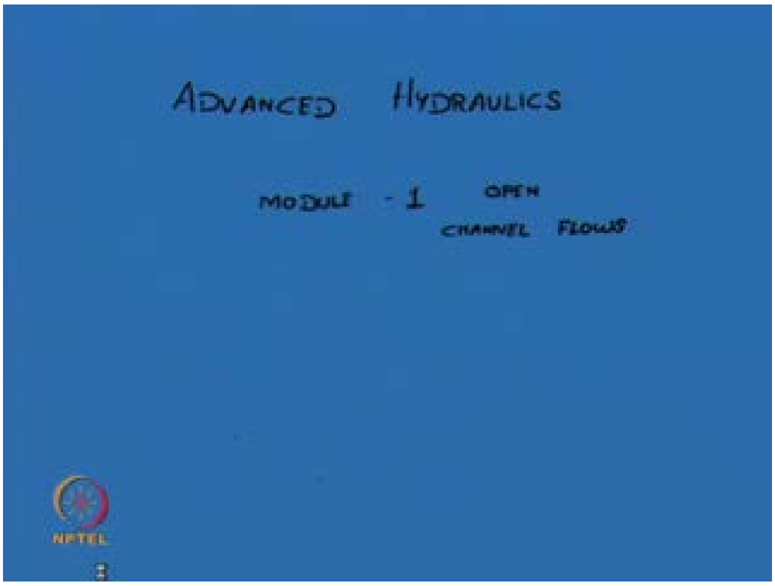
Advanced Hydraulics
Prof. Dr. Suresh A Kartha
Department of Civil Engineering
Indian Institute of Technology, Guwahati

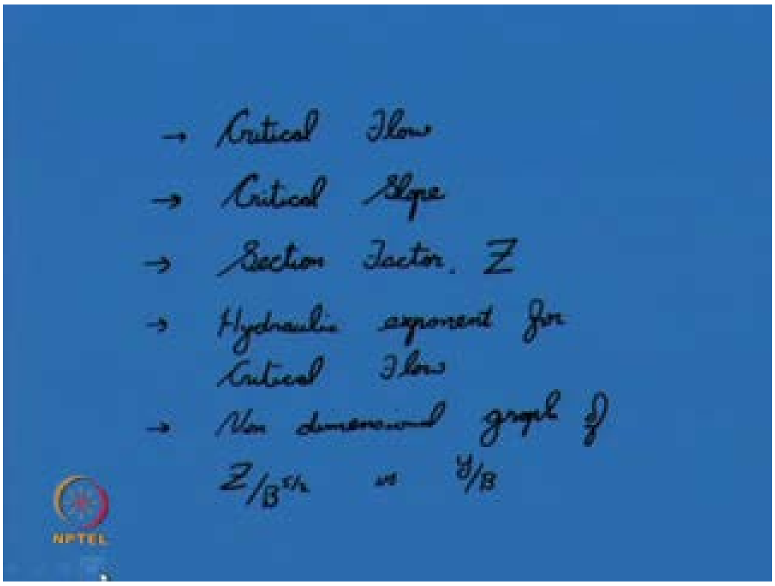
Module - 1
Open Channel Flow
Lecture - 9
Critical Flow Computations Part - 2

(Refer Slide Time: 00:18)



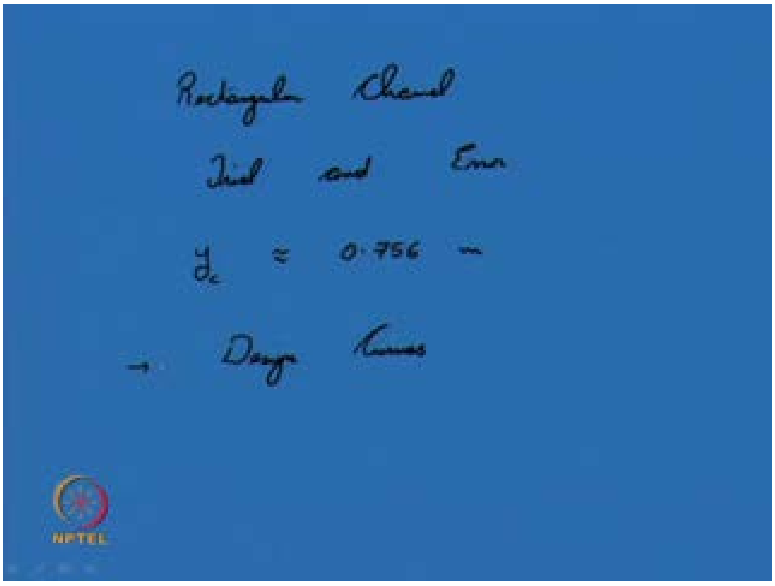
Welcome back to our course series on Advanced Hydraulics. We are in the first module, the module name is open channel flow, and we are in to the ninth lecture of this module.

(Refer Slide Time: 00:34)



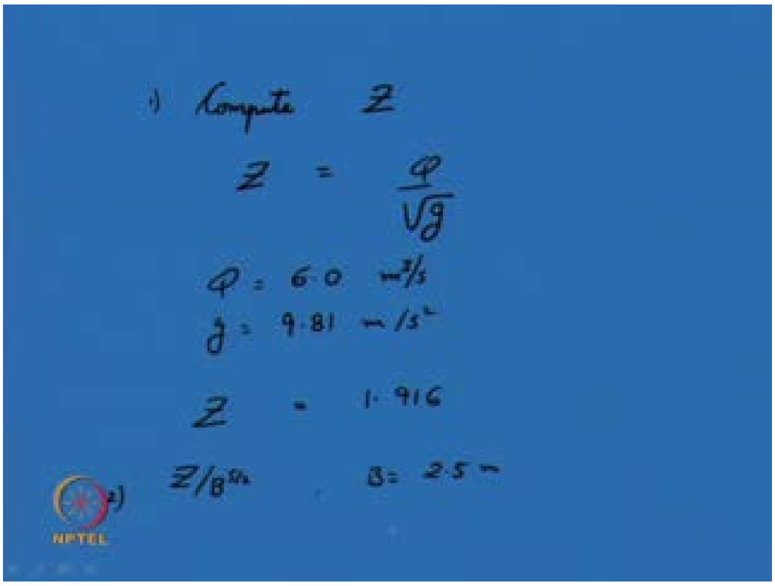
In the last class we had gone through the following topics; critical flow, critical slope, section factor, hydraulics exponent for critical flow, non dimensional graph, how to develop the non dimensional graph of, the section factor verses the depth of flow. If you recall them, we had developed them those graph and all.

(Refer Slide Time: 01:07)



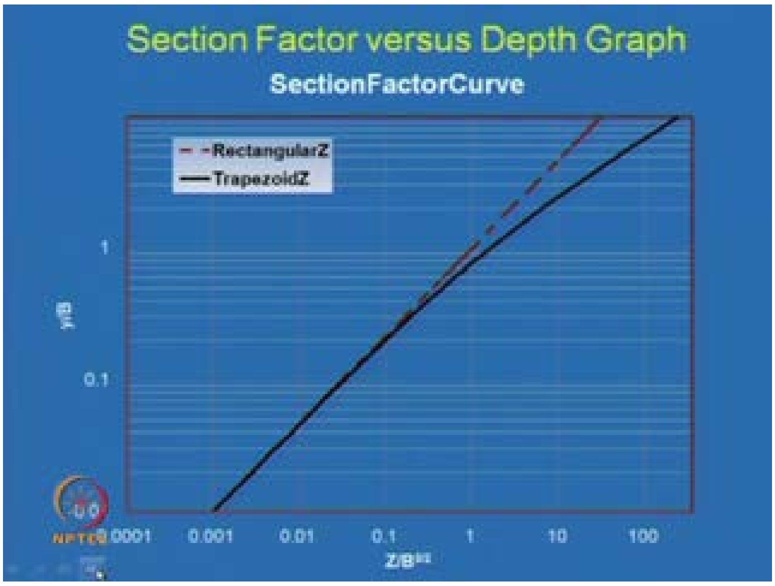
We had even solved one problem for a rectangular channel, we had solved the problem using trial and error method. We asked you to do them as a home work, and see where what is the value you are going to get and all, may be most of you might have got the critical flow approximately around 0.756 meter and all. The same problem you can again solve using the design curves or design tables you have developed. We had developed the non dimensional graph of section factor verses depth of low, similar using that for the rectangular channel, you can again solve the above problem. Let us see how you can do with the following situation.

