The Dangers of Flood Scouring on Buried Pipeline River Crossings

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Pipelines that traverse a river are often buried beneath the riverbed and channel banks (see Figure 1). If the pipeline becomes exposed, it can be damaged by flowing water, debris transported in the water, or a phenomenon called vortex-induced vibration (VIV).

River Scour

River scour is defined as the erosion of a riverbed (vertical scour) or riverbanks (lateral scour) by flowing water. Scour can occur gradually or episodically during floods. Factors that control scour are the river flow, the characteristics of the riverbed and riverbank sediments, and the capacity of the river to transport sediments. Construction or other changes upstream and downstream of a pipeline crossing can influence river flow and channel morphology.

Riverbed scour occurs when the shear stress induced on the riverbed by flowing water exceeds the resistance of channel bed material (i.e., the critical shear stress for erosion). The eroded sediments are transported as bed load (i.e., movement of the bed material by rolling, sliding, or saltation along the bed) or suspended load or both, depending on the composition of the bed material. Riverbed scour may occur due to high flows, a decrease in the sediment supply (such as might result from construction of a dam upstream), or an increase in longitudinal slope of the channel resulting from reduction in channel sinuosity or loss of river floodplain with distance downstream.
Riverbank erosion typically occurs when higher flows within an incised channel cause increased forces along the channel banks that exceed the resistance to scour of the channel bank material. Erosion of one or both banks leads to widening of the river. The process of aggradation (sediment deposition) in the river may result in the formation of sand and gravel bars in the channel. The sand and gravel bars concentrate flows against one or both banks causing erosion of the riverbank and widening the river, potentially exposing a buried pipeline at its approach to a crossing.

Once the pipeline is exposed, debris in the flowing water, specifically during high-flow events, can directly impact the pipeline resulting in failure of the pipeline crossing. In addition, an exposed pipeline may experience vibration due to the flowing water.

**Vortex-induced Vibration of an Exposed Pipeline**

A pipeline subject to a flow perpendicular to the axis of the pipeline will experience vortex formation and vortex shedding in its wake. This vortex shedding leads to oscillating forces on the pipeline, as shown in Figure 2. If the frequency of vortex shedding is close to a natural frequency of vibration of the pipeline for a specific vibration mode, the oscillating forces will cause vibration of the pipeline. This phenomenon is known as vortex-induced vibration (VIV). Since VIV relies on matching between a forcing frequency—the frequency of vortex shedding—and a natural frequency of vibration, it is an example of resonance. It is different from classical resonance, however, because the motion of the pipeline influences the frequency of vortex-shedding in the wake and can adjust the vortex shedding frequency such that it “locks-on” to the natural frequency of the structure. This “lock-on” phenomenon means that VIV is a problem over a much wider range of frequencies than would be expected under classical resonance.

A pipeline can vibrate due to VIV in both the transverse direction (perpendicular to the direction of flow, which would be up and down in the case of a typical river crossing) and the in-line direction (along the direction of flow). Transverse VIV typically results in larger amplitudes of vibration and thus larger stresses on the pipeline. Vibration amplitudes equal to the diameter of the pipe are possible. The frequency of vibration scales linearly with the flow velocity and inversely with the pipe diameter. For example, if the pipeline is 1 foot and diameter and flow velocity is 10 ft/s, the vortex shedding frequency is approximately 2 Hz. At double the flow velocity (20 ft/s), the frequency doubles to 4 Hz. Thus, such a pipeline experiencing VIV will experience oscillatory stresses on the order of one cycle per second or about 100,000 cycles per day. The cyclic stresses can cause fatigue failure of the piping.

![Diagram of vortex-induced vibration](image)

*Figure 2. Vortex-induced vibration of a pipe is caused by the oscillatory forces imparted by vortex formation in the wake.*
VIV is not just a potential problem during the flooding event itself but after the flood event as well, as long as the pipe continues to be exposed. In fact, since VIV is a type of resonance, in some case the stresses can be higher on the pipe when the water flow velocity decreases, if the lower velocity leads to a closer matching of the vortex-shedding frequency to the natural frequency of vibration of the pipeline.

**Conclusion**

Buried pipeline river crossings can be exposed by multiple scour mechanisms. Once exposed, a pipeline may be subject to failure due to hydrodynamic forces of the flowing water, debris carried by flowing water, and/or fatigue failure due to VIV. To prevent breakage and subsequent accidental product releases, all stream crossings should have burial depths and/or erosion countermeasures designed and constructed according to site-specific conditions and acceptable flow return frequencies.

Exponent has extensive experience investigating failures of pipelines and piping systems of various kinds, including pipeline river crossings. We can also provide assistance with assessing designs or current conditions of pipeline river crossings.