Лекція 1 **Technical mechanics of liquid and gas. Hydraulics**

**Bernoulli's equation**

**https://www.youtube.com/watch?v=DW4rItB20h4&ab_channel=TheEfficientEngineer**

Bernoulli's equation is a simple but incredibly important equation in physics and engineering that can help us understand a lot about the **flow of fluids** in the world around us. It essentially describes the relationship between the **pressure**, **velocity** and **elevation** of a flowing fluid.

It has countless applications. We can use it to explain how planes generate lift, or to calculate how fast liquid will drain from a container, for example.

We'll explore these applications and a few more later on, but let's start by reviewing the equation itself. It was first published by the Swiss physicist Daniel Bernoulli in 1738, and it looks like this.

The equation states that the sum of these three terms remains constant along a **streamline**. Each of the terms is a pressure. The first term is the **static pressure**, which is just the pressure P of the fluid. Then we have the dynamic pressure which is a function of the **fluid density** and velocity, and represents the fluid **kinetic energy** per unit volume. And the last term is the **hydrostatic pressure**, which is the pressure exerted by the fluid due to **gravity**. G is **gravitational acceleration** and H is the elevation of the fluid, which is just its height above a **reference level**.

This is the pressure form of the equation, but it can also be presented in the **head** form, and the energy form.

We can think of Bernoulli's equation as a statement of the **conservation of energy**. It says that along a streamline the sum of the pressure energy, kinetic energy and potential energy remains constant. This is really valuable information that can help us analyse a whole range of fluid flow problems.

The equation does have a few limitations, which I'll cover later on in the video, but for now the important thing to note is that it can only be applied along a streamline.

We can define a streamline in **steady flow** as the **path** traced by a single particle within the fluid. Or more technically as a **curve** that at all points is tangent to the particle velocity vector.

Let's look at an example where we apply Bernoulli's equation to flow through a pipe which has a change in diameter. We want to use the equation to see how the pressure changes as the flow passes from the larger to the smaller diameter.

Bernoulli's equation is usually used to compare the flow at two different locations, so we can rewrite it like this, with points 1 and 2 both being on the same streamline. There is no significant change in elevation between Points 1 and 2, so the potential energy terms cancel each other out. And if we put all of the static pressure terms on one side we get this equation for the change in pressure.

If we assume that the fluid is **incompressible**, the mass flow rate at points 1 and 2 must be equal. This gives us what is called the **continuity equation**, which is just a statement of the **conservation of mass**. Mass flow rate is equal to the product of the fluid density, the **pipe cross-sectional area** and the fluid velocity.

So we can re-arrange the continuity equation to obtain an equation for the velocity at point 2. The cross-sectional area A2 is smaller than A1, which means that the velocity of the flow increases as it passes into the smaller diameter pipe. This is quite intuitive.

By substituting this equation for V2 into Bernoulli's equation, we can see that since the velocity increases between Points 1 and 2, the pressure between both points must decrease.

This concept, that for horizontal flow an increase in fluid velocity must be accompanied by a decrease in pressure, is one way of formulating what we call **Bernoulli's Principle**.

### Hydraulic jump and energy dissipation

The most common application of the **momentum equation** in **open-channel flow** deals with the analysis of the **hydraulic jump**.

The rise in water level, which occurs during the transformation of the **unstable rapid** or **supercritical flow** to the **stable tranquil** or **subcritical flow**, is called hydraulic jump, manifesting itself as a **standing wave**. At the place, where the hydraulic jump occurs, a lot of energy of the flowing liquid is dissipated (mainly into heat energy). This hydraulic jump is said to be a **dissipator** of the **surplus energy** of the water. Beyond the hydraulic jump, the water flows with a greater depth, and therefore with a less velocity.

The hydraulic jump has many practical and useful applications. Among them are the following:

- Reduction of the energy and velocity **downstream** of a **dam** or **chute** in order to minimize and control erosion of the channel bed.
- Raising of the downstream water level in irrigation channels.
- Acting as a mixing device for the addition and mixing of chemicals in industrial and water and wastewater treatment plants.