(Refer Slide Time: 02:09)



First you need to compute for the given delta; compute z; that is the section factor z, you know z is equal to Q by rho g, what the given problem, Q is was found to be 6 meter cube per second, and you know what is the value of g. So, then your section factor is identified as 1.916, what is the non dimensional form of this z. So, you just evaluate z by B to the power of 5 by 2, you have you know what the given value of B is 2.5 meter, therefore z by B to the power of 5 by 2 is, just rub this portion, you will get this quantity as around 0.194. So, you use the same graph of rectangular section factor verses depth of flow, the same graph if you recall them.

(Refer Slide Time: 03:51)



See from this graph for the rectangular, in a rectangular cross section, you just check what is z by B to the power of 5 by 2, it was given as 0.194, you just check it where the depth is coming. This is coming roughly, 0.194 is coming roughly around somewhere here, you will get to the corresponding y by B ratio; say somewhere here, you will get some roughly around that value, you can take that y by B value, and try to evaluate what is the depth of flow.

(Refer Slide Time: 04:35)

0.9	0.853814968	1.336334405		
1	1.000000000	1.632993162		
2	2.828427125	6.57267069		
3	5.196152423	15.7116881		
4	8.000000000	29.8142397		
5	11.180339887	49.54336943		
6	14.696938457	75.49223088		

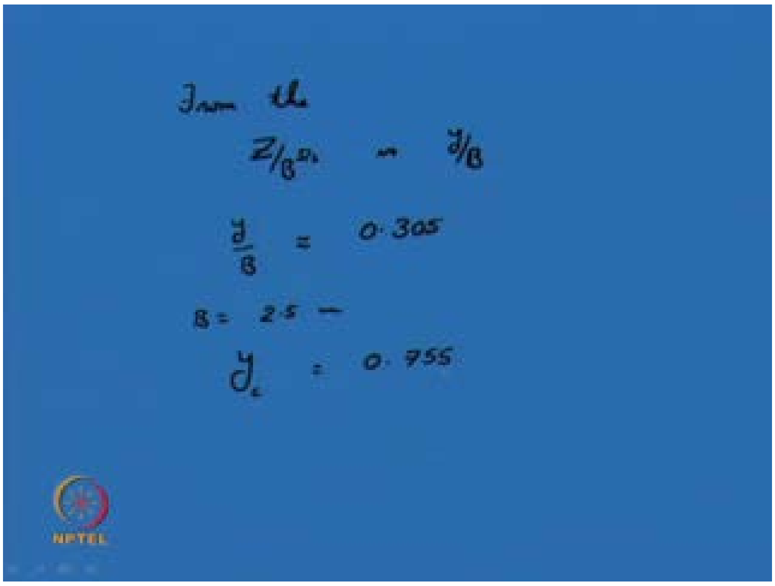
(Refer Slide Time: 04:42)

Data For Section Factor versus Depth Graph

y/B	$Z/B^{5/2}=(y/B)^{5/2}$ Rectangular	$Z/B^{5/2}=(y/B)^{3/2}[1+(y/B)]^{3/2}/(1+2(y/B))^{1/2}$ Trapezoidal (m=1)
0.01	0.001000000	0.001005037
0.02	0.002828427	0.002857121
0.03	0.005196152	0.005275757
0.04	0.008000000	0.008164472
0.05	0.011180340	0.011469451
0.06	0.014696938	0.015155723
0.07	0.018520259	0.019198633
0.08	0.022627417	0.023579882

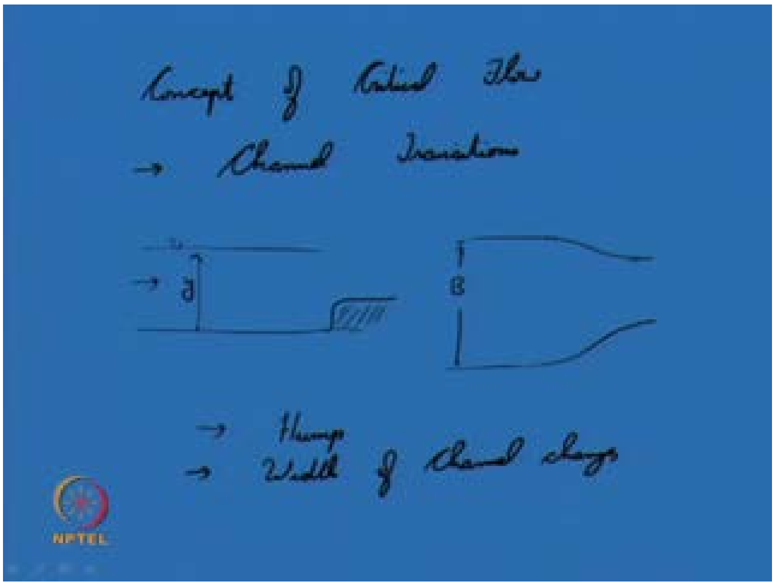
You can use the same table tabular form which we had developed. So, this is the tabular form; y by B for the rectangular channel. And you can see that from that, where 0.194 value. This 0.194 values lies somewhere in between 0.3 and 0.4, use that value now. So, let me suggest that it is around 0.31or 0.32 something like that.

(Refer Slide Time: 05:21)



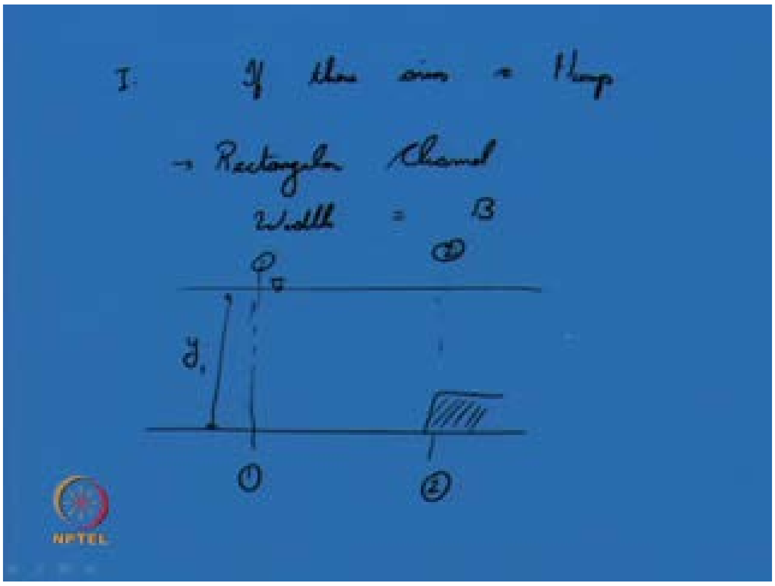
So, from the z by B to the power of 5 by 2 verses y by B graph, you got y by B approximately around 0.305 or something, B is equal to 2.5 meter. Therefore, your critical, your critical depth of flow is around 0.755 meter something like this. Like this also you can determine the depth of flow, in a rectangular channel. For the next portion, which we want to discuss with you is that, your critical flow concepts.

