Cavitation for Outlet piping and valves

Cavitation in pipe:
From the drainage piping, the dam enters into a free atmosphere, so the total height pressure is consumed to create a flow rate of water and loss in the pipeline. Therefore, there are high flow rates and low pressures inside the discharge pipe, unlike the inlet pipe to the hydroelectric power plant, which is a very favorable condition for cavitation.
In the case of a pressure pipe, a strong pressure drop can result in a sudden or gradual expansion of the cross section (in the narrower cross section) and in the curved parts of the pipeline of the most curved water fibers. With the gradual expansion of the pipe, the absolute pressure in the narrower section of the cross section is closer to zero, and thus there is a greater risk of cavitation than in the suddenly expanded pipe. In practice, however, zero pressure in the pipeline cannot arise because water is excreted out of the water when the pressure drops, the gases contained in the water and forming water vapor.
At normal temperatures, the water vapor pressure is about 0.1 m of the water column and therefore the cavitation boundary will be 10 m under the pressure.
So, we will expect cavitation phenomena wherever we experience under-pressure, that is, pressures lower than atmospheric, and where the under-pressure reaches considerable values approximating the absolute value of barometric pressure.
From the basic Bernoulli equation

$$\frac{v^2}{2g} + \frac{p}{\rho g} + h = constant$$

it follows that the pressure value is the smaller, when the dynamic pressure and the height position above the base plane greater. From the position, we expect that cavitation phenomena will be expected at the upper part of the outlet pipes rather than at the bottom.
Reduction of pressure and speed increase occurs at each narrowing of the flow profile. However, in the case of a reduction in pressure due to the change in these two factors (velocity and position), we know beforehand what reduction occurs and we avoid the value of the under-pressure causing the cavitation. However, the most important but most predictable factor in under-pressure and cavitation is the pressure drop due to the curvature of the current fibers, which is not reflected in Bernoulli's basic equation. The pressure drop on the internal (convex) side of the curvature of the current fibers occurs at the inlet into the pipe, in all arcs and changes of direction, in all the obstacles inserted into the water stream and in the interruption of the water flow in the protruding and receding surfaces etc. Whether the pressure drop is such that under-pressure or even cavitation occurs in each case is to be considered in particular on the basis of analysis and experience, and in controversial cases the pressure must be verified by laboratory research.
The most common in water engineering are under-pressure and cavitation phenomena when the dam is drained. Here, under-pressure can occur at the inlet, in pipes, in grooves, valves, elbows and unevenness. We face the under-pressure by the correct hydraulic designing of the outlet pipe, and if we cannot avoid cavitation and under-pressures (e.g. for some types of valves), we use aeration piping. When assessing the possibilities of incidence of cavitation in outlet pipes, it is necessary to draw on the hydrotechnical calculations of the course of the pressure line and its position relative to the axis of the pipeline.
In order to raise the pressure line above the outlet at all points at least at high pressure and to prevent easy cavitation at all inequalities, we introduce outlet piping protection by

reducing flow area outlet. This will give us a sharp rise in pressure against the water, because not only the increased pressure loss of the friction and change of profile, but above all the difference in the dynamic pressure. Where there is an output valve at the end, its flow area is less than the area outlet pipe about 11-17%. Thus, for the tube valve, the outlet area is about 83% of the pipeline area. Where the valve is not outlet pipes at the end, we must introduce the outlet pipes protection by reducing the outlet profile. However, it is still necessary to place emphasis on the careful execution of the entire outlet pipes and the elimination of all unevenness at high pressures, and thus with high water velocities.

Cavitation:

Cavitation starts with a cavitation number $\sigma \leq 3$

$$\sigma = \frac{p_0 - p_{vap}}{\frac{v^2}{2g}}$$

σ	cavitation	[]
p_0	absolute specific pressure before cavitation	[m]
p_{vap}	water vapor pressure	[m]
v	speed before cavitation	[m/s]
g	gravitational acceleration	[m/s^2]

Absolute specific pressure before cavitation:

$$p_0 = H - \frac{v^2}{2g} - \sum \xi * \frac{v^2}{2g} + 10$$

p_0	absolute specific pressure before cavitation	[m]
H	pressure height before cavitation	[m]
v	speed before cavitation	[m/s]
Σ ξ	the sum of pressure losses before the cavitation	[]
g	gravitational acceleration	[m/s^2]

Water vapor pressure:

$$p_{vap} = 0{,}1m$$

p_{vap}	water vapor pressure	[m]

Example:

We have to determine cavitation number with the following parameters for operating valve which is located on the air side and is open to 100%:

Pressure height before cavitation H = 24m; diameter before cavitation d = 2m; steel pipe length l = 22m; loss in trash rack ξ_1 = 0,1; loss in the inlet ξ_2 = 0,25; loss in the revision valve ξ_3 = 0,24; pipeline flow Q = 42,724m^3/s.

Friction on pipe walls:

$$\xi_4 = \lambda * \frac{l}{d} = 0{,}026 * \frac{22}{2} = 0{,}286[\,]$$

The sum of pressure losses before the cavitation:

$$\sum \xi = \xi_1 + \xi_2 + \xi_3 + \xi_4 = 0{,}1 + 0{,}25 + 0{,}24 + 0{,}286 = 0{,}876[\,]$$

Flowing area:

$$F = \frac{\pi d^2}{4} = \frac{\pi 2^2}{4} = 3{,}142[m^2]$$

Speed before cavitation:

$$v = \frac{Q}{F} = \frac{42{,}724}{3{,}142} = 13{,}599[\,m/s]$$

Absolute specific pressure before cavitation:

$$p_0 = H - \frac{v^2}{2g} - \sum \xi * \frac{v^2}{2g} + 10 = 24 - \frac{13{,}599^2}{2 * 9{,}81} - 0{,}876 * \frac{13{,}599^2}{2 * 9{,}81} + 10 = 16{,}316[m]$$

Cavitation:

$$\sigma = \frac{p_0 - p_{vap}}{\frac{v^2}{2g}} = \frac{16{,}316 - 0{,}1}{\frac{13{,}599^2}{2 * 9{,}81}} = 1{,}720 \rightarrow Cavitation$$

Literature:

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