INTAKES ON SEDIMENT-LADEN RIVERS

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Contents

Summary

The chapter describes the hydraulic engineering concepts involved in the design and selection of intake structures for water abstraction from sediment carrying rivers and streams. A number of practical solutions involving the exclusion of sediment from water intake works are described, as well as methods of analysis and refinement of design. The fluid dynamic principles governing suspended and bed load are described as well as utilizing these phenomena to exclude sediment as far as possible from entering water abstraction intake structures.

1. Introduction

One of the most difficult problems in hydraulic engineering is the proper design of bulk water intake structures on rivers with high sediment loads, due to the unpredictable nature of entrained sediment and its behavior over time, often resulting in sedimentation problems at intakes, with serious maintenance implications. This article presents an in-depth investigation into the fundamental principles that govern sediment movement in the vicinity of intakes and the available technology. A new approach, based on experience with recent failures in proper functioning of some main intake works, is necessary.

Sediment transport occurs in various forms, depending on the hydraulic conditions of the water body and the sediment properties. The flow energy, or stream power, transports material as bed load, suspended sediments, or both. These are rough classifications made for practical purposes. In reality the two modes of transport are complicated and the distinction between them not clear. There seems to be an intermediate set of conditions where both modes operate together.

These concepts are well-known to the hydraulic engineer, and are mentioned here for the sake of their importance in the design of intake structures. Experience has shown that it is much easier to exclude bed load than suspended sediment from entering intake structures. Therefore, the first step towards proper intake design is to try to influence the sediment distribution by applying appropriate measures in such a way that the concentration close to the bed is maximized. Concerning the transport mechanism, the problem could be divided into two categories: control of bed load, and control of suspended sediment (see *Sediment Phenomena*).

Scheuerlein distinguishes between the following intake types according to the hydraulic principles that govern their function: lateral intake; frontal intake; bottom intake; and suction intake. Three techniques of dealing with bed load are identified: rejection, extraction and ejection. For the control of suspended sediment the only available techniques are the variants of settling basins or detention tanks (see *Sediment Exclusion at Intakes in the Uses of River Water and Impacts*).

2. Siting of Intakes

To avoid eventually problematic intakes, careful consideration on where to position the intake would prove invaluable in future. The following are the most important principles to consider:

2.1 Intakes on Rivers

- The intake should preferably be placed in close proximity and on the upstream side of a hydraulic control point, such as a weir.
- The intake must not be placed in a morphologically unstable reach of river, for instance in some meandering river reaches where oxbows are present.
- The intake should be placed at or near the riverbank on the outside of a bend in a river, where depths are deeper and more stable than on the inside of a bend (see Abstracting Water from Sediment-Laden Streams).
- The water level at the abstraction point should be reasonably stable and the water should be accessible to the intake during low flows.
- If the flow drops so low that it cannot be accessed, abstraction should be assisted by directing the flow towards the abstraction point by means of groins, spur-dikes, or channels.
- With variable water levels, water abstraction pumps could, together with their bell-mouth intakes, be placed on a trolley on a sloping rail track, along the riverbank or reservoir shoreline, for convenient removal of the pumps during floods.

2.2 Abstraction Works from Reservoirs

- The intake should be located as close as practically possible on the upstream side of the dam wall, as this is the area that will be least affected by sediment deposition in the reservoir basin. If sediment does settle in this area, it could be removed by flushing or sluicing through the low-level gates of the dam.

- The delta area in the backwater zone of the reservoir basin should be avoided at all cost for siting abstraction works or intakes, unless sediment levels have already reached an equilibrium state.

2.3 Intakes Taking Advantage of Scour at Bridge Piers or Obstructions in the Flow Path

Ahead of a bridge pier or similar obstruction, the flow stagnates, causing the surface water, which has the highest velocity, to dive and swirl around the obstruction. At a bridge pier the swirl assumes the form of a so-called horseshoe vortex which wraps itself round the pier, scouring a hole at the nose and building a mound on the downstream side. The bed load is diverted away from the upstream side of the pier in the process.

The principle is employed in the design of river intakes situated in the mainstream of the river. By placing the entrance of the intake in such a position that it coincides with the upstream face of a pier-like intake structure, the entry of bed load into the intake can to a large extent be successfully prevented.

2.4 Intakes Taking Advantage of Scouring on the Outside of River Bends

The radially outward increase in pressure with angular acceleration produces a greater depth of water at the outer boundary of a bend, and a considerable velocity gradient adjacent to the bed. As a result the opposing hydrostatic force is greater than the centrifugal force at the bed. A secondary transverse current component is thus induced which is directed radially inwards at the bed. From continuity there must exist also a radially outward directed current component near the surface, so that the resultant motion is spiral or helical in nature. This type of current leads to scouring and transportation of material away from the bank and bed on the outside of the bend and its deposition downstream on the inside of the bed.