(Refer Slide Time: 06:20)



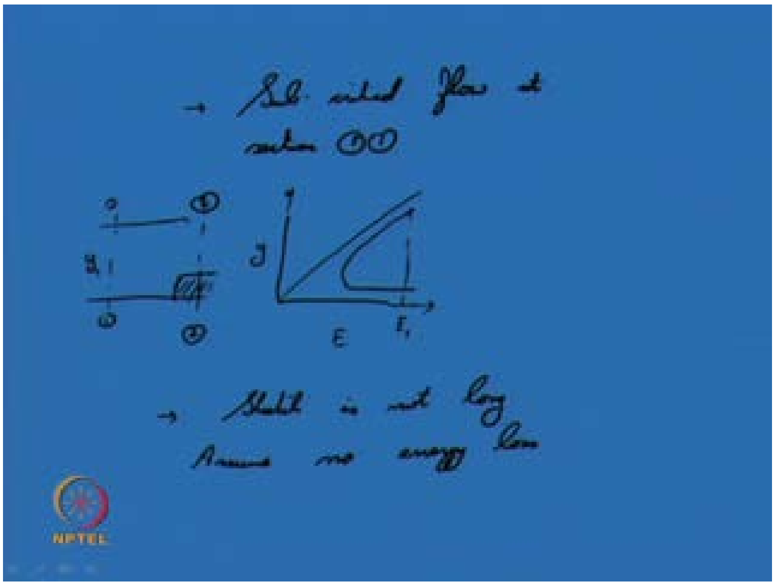
The concept of critical flow, they are also used in channel transitions. So, what is meant by channel transitions. Say a channel, if you take the longitudinal view of a particular channel; say if this is the depth of flow, flow is in this direction, this is the vertical depth. If in the channel, where if any hump is being constructed, or hump arises, what happens to the flow, this is one type of channel transition. Or if you take the horizontal view, this is the width of the river or channel. If all of us suddenly it gets constricted, or enlarge wise versa, what happens to your flow. So, these are some of the channel transitions that one can study, so if there arises hump in the flow, or if the width of the channel changes. So, let us see for these two situation, how the flow changes, or how you can compute the flow parameters.

(Refer Slide Time: 08:10)



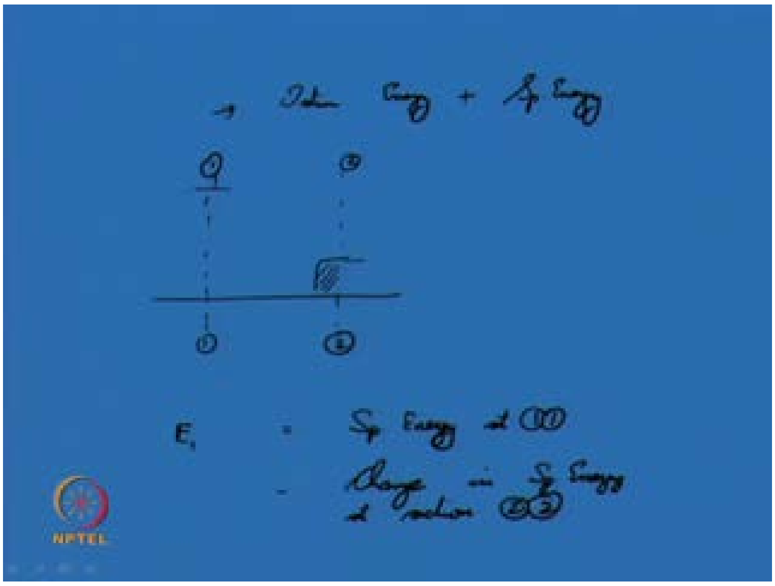
So, first if there arises a hump, what happens? For our demonstrative purpose let us take only a rectangular channel. We are only considering rectangular channel, its width is B. So, if you take the longitudinal profile; say at a particular cross section, this is the depth of flow, y 1 is the depth of flow in the rectangular channel. Hump is situated somewhere here downstream and not that far, and let us consider across section at this location, what happens to your flow, this was the depth of flow. Now you may see that there will be some change in the flow pattern. Initially, let us consider sub critical flow at section 1 1.

(Refer Slide Time: 09:31)



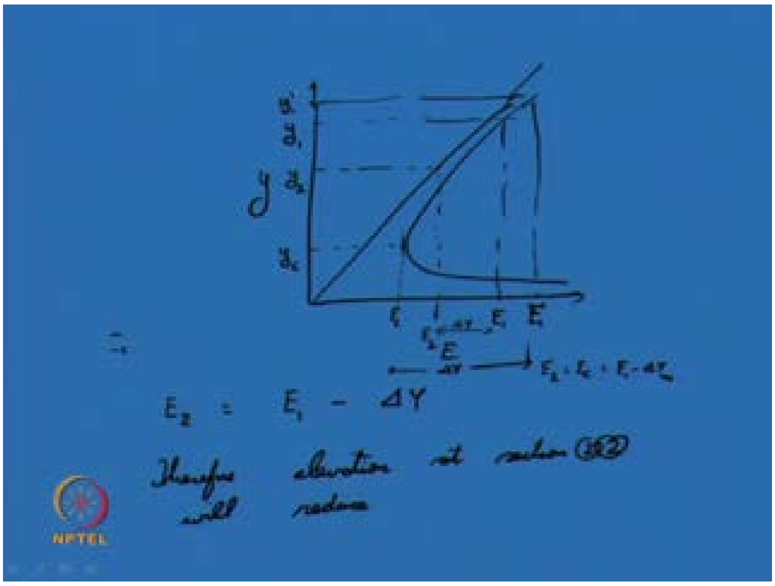
So, if the flow is sub critical, again I will just draw for demo purpose, there is hump smooth hump, so we are just taking a section 2 2. So, the sub critical flow depth y 1 for this you have seen how the specific energy verses depth of flow curve is there. So, for this depth, this is the corresponding energy E 1. Then you can use the same concepts, whatever you have studied, just go back. Now you will see that, as the stretch is not too long; that is, the distance between the section 1 1 and section 2 2, it is not too long. We assume no energy loss; that is the total energy between these two sections are not going to change, this is an assumption we are going to incorporate. If this assumption is there, what will happen then.

(Refer Slide Time: 11:24)



You will see that, at any section total energy is, total energy you have means datum energy plus your specific energy, this will give you the total energy at any cross section. So, based on this, this datum energy is nothing but the potential energy. If you see the same relationship now, at section 1 1 your specific energy is E 1, at section 2 2 the total energy is same. However, due to the hump here, there is change in due to the hump there is change in specific energy at section 2 2. So, we will see what is the change.

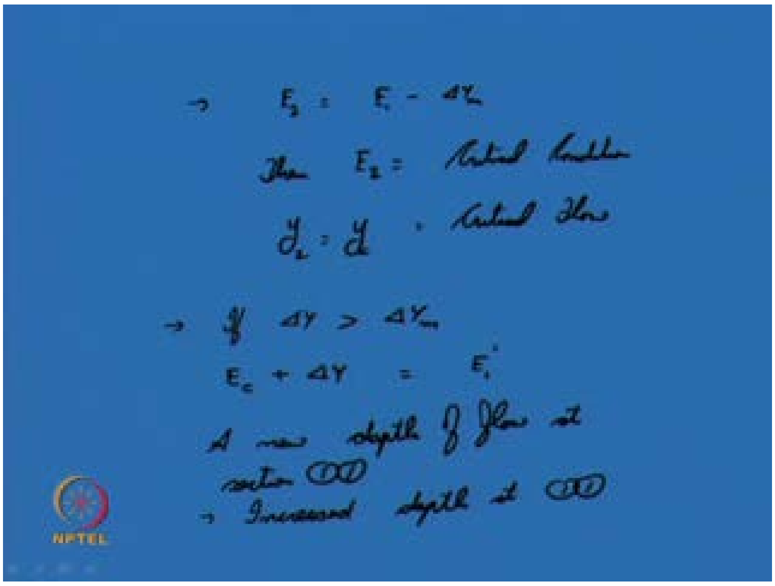
(Refer Slide Time: 12:58)



Again go back to your E verses y curve, so this was your depth of flow at y 1 at section 1 1 in the corresponding energy at E 1. The total energy being constant, you have to see that there is a raise of elevation. If you see the previous section, there is a raise of elevation at this location, by a magnitude say del y, let me give this as a del y. Then that amount the bed is stressed by elevation of del y, you will see that the energy, specific energy at section 2 2, it is nothing but E 1 minus del y, keeping this in mind from this graph, you just deduct the amount del y. See if it something around here, then this your E 2; specific energy E 2, extend it into the graph, and you will get your corresponding depth of flow y 2. So, if an a, for a sub critical flow, you will see that due to the change in the elevation, due to a hump coming into the picture, or hump I seen in a flow, this will cost the depth of flow at section 2 2, depth of flow to reduce, so that the specific energy which ever specific energy as it is getting reduced, due to the hump elevation, the height of the water is also reduced subsequently; that can be seen from this particular graph.

