
CAVITATION EROSION IN STREAM CHANNELS

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INTRODUCTION. The term, cavitation, means the production of vapor-filled cavities or bubbles in a flowing liquid. It is the collapse of these cavities that results in the generation of high pressure impacts or hammer-like blows that give certain portions of stream channel walls and beds a pitted, sand-blasted, or frosted appearance. Commonly the bubbles form and collapse very close together, for cavitation is a localized phenomenon. Although the high pressure impacts are in some target area, there are differing aspects of cavitation damage. Cavitation is a surface attack, and the damaged area suggest hammering or the removal of tiny pieces of rock. There may be merely roughened surfaces or deeply pitted ones. Severe cavitation may produce depressions as much as two feet in depth. Some rocks yield only because of fatigue. Instead of crystal fracture, there may be crystal deformation, possibly some sliding, and finally the formation of fatigue cracks in zones of weakness. It is not always possible to distinguish between cavitation damage and the erosion caused by sediment-laden waters.

When cavitation erosion is taking place there is crepitation and vibration. The noise is comparable to that made by a number of firecrackers exploding in rapid succession with intermittent loud reports. Such noises become a steady roar, if cavitation is severe. The thuds of low energy blows and the clicks of high energy blows from collapsing bubbles in the high velocity flow of the Middle Popo Agie near Lander, Wyoming, were heard, but it was not possible to examine the surface being pitted. There was a very slight and momentary vibration of the ground near the stream. This vibration could be felt through the soles of the shoes.

Vortices which formed near the bank of this stream increased in size very rapidly. They had a core of bubbles such as those produced by marine propellers. When the vortices collapsed there was an especially loud noise, and a small column of mist and minute bubbles filled the central opening of the vortex. Sometimes this misty spray shot up a few inches before it was engulfed by the whirling waters. Other vortices emitted a small smoke-like cloud when they collapsed. Three or four vortices would appear in rapid succession and in a few moments others would appear.

On streams in the Duluth, Minnesota, area a few cavitation surfaces were found in channel walls after a big spring flood. The floor of a concrete and quarried rock bridge had a large pit probably formed by cavitation erosion during especially high water. Some of the baffle piers below a dam showed signs of cavitation erosion.

CONDITIONS FAVORABLE FOR CAVITATION. Cavitation may occur if there is a localized low pressure area in the channel, but rock damage takes place immediately downstream in an area of considerably higher pressure. Whether or not a low pressure area will cause cavitation depends upon conditions elsewhere in the channel, either upstream or downstream. General cavitation may occur when the average pressure at any cross section of flow approaches the vapor pressure of the liquid. Local cavitation may occur if the conditions are favorable for general cavitation. High velocity flow is another variable to be considered, and it is closely linked with pressure conditions. A non-streamlined channel offers favorable locations for the development of cavitation. Sharp bends, abrupt corners, abruptly flaring cross sections, any depressions or protuberences, or even a roughened surface may produce the necessary pressure area. Cavitation may develop any place where vortices may form. If cavitation once starts in any depression, no matter how small, it will develop in intensity and severity as it enlarges the target area. Cavitation erosion will cease when the depth of water in the depression, or on a larger scale, a plunge pool, is sufficient to cushion the blows of the cavitating water.

Although cavitation is thought of as a phenomenon of a non-streamlined channel, it may originate as a result of the mixing of two jets of water. Stream bed configuration of the Middle Popo Agie was such that there was an intermixing of jets of widely differing velocities. This was responsible for the cavitation that was observed. In a waterfall a high velocity jet may impinge on and merge with one of low velocity. When that happens such tremendous turbulence may be produced that a large number of whirling vortices are formed. Those vortices that form along the line of demarcation between the driven water and the mixing zone are capable of doing the most damage. When the vortices form and the average pressure is sufficiently low, vapor pockets form at the center of each vortex. As the vortices make their way downstream and towards the boundary surfaces, the core of each becomes a cavity. The progressive collapse of each vortex gixes rise to the projection of water at terrific velocities. Severe cavitation damage them results.

MECHANICS OF CAVITATION. When stream flow is increased, velocity head is increased, and there is a compensating reduction in pressure head. This relation between velocity head and pressure head holds good until at some point within the liquid, the absolute pressure reaches the vapor pressure. Since the absolute pressure cannot go beyond this point, a marked change occurs. There is an interconnected pressure pulsation and condensation and evaporation of vapor pockets. The time from pressure rise to pressure dissipation is almost instantaneous, i. e. it probably does not exceed 10 microseconds, but the rise and fall may be repeated more than 10,000 times per second at some points. When the pressure is increased above the vapor pressure, the vapor turns to liquid so that the cavities suddenly collapse. When the cavities collapse near a rock surface they pit it much as a rain shower does the ground, but the hammer-like blows are in some target area. If however, the bubbles do not form near some boundary surface, their collapse sets up a supersonic or near supersonic compression wave. If the amplitude of this wave is very large a number of cavities may be formed and the channel severely pitted. The wave travels with a velocity of about 500 fps.

RESISTANCE OF ROCKS TO CAVITATION. Porous rocks are easily damaged by cavitation, but if their surfaces are covered with oil they will suffer little or no cavitation damage. Cavitation erosion may be severe if the rocks are brittle, or contain large or flaky minerals. Rocks containing sulphur or the ferric iron minerals are readily broken down by cavitating water. Some rocks yield only because continual bombardment causes them to develop fatigue cracks. In all cases the sudden application of pressure of perhaps 10,000 psi from collapsing cavities will cause more damage than a slower application of the same pressure. Since cavitation is a surface attack, it is questionable whether or not a thin hard surface will offer greater resistance to pitting than will a thick layer of lesser hardness.

Other factors being equal cavitation erosion will be more severe when the waters of a stream are warm than when they are just above the freezing point. Colder waters have entrained in them more oxygen and other gases which act as an air cushion and hence reduce the force of the blows engendered by the cavitating waters. A high percentage of sodium chloride in a stream will act to increase the severity of cavitation erosion.

CONCLUSIONS. Cavitation is responsible for much of the rapid deepening of plunge pools during floods. It may cause rapid channel widening, the development of big holes in stream beds, and the relatively rapid lowering of some waterfalls. It is suggested that the formation of crescentric scars on the channels of streams flowing under glaciers during deglaciation, may have been caused by cavitation erosion. In outline they are the same as those formed in some instances by cavitation erosion. In spite of the low temperatures of waters of those streams, channel configuration may have been especially favorable for the development of severe cavitation. Likewise the flow would be in closed channels very often, rather than in open channels. This fact would doubtless favor the development of cavitation..