2.5 Sediment Distribution over the Flow Depth

It is seen that clays and silts (suspended sediment mainly) are more or less evenly distributed over the depth, while sand (mainly bed load) moves along in a relatively dense concentration close to the bed.

This principle is often used where the clearer upper layer of the flow is separated from the more dense suspension close to the riverbed. Examples are sills and so-called skimming weirs, where the clear water is drawn off over the top of the sill or skimming weir. Another example is sediment tunnels where the upper and lower layers of flow are separated by means of a horizontal apron. The upper layer constituting relatively clear water is abstracted for use and the lower layer containing most of the sediment is conveyed downstream through tunnels and returned to the river.

3. Remedial Measures at Intakes

Several localized devices may be utilized to improve sediment conditions at intakes, such as guide vanes, induced currents, vortex tubes, islands and curved channels.

3.1 Guide Vanes

Guide vanes are used in straight channel reaches to induce localized helical flow patterns in a process called bed sweeping, similar to the patterns generated in flow around a bend as described previously. Two types are generally being used: bottom guide vanes and surface vanes.

- Bottom guide vanes are placed so that their bottom edges are on or near the streambed. The flow over the lower part of the stream prism is redirected by these vanes. Submerged-type bottom vanes direct the water near the bottom away from the canal head works and with it, therefore, also the highly concentrated bed load.

  The height of the vanes relative to the depth of flow is critical, and they can only be used where adequate flow depth can be maintained. Test results indicate that for effective sediment rejection the vane height, *h*, and the spacing, *w*, should be about a quarter and three-eighths, respectively, of the prevailing flow depth. Vanes are not effective if the quantity of water to be abstracted exceeds one-third of the main river discharge.

- Surface guide vanes are suspended from rafts from which they protrude downwards deep enough into the water to influence the flow direction of the surface water. The surface vanes direct the surface water, containing the lowest concentration of suspended sediment, towards the canal head works. This also induces a transverse current, close to the bed, that sweeps the bed load away from the canal head gates.

3.2 Induced Bottom Return Currents

The principle of a bottom return current induced by a parallel barrier wall constructed upstream of the off-take and parallel to the riverbank. Flow stagnation causes the water surface level at A to rise higher than at B. Consequently, a bottom return current is set up from the inside of the barrier carrying bed load away from the off-take. Simultaneously, a diving current of clearer surface water is induced and carried into the off-take.

3.3 Vortex Tubes

Due to the momentum of the water entering the tube which is situated underneath a slot in the bottom of the off-take canal, the sediment moving in the lower layers of the flow enters the tube. It is essentially a horizontal, recessed tube, with a slot in its crown, coinciding with the canal bottom and laid at an angle of from 45 to 90 degrees to the flow.

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Biographical Sketch

Nic Myburgh is a registered Professional Engineer, who graduated with a B.Sc. Civil Engineering degree from the University of Pretoria, South Africa. He has devoted his entire professional career to the service of the Department of Water Affairs and Forestry of South Africa. He has ten years' experience in the design and two years' experience in the construction of canals and weirs on various large irrigation projects, and has been active in project planning over a period of two years. He has considerable experience in the design of hydraulic structures, including dams, canals, intake works, pumping station layout and hydraulic modeling, both physical and numerical. For the past seven years he has been head of the subdirectorate Hydraulic Studies, with a staff of six professionals and twelve support personnel, which includes a Hydraulics Laboratory and a Computer Studies Section. Typical laboratory activities that he directed included the design and testing of hydraulic models of pump station intakes, spillways of weirs and dams, inlet and outlet works, channel controls and sediment studies. Computer studies comprised numerical analysis by means of sophisticated software programming of one- and two-dimensional flow problems, backwater curves, water-hammer calculations, dam-break studies and flood-absorption and -routing computations. Typical projects which he was responsible for included the analysis of a flood-protection dam for a medium-sized town, the exclusion of sediment from a major water-transfer pumping station on a silt-bearing river, the behavior or large reservoirs subjected to sedimentation, and the analysis of pumping mains experiencing transient-flow pressure pulses. In the course of his managerial duties, as project leader of the hydraulic studies group, he arranged a number of inspection-and-study field trips, for staff training purposes, to water works such as pump stations, intakes, canal control structures and flood-subjected areas. He has attended courses and published several papers at international conferences on flood studies and the design of dams and reservoirs, both in South Africa and abroad. He has completed part of his postgraduate studies for the Masters degree at the University of Pretoria, where he has given lectures to graduate students on hydraulic subjects. He is also active in the training of technicians and junior engineers in the water supply field.