Therefore, elevation at section 2 2 will, or the level of elevation of water surface, or the water surface, it will reduce at section 2 2, we can see the same portion. Similarly, what happens, if in this particular situation, if your depth of the, if your height of the hump, or the hump height, if it is increases further. From this graph it is quite obvious it can increase up to this particular portion. So, this will be the minimum specific energy possible at the particular cross section. At section two, this is minimum specific energy, so E c, you cannot reduce the specific energy below E c. So, you can see that, at what location E 1 E 2 is becomes the critical energy, let me give this as del y m. So, beyond this what happens then or at this height what happens, your flow becomes critical.

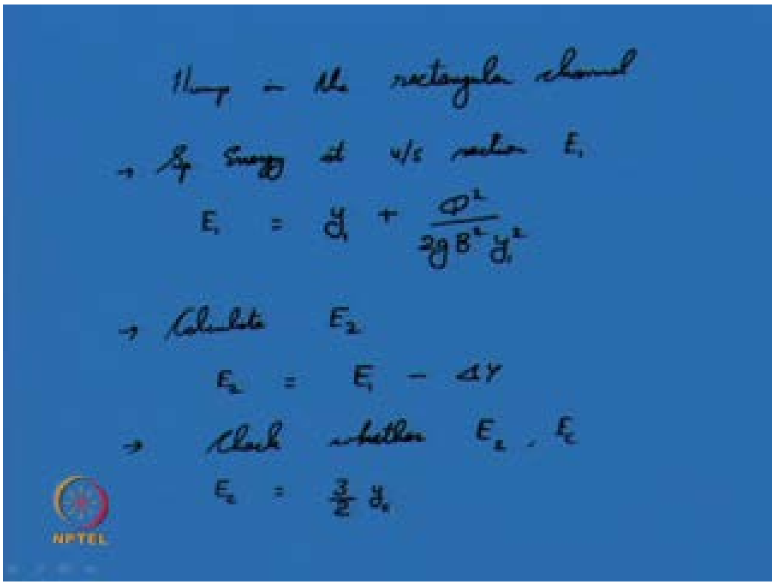
(Refer Slide Time: 17:05)



If E 2 is equal to E 1 minus del y m, then E 2 is critical condition, y 2 is equal to critical flow depth, and the flow in section 2 2 will be critical. If the hump height, if your hump height is greater than the height that is required for a critical flow at section 2 2, what happens. Well you have to think on your own self, again go back to the curve. Here if from E 1, E 1 minus del y m will give you the critical energy at section 2 2 E c. And if your hump height is greater than del y m, your critical energy cannot, means your energy at section two cannot go beyond E c; that is not theoretically possible at all, so what happens. So, your energy at section 2 2 will remain at critical condition; that is whatever is the critical there, and critical flow. From there you need to add del y m, so E c plus del y m.

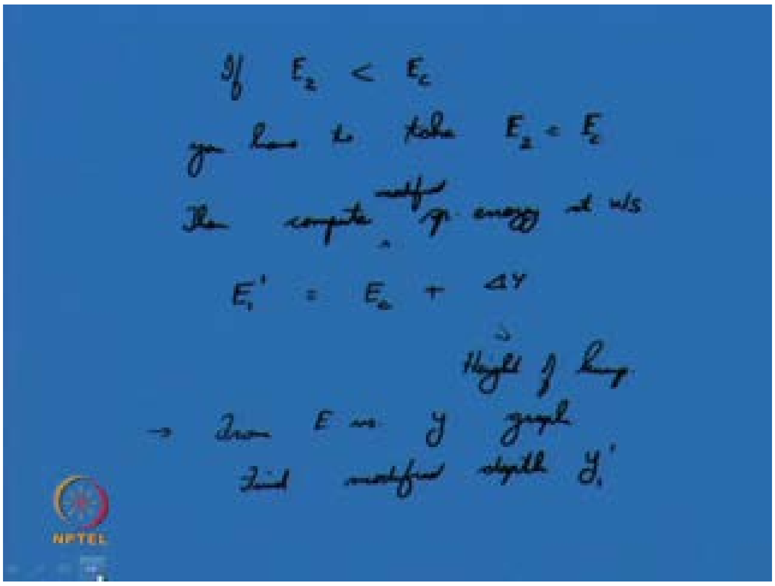
Can I just give it in a next slide; E c plus the del y, that will give you a new specific energy at section 1 1. So, you need to in cooperate this thing; that is in the graph, this will go from here, if del y is greater than this like this, then this portion E 1 dash will come into picture here, you just elaborate that see from the graph, and you will see a new depth of flow at section 1 1, so such situation arises. Now, you can see how the critical flow is being applied here, if the flow, if sub critical flow in the channel section, if they are arises a hump you will see that, the minimum possible is that flow will become critical at section 2 2, and if the hump height is still much higher, than the flow at section 1 1 it changes its specific energy, and it raises it elevation, so at section 1 1 the depth of flow increases. So, this is an increased depth at section 1 1.

(Refer Slide Time: 20:45)



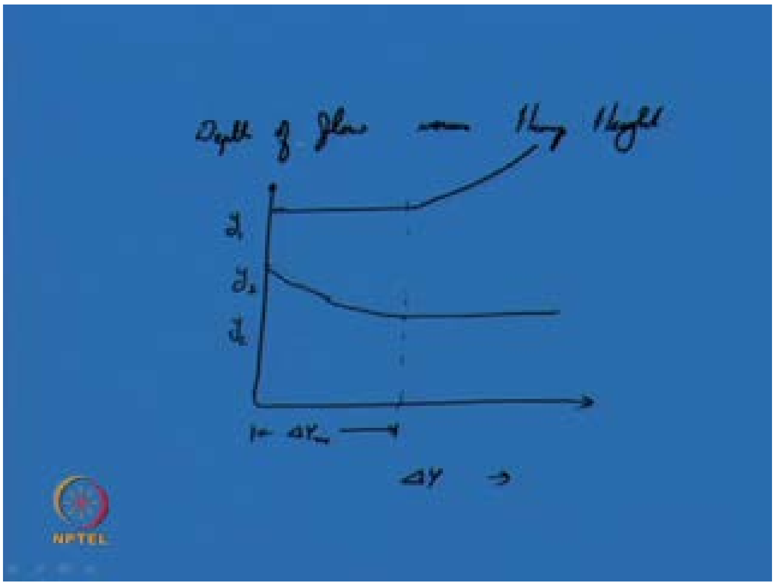
So, in the presence of hump, in the rectangular channel, first you need to evaluate specific energy at downstream pardon may I beg pardon at upstream section E 1. So, E 1 you know for the rectangular section, it is nothing but y 1 plus Q square by 2 g B square into y 1 square. Now calculate E 2; that is the specific energy at downstream section. E 2 is equal to E 1 minus del y. Once you compute this, you will you have to check, whether E 2 with respect to the critical energy at section two. For critical energy at section two you know this is for rectangular channel, this is nothing but 3 by 2 into y c, this you have already derived them in previous classes.

