LECTURE NOTES – I

« HYDROELECTRIC POWER PLANTS »

Prof. Dr. Atıl BULU

Istanbul Technical University
College of Civil Engineering
Civil Engineering Department
Hydraulics Division

Chapter 1

Potential Energy of Surface Water

Every particle of water that appear, either as precipitation or as ground water, on the surface or in the ground disposes of a definite potential energy, the magnitude of which depends upon the elevation above sea level of the ground where it reaches the surface or where it emerges from ground.

The flowing water has a kinetic energy as well which is $V^2/2g$, which is comparably high at the steep areas usually in uplands around 5 – 6 m/sec and decreases to 1 – 2 m/sec in lowland areas, or at the mouth of the river.

When descending from the high elevations to the sea or the lake, the surface flow as rivers, potential and kinetic energies are converted to non-usable energy, the kinetic energy loss being negligible as compared to the potential energy.

The potential energy is dissipated to overcome internal friction of turbulent flow, to supply energy to whirls, eddies and spiral flows, to scour the material of the river bed and to transport bed load, while the water is descending to a body of water. The mechanical work, wasted in overcoming frictional resistance (bed resistance), is converted entirely into heat and lost.

The fundamental principle of water power development is to reduce the amount of energy dissipated as heat without paralyzing the flow of water.

Friction (energy) losses can be reduced in principle by three methods:

1. In any stretch of the river, the energy loss required for the conveyance of water is reduced by decreasing the velocity of flow.

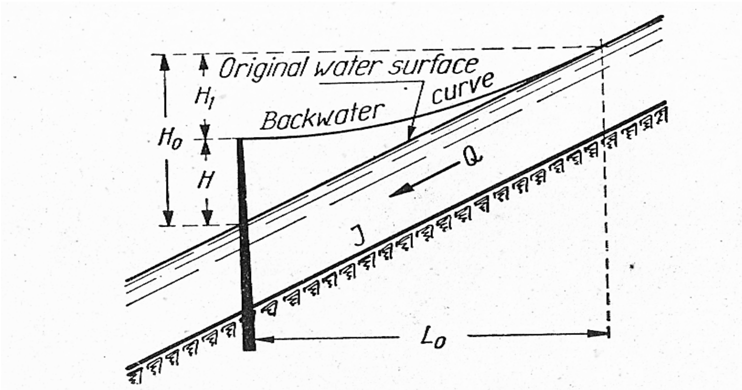
$$V = \frac{1}{n} R^{2/3} S_0^{1/2}$$

$$S_0 = \frac{V^2 n^2}{R^{4/3}} \rightarrow h_{loss} = S_0 L$$

$$S_0 \downarrow \rightarrow V \downarrow \rightarrow h_{loss} \downarrow$$

This can be achieved by increasing the depth of water through building dams. Thus at the dam, between backwater level and the natural surface of the stream, a certain head H is formed. For creating head H, backwater should be produced with a non-uniform flow curve (M1) extending to distance L_0. Out of the total water level difference H_0, on a river section L_0, with channel slope S_0, the head available for utilization is H, while the potential energy H_1 is dissipated in overcoming the reduced frictional resistance in the stream. The *degree of utilization of potential energy* in any section L_0 relating to an assumed head H, for any given discharge Q, is expressed by,

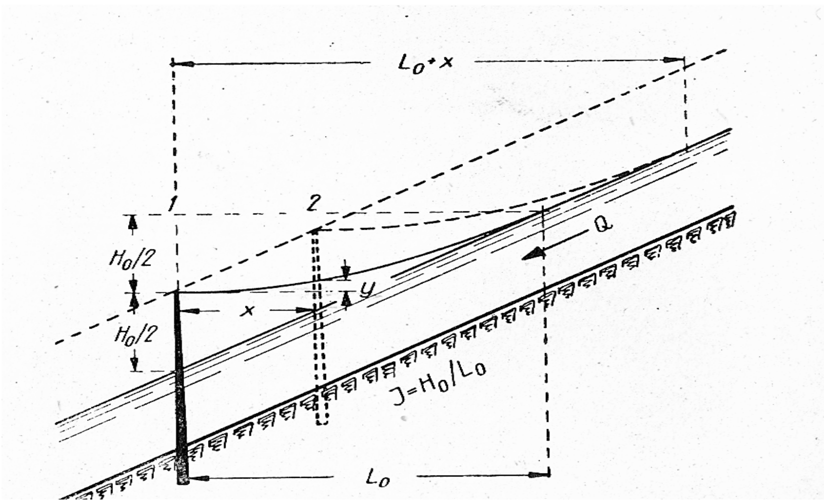
$$\eta_m = \frac{H}{H_0}$$



If a second dam is constructed at the downstream of the same backwater curve, the utilization is around 50%.

By erecting a series of dams and weirs, a considerable portion of potential energy in any stream or in an entire river basin can be utilized.

Let us examine two dams at an arbitrary distance x from each other, which does not exceed L_0 and staying in the same backwater curve.