In natural channels the hydraulic jump is also used to provide aeration of the water for **pollution** control purposes.

However, before dealing with the hydraulic jump in detail, it is necessary to understand the principle of the so-called **specific energy**. We will apply this principle for explaining the hydraulic jump **phenomenon**. In the following the flow is supposed to be **two-dimenssional**.

momentum equation – рівняння кількості руху

unstable rapid or supercritical flow- нестабільний швидкий або надкритичний потік

stable tranquil or subcritical flow - стабільний спокійний або підкритичний потік

standing wave - стояча хвиля

surplus energy - надлишкова енергія

chute – лоток

datum plane – данна площина

Plotting - складання

**Video A Rolling current in the Jordan River**

**https://www.youtube.com/watch?v=XsYgODmmiAM**

This is a video presentation of a rolling current in the Jordan River as presented at the 2012 Salt Lake watershed symposium presented by dr. Roland Hotchkis and Edward Kern from Brigham Young University. First we're going to take a look at a specific incident that occurred on the Jordan River. Then we're going to take a step back and look at a few basic principles fluid mechanics namely energy dissipation and hydraulic jumps. Then we're going to talk about the types

of hydraulic jumps at overflow structures. After that we will talk about the solutions to limit danger at overflow structures.

Now let's look at what happened on the Jordan River as reported a local news agency.

- And I know it looks small but it's a pretty deadly little thing.
- Two people are dead after kayaking over a deceptive looking waterfall in the Jordan River. The couple from Sandy and their friend were simply trying to enjoy a day on the river.
- They put their kayaks in near 114 south and the Jordan River Parkway. They ran into trouble when each went over a small waterfall near Murray.
- It was this waterfall that proved to be deadly for Joseph Glasser and his wife Kelly. Their kayaks flipped and got sucked into the water by the undertow. Kevin witness saw the glasses tried to make it over the waterfall.
- I ran down and grabbed a branch to see if I get a branch out to him but they were right in the middle
- He saw the couple's friend a third kayaker come through and make it across safely the two got the blesser out of the water we drag him branch to see if I get a branch out to him but they were right in the middle.
- He saw the couple's friend a third kayaker come through and make it across safely the two got 49 the blesser out of the water.
- We drag him up on the bank and started CPR on him about then very fire department got on sight.
- Swift water rescue teams use the ropes to pull 51 year-old Kelly Glasser out of the fast-moving water. They then began CPR.
- When they were found here neither one of more breathing or had a pulse.
- Kelly Glazer and a husband were rushed to Intermountain Medical Center both for pronounced dead. Wizna says despite having floatation devices on they simply underestimated the power of what looked to be a small simple waterfall.
- The people don't realize what a small little water falls maybe a foot and a half on tops but it just it has an undercurrent that is just deadly.
- Now there are signs posted in the area warning voters to get out and walk around the rapids because the current is too swift

Now let's talk about what happened on that tragic day.

As water goes over a drop structure like shown in this figure, it picks up momentum. When that water reaches the surface of the water at the base of the structure it entrains a lot of air, which it then pulls to the bottom of the channel. Now the water has a lot of momentum so it carries this air downstream along the bottom of the channel. When the air finally begins to rise, it rises at what we call the boil point. Anything upstream of the boil point gets pulled back towards the face of the drop structure. Anything downstream goes on its merry way down the river.

The next question is

- is this an isolated incident or has this occurred elsewhere. The following video is a body recovery attempt that happened in Binghamton New York. Binghamton New York 1975 a television news team videotaped this attempt to recover the body of a fireman drowned during a rescue today before. the boat is approaching the boil that the fire chief of the boat.