(Refer Slide Time: 22:51)



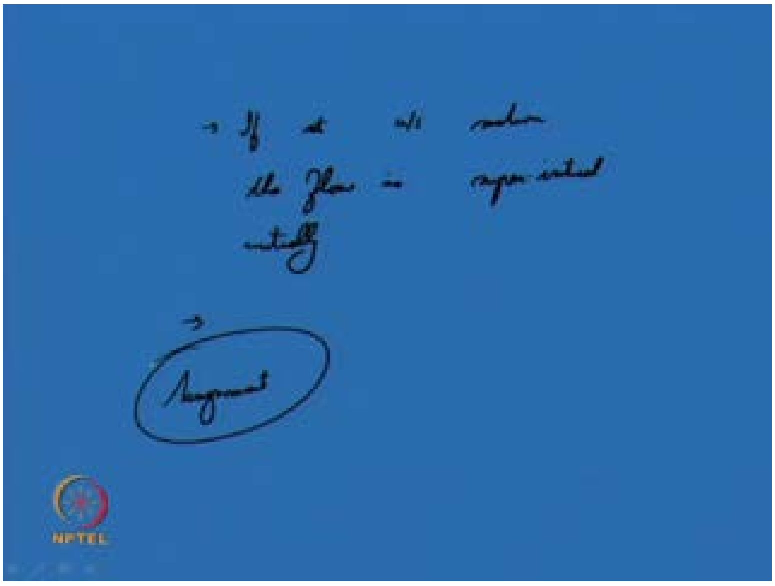
So, if you are computed E 2, comes less than E c, you have to take E 2 is equal to same as the critical energy flow, or the energy at the specific energy at the critical flow. Then compute specific energy at upstream, this is the modified specific energy at the upstream section; E 1 dash, this is nothing but E c plus del y, del y is the height of hump. So, once you compute E 1 dash from E verses y graph, find modified depth y 1 dash at section 1 1.

(Refer Slide Time: 24:31)



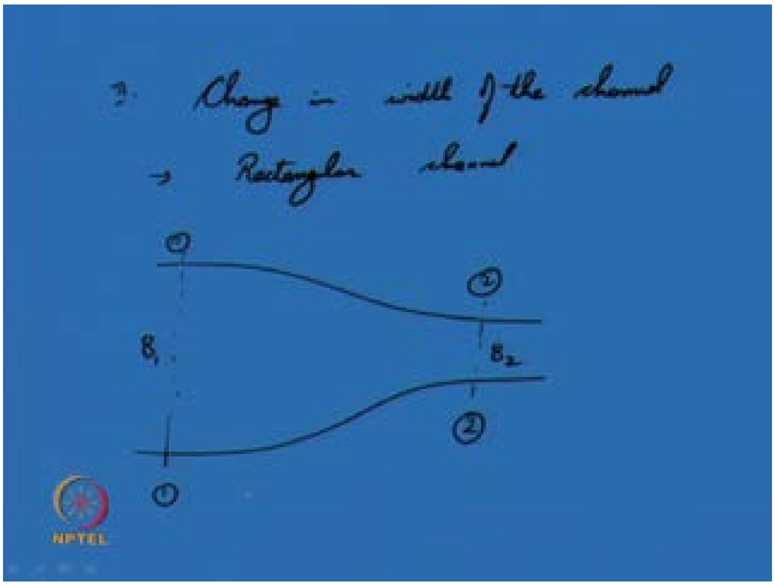
You can easily see that, if I plot depth of flow verses hump height, as we have assumed that initially at the upstream section, the flow is sub critical. So, you can just see for the various values of the hump height del y, what will happen. The depth of flow initially it is sub critical, and it will remain at section 1 1, it will remain at same elevation for a considerable time. Once it reaches the critical del y m value, then you will see that, on further increase of the hump, your depth of flow you will gradually increase at section 1 1. Similarly, at section y 2, you can plot the following situations, you will see; say it is starts at y 2, then it goes on decreasing as the height of the hump increases to reach at a particular level. Here this is your critical depth, and from here the section 2 2 will maintain the critical flow condition itself, whereas at section 1 1 the elevation of water will increase, this is how you can interpret the following graph or you can easily draw them. I would like you to do it as an assignment what happens.

(Refer Slide Time: 26:35)



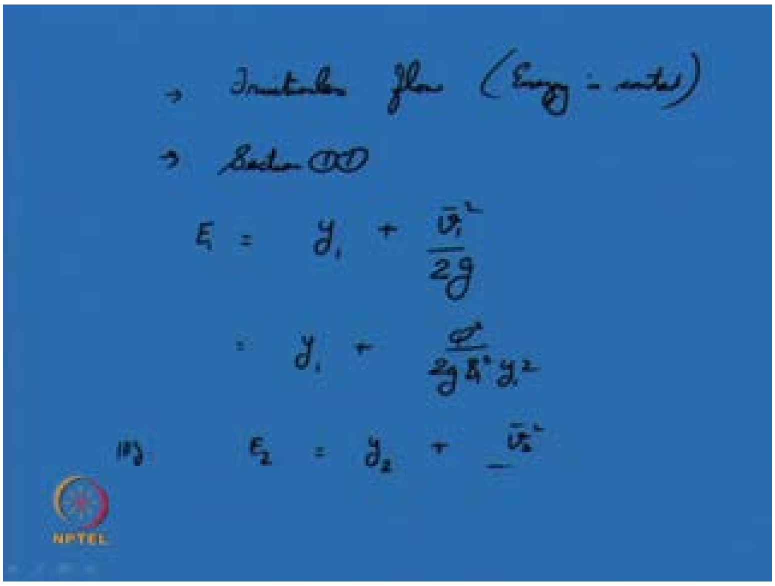
Say if at upstream section, the flow is super critical initially, what happens if there arises a hump at section 2 2 or at downstream section if there arises a hump, what will happen to your flow, what will happen to your depth of flow, this is you can do as an assignment. It will be better if you could work it out in at home and see.

(Refer Slide Time: 27:19)



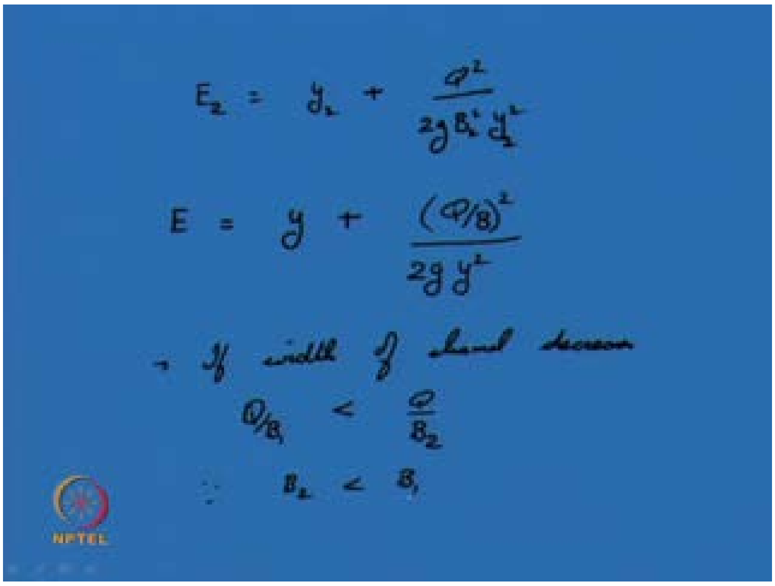
Now, the next channel transition we mentioned was, change in width. Again we are mentioning that for the demonstration purpose, we are using the rectangular channel. You can use these same concepts for the other cross sectional channel also. So, let us consider a channel stretch, this is your section 1 1, this is the top view or the horizontal view of your channel. Here the width of this channel is B 1, and it gets reduced at downstream to B 2. In fact, you can even draw the elevation of water based on this top view, how the elevation of water looks also, like that also can interpret them. So, far such type channel transition how will you inform the depth of flow and all.

(Refer Slide Time: 28:45)



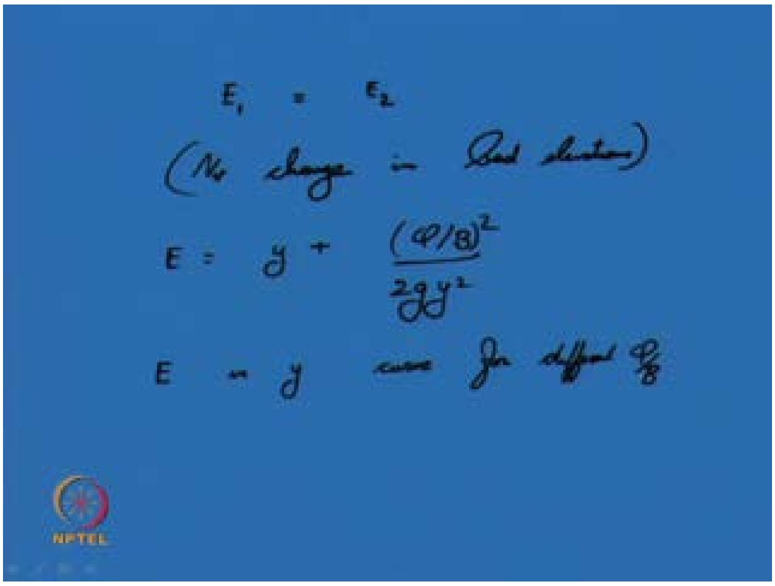
You use the same concept, again we are assuming that this is frictionless law, or total energy is constant, or the energy in the flow, energy for the flow this is constant, there is no energy loss due to friction and all, we are a assuming like that. At section 1 1 you have your specific energy E 1; E 1 is equal to y 1 plus v 1 squared by 2 g according to our formulations, this is nothing but y 1 plus Q square by 2 g B 2 square y 1 square.

