Local Energy Losses

SPEAKER Bob Holmes: Okay, welcome to lecture 14. We're going to talk about local energy losses in natural channels. Now, we've been talking in prior lectures, we've run through the energy equation, we've talked about losses that we would have due to friction loss and those that are due to other kinds of phenomena such as expansions, contractions, bridge openings, that kind of phenomena, we talked about how to deal with that. In this lecture, we're actually going to put it altogether and look at a natural channel and those kinds of things that you're going to involve--that would involved computing, like discharge from high watermarks and that. So this lecture here is kinda turning a point to where we're going to go in subsequent lectures looking at interacts.

Now, some main points for this lecture; earlier on in one of the previous lectures, we talked about using friction equations or resistance to flow equations, like Manning's equation, [PH] Chase's equation, or the Darcy-Wiesbach equation. We're going to use one of those equations. In this case, we're going to stick with Manning's equation to actually compute the energy grade line slope. We're also going to look at energy losses through natural channels with other kinds of obstructions and disturbances such as the expansion and contraction. We're going to calculate the energy loss in that manner using basically a coefficient.

If you recall the energy equation, we have the Coriolis coefficient, alpha, times the mean velocity at that particular section, squared, divided by two times acceleration of gravity, and that's abbreviated to small letter "g". That in itself is the kinetic energy. We can add to that, the potential energy, which is the capital "Z", and then we add the pressure potential, which is our depth. And as we've mentioned many times throughout this course, sometimes we use "Y", sometimes we use capital "D", sometimes we might even use "H", but they're all--you have to look carefully when you see the equation in the textbook to make sure that we are talking about depth. But most often, we're always talking about depth. So if we are at Section 1, those would all have a subscript "1", and then we would differentiate that to the other sections, like Section 2 or Section 3, et cetera.

On your screen, you see that we have the energy equation written out there. So we have all the terms--the kinetic energy term at Section 1, the pressure potential at Section 1, and the potential

energy at Section 1, and then we have an equal sign. And on the right side, we equate it to the energy at the next section, and then we add in that head loss term. Remember, we're dealing with the real fluid, not an ideal fluid, so we have to account for the losses.

Now, those losses are going to be due to one of two things. I've just have said previously, either due to friction. In that case, then we're going to calculate the friction slope of that particular length or that particular reach, and we're going to multiply it by the distance of that reach, and I'll show you that in a second. Or we have local disturbances such as the boulders in the area, fallen trees; maybe you've got a bridge constriction or expansions and other contractions.

Now, on your screen, you see a drawing, and the top of that figure is looking in plan view. And you can see that we have a constriction as we go through, and we have what we've already covered which is a vena contracta, and so the flow is basically constricting down into a much smaller channel. If you look at the lower part of the figure, that's a plan view where you--or I'm sorry, it's an elevation view or a side view that would show you what the water surface looks like and how that drops to that constriction, and also has the energy grade line. You can see that Section 1 is well above the constriction, Section 2 corresponds to right at the face of the constriction, and then we maintain that same constricted channel all the way through for some distance downstream and we don't even show you an expansion again. So Section 3 is farther downstream but it's in the same constriction as Section 2.

Now, on your screen now, we actually have defined what the energy equation looks like for this particular problem setup. You'll see that we have the Coriolis coefficient, that's alpha 1 at Section 1 times the mean velocity at Section 1, and that quantity is squared--the V1 is squared--divided by two times the acceleration of gravity. We then add the pressure potential and the potential energy to come up with the energy at Section 1. We then look--and we're going to write this equation all the way to Section 3. So we're quite aways downstream from the actual opening of the constriction.

So we're going to, first of all, on the right side, we look at the total energy at Section 3. So that would be the Coriolis coefficient for Section 3, alpha 3, times the mean velocity at Section 3,

squared, divided by two times acceleration of gravity, plus the potential energy or the pressure potential energy. In this case, we're abbreviating it "H sub 3", and then we add on our value for the potential energy.

Now, one thing I want to clarify here is that H1 would be the summation of both the potential energy and the pressure potential. So instead of writing Z1 plus Y1, we've actually just basically lump those into the same term, H1. The same thing on the right side we're doing at Section 3 where lumping into that term H3 has both the potential energy component, which would be the Z3 and the pressure potential, which would be the Y3. So again, don't get confused here. In this particular case, we're lumping things together.

Now, because we have the real fluid, we also have to account for the friction losses, and so we have "H sub F", which would signify the loss due to friction from Section 1 to 2. And then because we have a little different channel setup, we break that into a separate component for the friction loss from Section 2 to 3. As we've noted, anytime you'd get some kind of local condition--in this case, a contraction--we're going to account for that by calling it out separately, and we're going to abbreviate that "H sub E." That is for the contraction loss.

Now, as I've mentioned, we're going to compute the friction loss, H sub F. We're going to actually compute that as the product of the slope of the energy grade line, S sub F, times that distance, L. And for our contraction energy loss, H sub E, we're going to use it as some percentage of the velocity head.

Now, you can see, Equation 2, that percentage of the velocity head, we break that out by saying, "All right, H sub E, which is our contraction loss here is some coefficient, K sub E, times the difference in velocity head from Section 1 to Section 3," and that is shown in absolute bars here just so we'd get an absolute difference. We don't want a negative term in there. That energy loss to the contraction is always positive.

Now, if we have a sudden contraction, you can see that the coefficient, K sub E, is somewhere around 0.5. If we have a contraction that's much more gradual, we're going to have a smaller

value, so it's going to be somewhat less depending on the particular type of contraction. And in subsequent lectures, we'll talk about how to assign that value for K sub E.