In Binghampton New York that day there was at least one survivor however not everyone in that boat survived. At BYU a student named John Diamond began a database to keep track of fatal incidents that have occurred across the United States. He has recorded 65 locations across the country where fatalities have occurred. And a total of over 300 deaths are recorded. This database is woefully incomplete. We know that there is at least one location in every state where a fatality has occurred based on the literature that we've read. We also know being that I am a native of Southern California that there are many drainage canals in. That there are many drainage canals in Southern California where this has been a problem.

Now let's talk about why low-head dams are built in the first place. Usually it is because we need a guaranteed water surface elevation. If we have a field we want to irrigate. We don't want to have to pump the water out because that's expensive. Instead we go a little bit upstream in the river, we dam it up so that the elevation of the water is just higher than our field. And then we let the water drain to our field like shown here. Local dams and diversions come in all different sizes. Take for example this one at about 4,500 South on the Jordan River about three miles away from where that deadly current developed. On this diversion you can see that even during low flow like right now you can still divert water out of the river because you have that guaranteed water surface elevation.

Now let's take a step back and start looking at some basic principles of fluid mechanics. This here is the hydraulic jump this is the ultimate cause of the keeper or the roller or that dangerous current. So, what you have is, you have very fast-moving water coming from the right. It's very fast it's very shallow. Then you get a very turbulent region where the water level increases dramatically. After that you have a higher what we call tail water elevation. So the water downstream is much higher than the water coming in and therefore it is also slower. So a question that was posed during the Salt  Lake watershed symposium was does the hydraulic jump occur naturally? And the answer to that question is yes so let's look at an example. This is my kitchen sink turn on the water and you get very fast-moving water where the water stream meets the sink. Then as the water goes up against the side of the sink its impounded and it tries to get back towards where the falling water is. But it can't that is a hydraulic jump that you see here. Where the water is very shallow very fast. Then you have turbulence and air bubbles. Then you have the water impounded against the side of the sink. Now let's talk a little bit about what we can do to predict hydraulic jumps. We are going to talk about the principles required to predict hydraulic jumps. But we are going to do it very quickly.

Let's talk about a few ways that we can describe the flow. The first is with something called specific energy. It's essentially the amount of energy that the fluid has according to Bernoulli's equation. The next way we have to describe the flow is the momentum factor the momentum factor takes into account the momentum of the fluid as well as the hydrostatic force of the fluid. If we assume steady flow we can find what the specific energy and momentum factor are for different water surface elevations. In the graph here the water surface  elevation is shown on the horizontal axis. An important fact is that momentum is conserved across a hydraulic jump. The water going into the hydraulic jump has  the same momentum as the water coming out of the hydraulic jump. But there is energy loss as water passes through the hydraulic jump. There is a lot more energy going into the jump than there is leaving the jump. Hydraulic jumps can form when there is a sudden change in the slope of a channel or where fast-moving water meets slow-moving water. Like in my sink when the water couldn't go anywhere when it hit the  edge of the sink. Let's look at how we make a hydraulic jump in the lab. This is water flowing in the flume and the hydraulics lab at BYU. To make a jump we create hightail water or we force the water surface on the downstream end of the

flume to rise. We do this by raising a gate at the end of the float. As we continue to raise the gate we force jump to migrate up the channel. In this case it is more important to look at what is happening on the downstream end. The fast-moving water would have continued to flow quite quickly if we did not force the water to slow down at the base of the flow. Now take a moment to look at what's happening at this hydraulic jump, what's coming in, what's happening at the jump and then what  happens afterwards. Now let's talk about hydraulic jumps at drop structures. There are four cases of hydraulic jumps at drop structures.

The first case is case A where the falling water has enough momentum to push the hydraulic jump a short distance away from the face of the structure. This is  called a swept out jump.