(Refer Slide Time: 30:04)



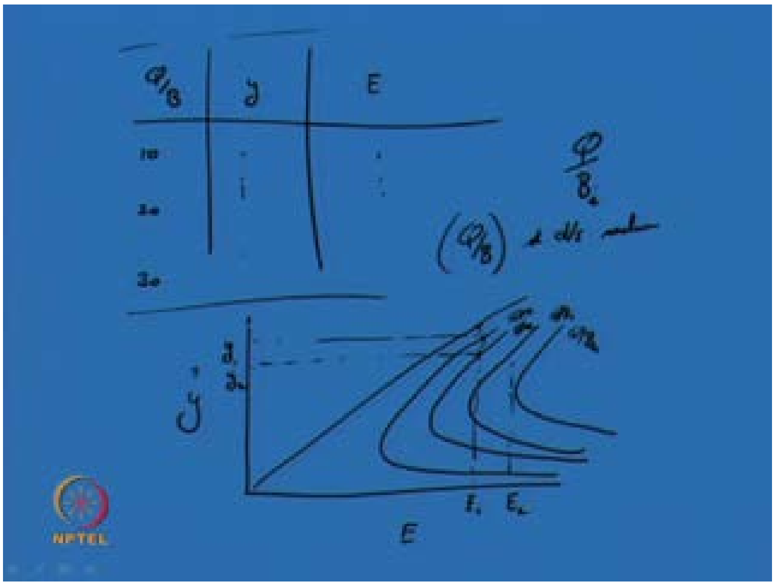
Similarly, you have specific energy at section 2; this is E 2, this is y 2 plus v 2 square by 2 g E 2 is equal to y 2 plus Q square by 2 g B 2 square into y 2 square. From these two relationships, you can easily see that your specific energy is nothing but depth of flow plus Q by B whole square by two g y square, you can even try to analyze the quantities in this way, in this particular form. If width of the channel decreases, then you will see that; Q by B 1 is less than Q by B 2, because B 2 is less than B 1 and you have small discharge, there is no energy loss between the two section 1 1 and section 2 2.

(Refer Slide Time: 31:38)



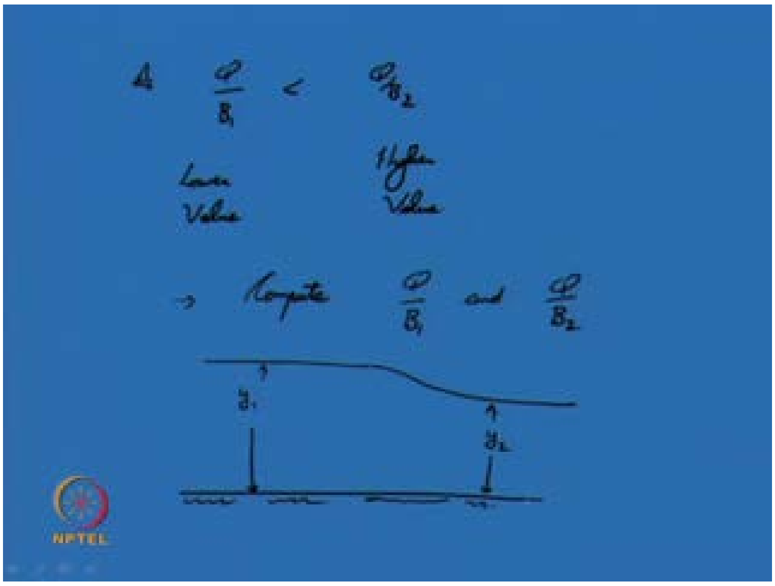
As it is a frictionless channel, you can see that E 1 is equal to E 2 in this case, because there is no change, no change in bed elevations. There is no change in bed elevations; therefore E 1 is equal to E 2. From the following equation, one can see that E verses y curve for different Q by B values one can interpret them, how will you do that.

(Refer Slide Time: 32:46)



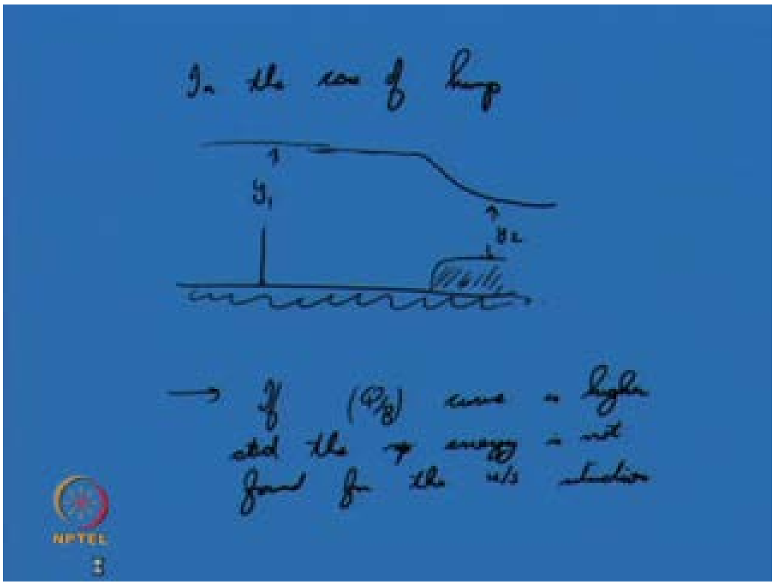
If I try to interpret say, for different Q by B, for different depth of flow, and E if I try to compute it in a table, so you can start with Q by B is equal to 10 20 30 from then from different depths E, like this if you try to compute them, you will see there you are going to get following type of curve. You will get a following type of E verses y curve or different values of Q by B. This is for Q Q by B Q by B 1 Q by B 2 Q by B 3 Q by B 4 like that you can just draw it. So, different values of Q by for different values of Q by B, you will get different specific energy curves of the following form.

(Refer Slide Time: 34:12)



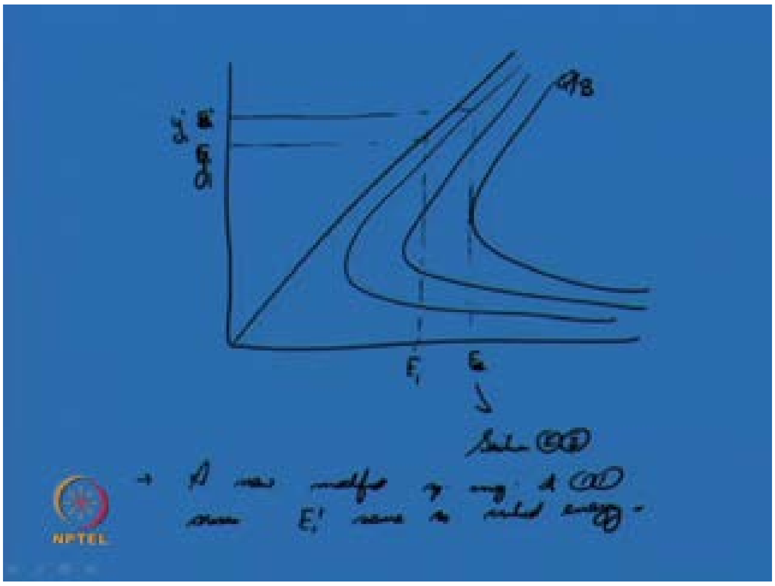
In the rectangular cross section as Q by B 1 is less than Q by B 2, what happens to your curve. In the above graph you have seen that; say for lower values of Q by B this are the curves, for higher values of Q by B this are the curves. You interpret them again in same form, at that upstream section Q by B 1 is a lower value, and this is higher value. So, in this particular channel section, compute Q by B 1 and Q by B 2 first, then go back to the curve, you have to interpret; say what is from this curve; say for Q by B 1 this was initial depth of flow available. This is the depth of flow at the cross section 1 1, then on channel restriction or the width getting the restricted, it will go into the next curve Q by B 2 or whichever is appropriate, and you will see, let us assume that Q by B 2 is the respective curve. So, here at section 2 2, the depth of flow will get reduce to y 2, as per the following graph; that is, this is the channel bed, here is your y 1, then as the channel width decreases the depth of flow at section 2 2, it reduces to y 2.