Now, if we have a sudden expansion, the K sub E value all of a sudden shoots all the way up to one, and that's because anything that's in excess--we know when that velocity goes back out to a smaller value, remember in continuity, if we assume that the discharge stays the same, the Q is equal to the cross section area times the velocity--the mean velocity of that channel. If we go from a smaller cross section to a larger cross section and the discharge stays the same, the velocity has to decrease in order to keep continuity. So what we have by saying that we have a sudden expansion when we go from a smaller channel to a larger channel that we're basically assuming that everything in excess of the velocity difference is lost to this expansion.

Now, if we have a flood peak usually and we're not able to get a discharge measurement, we're going to collect high watermarks. And in this particular case, we would use the contraction as a way to sort of indirectly measure the discharge. You can think of it as like a discharge meter where we're basically collecting some information here--in this case, it's high watermarks--and then we're going to use the energy concepts to actually back-calculate or calculate the value for the discharge. If we collect those high watermarks at Section 1 and 3 and then we know something about the contraction and we know something about the boundary friction--in this case, we would be selecting Manning's in because we're going to use Manning's equation--we can come up with a way or we can come up with a methodology to calculate or estimate the discharge at the peak from these high watermarks.

Now, if you'll recall, the Manning's equation states that the discharge is equal to 1.49 over the Manning's roughness value, N, times the cross-sectional area, times the hydraulic radius to the 2/3s power, times the friction slope to the 1/2 power. Now, you kinda remember now, we abbreviate the conveyance, we kind of shortened these terms up. If I assume that the large "K" is this conveyance term, I can equate that to 1.49 over the Manning's coefficient, N, times the cross-sectional area, A, times the hydraulic radius to the 2/3s power. That in its essence is the conveyance, defined as such. We can then plug that in. Instead of having that long-term, we just abbreviate the value for "K" or we used the letter "K" in that particular equation, and we can say

that the Manning's equation can be abbreviated to say that the discharge, Q, is equal to the conveyance value, K, times the friction slope to the 1/2 power.

Now, we're going to plug in for the value for the friction slope. We're going to actually say that the friction slope, S sub F, we're going to rearrange it algebraically and say, "That's equal to the discharge squared divided by the conveyance term squared." And so anywhere we have S sub F in this equation later on, we're going to plug in Q squared over K squared, and then we're going to multiply that value times the distance and that will give us the friction loss or the head loss due to friction in that particular reach. So if I expand Equation 1 to express these terms--the friction loss terms--in the terms of K--or I'm sorry--into the discharge and the conveyance K, and plug that in, you can see what Equation 2 becomes. And we've got to demonstrate here is Equation 3, which says that basically our velocity head--and that's, again, the alpha, the Coriolis coefficient times the velocity at Section 1 squared divided by 2g, plus our head term for basically the pressure potential and the potential energy, that's H sub 1, and then I have the same terminology for Section 3 on the right side of the equal sign, now you see the substitutions there. Instead of having S sub F times the distance, I plug in the Q squared over K squared to get that value for the head loss due to friction. You'll note again that we've broken it out from the friction from Section 1 to 2 and the friction from 2 to 3, okay? So those are distinct terms because we might have different roughnesses in those reaches.

Now, I've also plugged in--instead of saying H sub E for my contraction loss, we've actually plugged in an equation for that. In there, we have capital K sub E, which is the coefficient for the contraction times the difference in the velocity head from Section 1 to 3.

Now, this can be solved sometimes directly and sometimes you're going to have to use indirect means or trial and error means. And we've talked about our trial and error solutions. So let's discuss the setup for the problem in the textbook. I'm not actually going to work through the problem in this particular lecture because we only gave you one problem to work, and I think it's fairly straightforward, but let's talk about it.

On your screen, you'll see a bridge constriction, and this is what we have for this particular problem. We have Section 1, it's located 40 feet upstream at the bridge opening, and Section 3 is

located 15 feet downstream at the bridge opening, but still within the constriction. So it's very much similar to the setup that I showed you earlier in this lecture where we have the plan view of the constriction and then the side view.

Now, for part one of the problem, I want you to compute the peak discharge if you assume that the coefficient for the contraction is 0.5; that is, the K sub E is equal to 0.5. The second part of the problem, we want you to assume that the peak discharge is 575 cfs, and then I want you to calculate the K sub E. Now, on the problem, you're given a table, and that table gives you the characteristics of the channel at Section 1 and Section 3. So you have the water surface elevation there at both locations, and that water surface elevation would be equivalent to your H1 and your H3. So we've lumped both the potential energy and the pressure potential at Section 1, and that value is 10.81 feet. We've also lumped it at Section 3, and that value is 10 feet. So you have a fall in the water surface from Section 1 to Section 3 of 0.81 feet if you subtract those two.

We're also given the cross-sectional area there and the conveyance terms, and lastly, you're given the alpha coefficient, the Coriolis coefficient, that attributes the correction factor you have to have. Remember back from pervious lectures, because we're stuck with using a mean velocity that does not always do a good representation of the kinetic energy, so we have to apply a correction factor, and that's what this alpha is.

Now, you're going to use Equation 3 and plug in everything you know from these various tables, including end values and things like that, and you're going to solve either directly for Q, if you have the ability to do that. And some calculators and computational mechanisms that you might have can do that directly, but you can also do a trial and error solution where you assume a Q, calculate everything, and make sure that the two sides of the equal sign match. And that would be a trial and error solution.

Now, I want you to go ahead and try to work the problem. And then we have a flume demonstration that will complete our discussion of this lecture.