The second is case B it is similar to case A because the momentum of the falling water is able to push the jump away from the face of the structure. But this is also where the jump forms right at the base of the structure. This is sometimes called the optimum jump because it minimizes the distance. The jump is away from the structure. But also forms a safe jump that means that the energy from that is easy to contain. These two cases form what we call fully developed hydraulic jumps. This is where the momentum factor of the falling water is greater than or equal to the momentum factor after the jump. In other words when the falling water coming down the structure has enough force to push the tailwater away from the face of the structure. We think that calling a case B jump an optimum jump is a bit of a misnomer from a public safety standpoint. The reason is that a case B jump is sensitive to tail water depth. If we lower the tail water the hydraulic jump will move away from the structure and will no longer have a case B jump but a case A jump.

If we raise the downstream water then it will form a case C jump. A case C jump is no longer a fully developed jump but a submerged jump. Since the hydraulic jump is very turbulent there is a lot of air entrained in the jump. When the jump is forced against the face of the drop structure the air entrained water is forced to the bottom of the channel where it travels downstream. The air rises to the surface and forces a large amount of water to follow. Some of this water that is forced to the surface doubles back towards the face of the drop structure. the case C or submerged hydraulic jump is defined by the current doubling back at the surface. It is as recirculating current toward the face of the drop structure that can make the submerge hydraulic jump dangerous.

Case D jump forms when the tailwater is nearly the same as the surface of the water passing over the structure. Air entrainment is minimal and the water simply starts to move a bit faster as it travels over the structure. Since there is no upstream surface velocity this jump does not pose a public safety hazard like a case C.

So now let's look at the different cases of hydraulic jumps in the lab. We put a drop hydraulic jumps in the lab. We put a drop structure in the flume and we're going to watch as barbies buddy Ken goes over this drop structure.

Now let's watch that from a different angle Ken is swimming having a good time. He goes over the structure passes through the jump and safely continues his exciting journey. Now for the case B jump Ken goes over still passes the jump, still has a good day. Notice how little the tail water changes from case B to C. So here's Ken on a lovely summer day and his day is now ruined and just look at how fast the water on the surface is moving back towards the structure. And this shows why this current is just so dangerous. Now we're going to increase the tailwater and as you can see the C jump still forms. Although in this case the current is weak enough that Ken might be able to swim out of it. Now for a case D jump here's Ken passing the structure and able to go home from his vacation. Here he is again and having a great time. Now let's look at these cases outside the lab. This is a place called Howard's hole. It's located at 7800 south on the Jordan River. I would call this a case B since the jump is pretty much right at the base of the structure.

Hydraulic jump – гідравлічний стрибок
energy dissipation – гасіння енергії
overflow structures – водозливні споруди
deceptive – той що вводить в оману
flip - кувиркатися
suck – засмоктувати
undertow – валець
blesser – блаженний , щасливець
CPR - ardiopulmonary resuscitation - серцево-легенева реанімація
Undercurrent – підтоплення
Voters – виборці
Rapids – пороги, швидко токи
Current – течія

Crest - гребінь
Jet - струминка
Entrapment zone - Зона захоплення
Buoyancy - Плавучість
Super critical – вище критичної
Subcritical – нижче критичної
Momentum – імпульс (енерція)
Entrains – вміщати
Pull – тягнути
Diversion – відхилення, відведення
Tailwater – нижній б’єф
ultimate  - остаточний
keeper = roller – валець
shallow – неглибокий
specific  energy – питома енергія
momentum  - імпульс
momentum factor – коефіцієнт кількості руху, кінетичної енергії
steady – усталений рух
elevation – висота
conserved – зберігся
flume – лоток
swept out jump – недосконалий стрибок
optimum jump – досконалий стрибок
fully developed jump – повністю розвинений стрибок
submerged jump – затоплений стрибок
alteration – зміна
inherently – за своєю суттю
scour – промоєни
boulders - валуни
impound - прив'язувати
retrofitting - модернізація

low-head dam – низьконапірна гребля
standpoint – точка зору

sloping Boulder spillway – похилий водозлив  укріплений валунами
boulder face – поверхня валунів
riprap – кам’яний накид