(Refer Slide Time: 36:52)



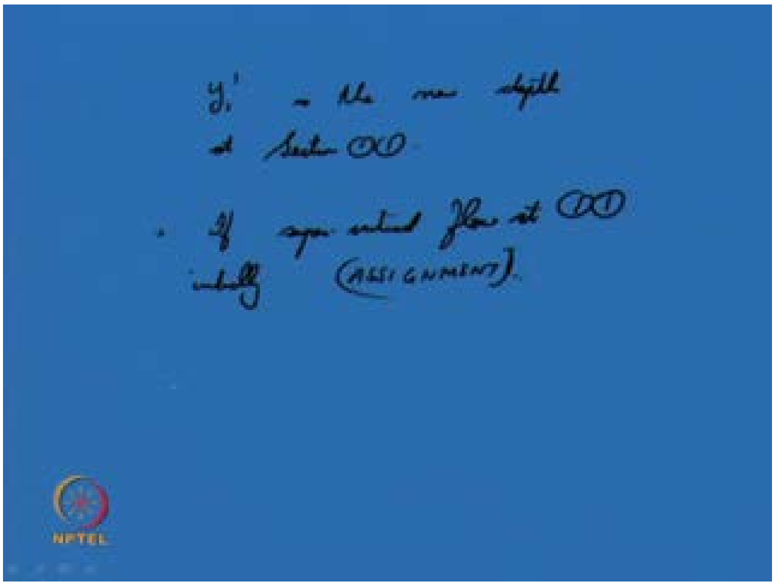
Similarly in the case of hump you have seen that y 1, and due to the hump here, the flow reduces to y 2. So, the same theory, you are using the same principle everywhere, critical flow computations. In this case, what happens; suppose your Q by B 2 or Q by B i, your Q by B i or Q by B 2 at the down Q by B at downstream section, whichever curve is coming, if say if this was the curve what happens then. Now here you will see that, the energy curve which ahs computed at the section 1 1, those that curve is not intersecting this curve at any location. Therefore, the depth of flow, or the energy the same specific energy is not available at the section 2 2; that is what it can be inferred. In such case, what happens to the flow is that, for the given cross section Q by B, whichever is the critical energy for the same curve, that will be taken as, the specific energy at section 2 2, from if Q by B curve is higher, if Q by B value is higher, and the specific energy is not found for the upstream situations.

(Refer Slide Time: 39:32)



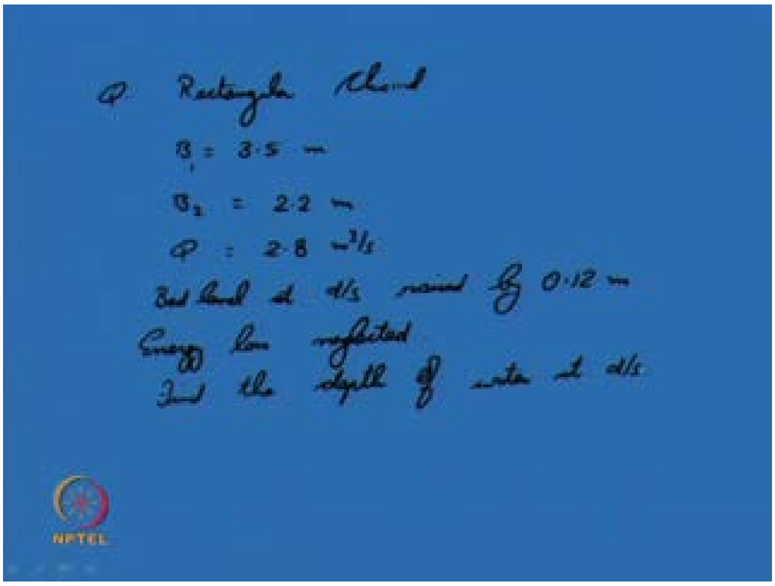
Then you have to see that from the same curve, you have to take the situation where; say this as the curve, you have to take your minimum energy, if this was the original energy at section one section 1 1, y 1 and this is E 1, and then you take at section 2 2, the minimum energy section 2 2; the minimum energy is possible than E c, because this is the curve for the particular cross section Q by B, this is the available curve. So, the minimum energy in that available curve is at this location; say you have to take that as the minimum specific energy at section 2 2, you extend it, and you see at which location this portion comes. So, you have to see a new modified specific energy at 1 1 arises, this is called E 1 dash, and you can see that this is same as the critical energy at section 2 2.

(Refer Slide Time: 41:48)



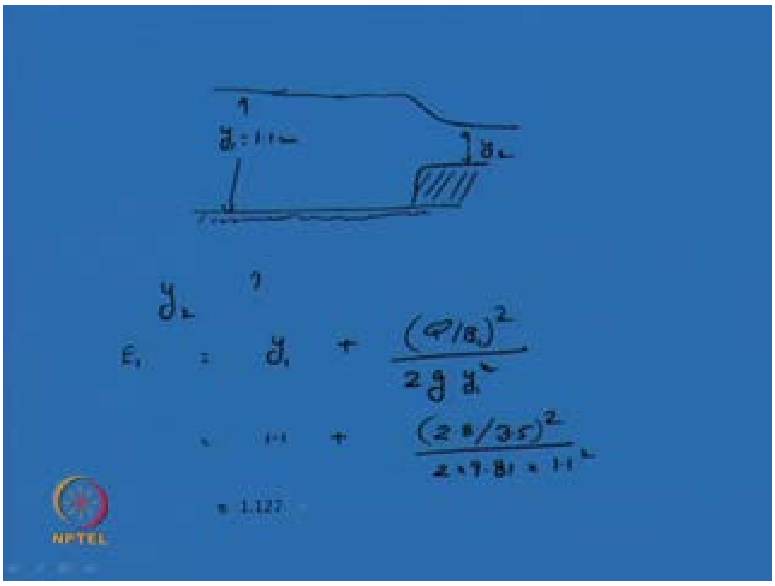
So, what is the corresponding depth of flow y 1 dash; y 1 dash is the new, that at section 1 1 in such situation. So, you have now seen two channel transitions now. For the second case also you can do as an assignment, if super critical flow at 1 1 is present initially, then what happens. You can do this as an assignment.

(Refer Slide Time: 42:43)



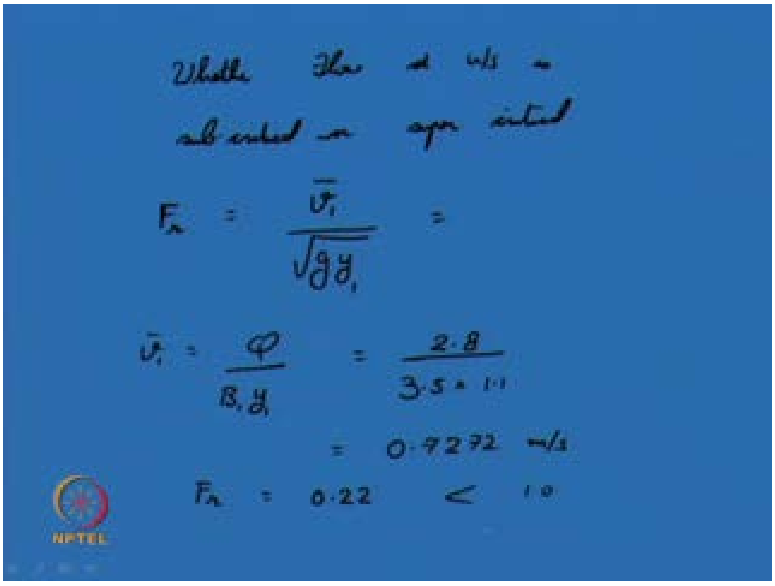
Let us do a numerical problem, based on this two cases; rectangular channel up stream width is 3.5 meter, it is reducing the width of the channel is reducing to 2.2 meter. The flow is 2.8 meter cube per second, bed level at section 2 2; that is at downstream raised by 0.12 meter, you are neglecting energy loss. Now, find the depth of water at the downstream location, can you do this problem. Let us see how this example is working now.