It is assumed that the backwater can be substituted by a quadratic parabola. The head created at the upper dam at distance x from the lower one can be expressed as;

$$S_0 x - y = \frac{H_0}{L_0 x - y}$$

When taking into consideration that,

$$\frac{H_0}{2} = cL_0^2$$

For the rise y of the backwater parabola, we get,

$$y = cx^2 = \frac{H_0}{2L_0^2}x^2$$

The total head created by both dams is,

$$H = \frac{H_0}{2} + y = \frac{H_0}{2} + \frac{H_0}{L_0}x - \frac{H_0}{2L_0^2}x^2$$

As the utilization of the above head refers to section (L_0+x), the mean hydraulic slope available for utilization,

$$S_u = \frac{\frac{H_0}{2} + \frac{H_0}{L_0}x - \frac{H_0}{2L_0^2}x^2}{L_0 + x}$$

The maximum value of J_u is determined by,

$$\frac{dS_u}{dx} = 0$$

$$S_u = \frac{H_0L_0^2 + 2H_0L_0x - H_0x^2}{2L_0^2(L_0 + x)}$$

$$\frac{dS_u}{dx} = \frac{d}{dx}\left[\frac{H_0}{2L_0^2}\left(\frac{L_0^2 + 2L_0x - x^2}{L_0x}\right)\right]$$

$$\frac{dS_u}{dx} = \frac{(2L_0 - 2x)(L_0 + x) - (L_0^2 + 2L_0x - x^2)}{(L_0 + x)^2} = 0$$

$$-x^2 - 2L_0x + L_0^2 = 0$$

$$x_{1,2} = \frac{-2L_0 \pm \sqrt{4L_0^2 + 4L_0^2}}{2}$$

$$x = -L_0 + 2L_0\sqrt{2} = L_0\left(\sqrt{2} - 1\right) = 0.414L_0$$

$$S_{u\max} = \frac{\frac{H_0}{2} + \frac{H_0}{L_0} \times 0.414L_0 - \frac{H_0}{2L_0^2} \times (0.414L_0)^2}{L_0 + 0.414L_0}$$

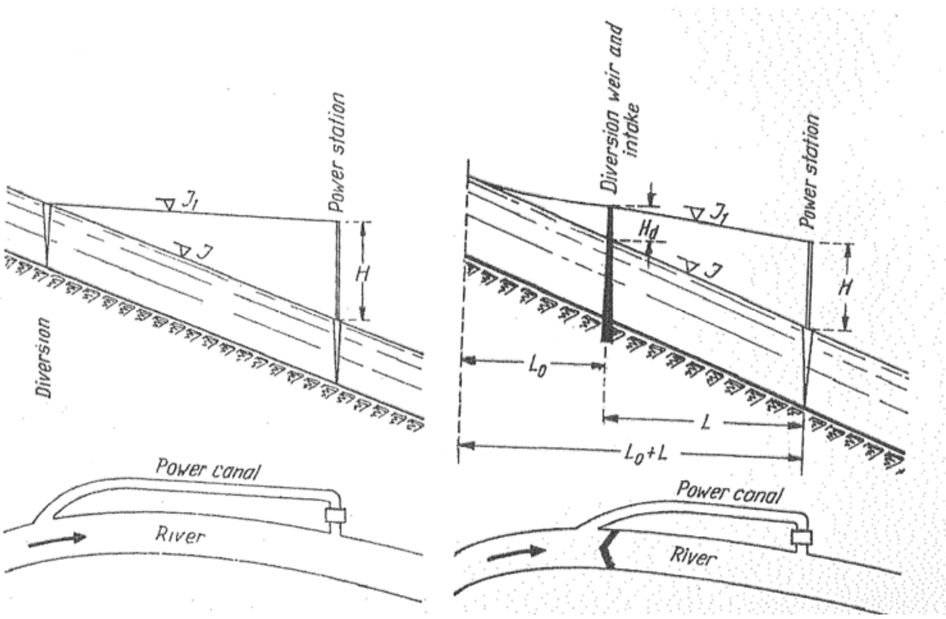
$$S_{u\max} = \frac{0.828}{1.414} \times \frac{H_0}{L_0} = 0.586\frac{H_0}{L_0}$$

The degree of utilization is,

$\eta_m = 0.586$

It can be proved that, by increasing the number of dams, the degree of head utilization can be raised hydraulically, but it is questionable whether or not this solution is economical as far as construction costs are concerned. If three dams are installed on the same backwater curve, the degree of utilization is 0.670 while in case of four dams this value is increased to 0.725. Whereas the ratio between developments with two and four dams amounts to 0.725/0.586= 0.24 increase in the degree of utilization, the costs of investment go up excessively and may reach almost the double. It can be concluded that by a series of dams, not more than 60% of the total head can be developed.

B) Another method of reducing the head required for the conveyance of water is to divert the whole part of the flow into an artificial bypass, usually termed *power canal,* the slope of which is considered flatter than that of the original water course. The difference in elevation between the power canal and the original watercourse is thus gradually increased and a head available for power generation at the most suitable site is created.



How can this gain in elevation be obtained? Again through the reduction of frictional losses, that is, through improving conveyance conditions by shaping the canal according to a design of a suitable cross-section, by removing aquatic growth from the bed and by lining the canal. The resulting head can be especially high if there are rapids in the original water course.

The diversion of water into power canal is affected by a diversion dam or weir built across the river bed. The head created for the purposes of utilization on any river $L_0 + L$ is,

$$H = H_d + (S - S_1)L$$

Out of which,

$$\left(S - S_1\right)L$$

Is the gain in head attributable to the power canal of length L.

In case of developments with power canals, the degree of utilization varies very wide limits and under average conditions a value $\eta_m = 0.80$ can be assumed.

C) If the river is sinuous and especially if the valley itself is characterized by sharp or horseshoe bends, they can readily cut by a channel or a tunnel. With this of development, a difference in elevation capable of being utilized is obtained.

In power utilization the above mentioned possibilities of developing the available fall are usually combined.