(Refer Slide Time: 44:08)



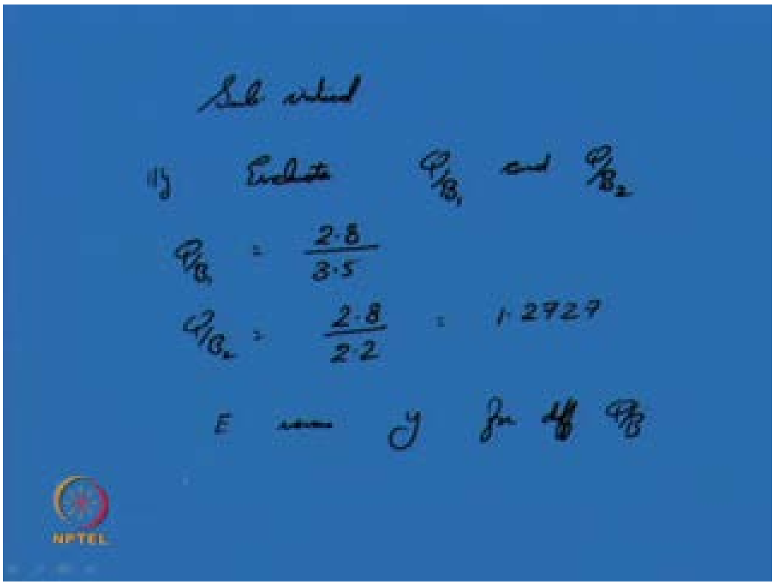
As you know the channel that is of this style, at the upstream section the depth of flow, is y 1 equal to 1.1 meter, downstream a smooth hump is placed, and as you seen according to our theory, the flow may be something like this type, and we need evaluate the depth of flow y 2. For that, first you need to evaluate the specific energy at section 1 1; that is at the upstream, E 1 is equal to y 1 plus Q by B 1 whole square by 2 g y 1 square, this comes out to be 1.1 plus 2.8 or you see, you can just rub it out we get a single notation, this is coming out to be 2.8 by 3.5 whole square by 2 into 9.81 into y 1 square is 1 point. So, this comes out as 1.127.

(Refer Slide Time: 45:53)



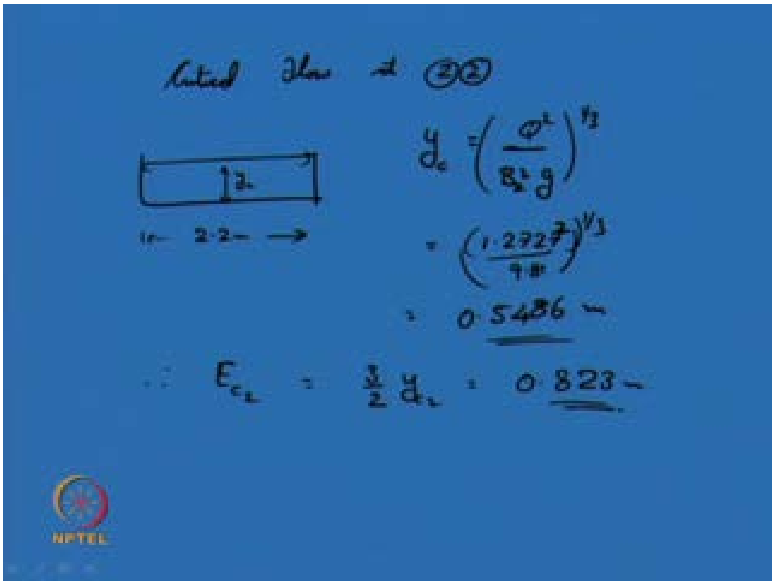
You have to also check, whether flow at upstream section is sub critical, or super critical, or critical. For that you have to evaluate the fluid number, we have studied that, the average velocity at the cross section divided by root of g y 1 v 1. What is v 1, v 1 is equal to Q by B 1 into y 1, this is coming out to be 2.8 0.7272 meter per second. So, your fluid number using this data, it was coming to be around 0.22, which is less than the required criteria. So, fluid number less than 1 means, the flow is sub critical.

(Refer Slide Time: 47:25)



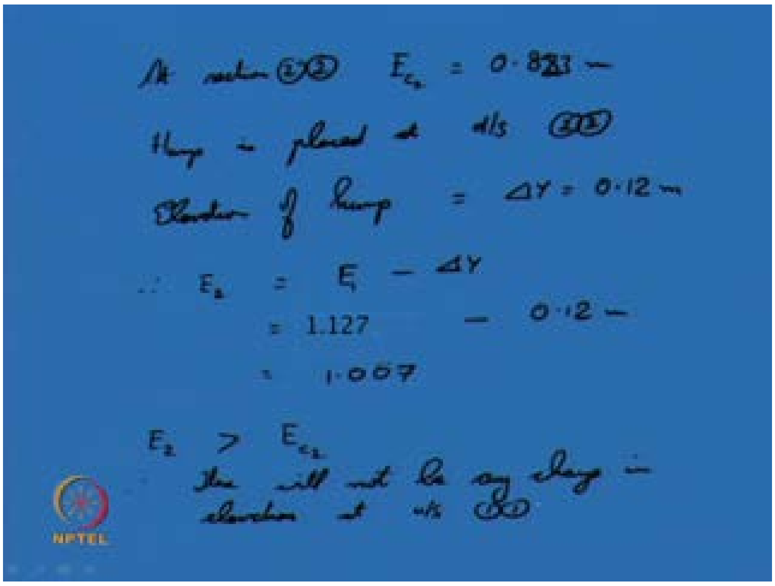
Similarly, evaluate Q by B 1 and Q by B 2, you know Q by B 1 is equal to 2.8 by 1.1, Q by B 2. Well I beg pardon, Q by B 1 is 2.8 by 3.5, and here this 2.8 by 2.2. So, you have the respective curves of Q by B, is a you have the respective curves of E verses y for different Q by B, you obtain those thing, Q by B 2 is found to be, it has been found to be 1.2727.

(Refer Slide Time: 48:51)



What is the critical flow at section 2 2 or the downstream. Critical flow is the, flow means it is the only one type flow, critical flow at section 2 2 for the given channel cross section; that is your width is 2.2 meter channel cross section. Your critical depth, it is coming out to be Q square by B 2 square g. This is nothing but your 1.2727 whole square by 9.81 whole to the power of 1 by 3.5486 meter. Therefore the critical flow possible at section 2 2 is 3 by 2 y c 2, is equal to 0.823 meter.

(Refer Slide Time: 50:29)



So, you know at section 2 2, the critical energy possible is 0.83 823 meter, also a hump is placed at downstream; that is section 2 2. The elevation of hump as per the data is equal to 0.12 meter. Therefore, the specific energy at section 2, is at the downstream is nothing but the specific energy, at section 1 minus del y, this is coming out to be 1.127 minus 0.12 meter is equal to 1.007. This value is found to be greater than the minimum possible energy at section 2 2, and therefore, there will not be any change in elevation at upstream section 1 1. So, let us conclude this module, with this problem we are even concluding this module, in the lecture next based lecture onwards, we will be going into the second module; second module on the uniform flows in open channel. So, I request you to go through the books, and have some idea before coming to class what is meant by uniform flow and all.

Thank you.