WATER RESOURCES ENGINEERING

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Contents

Summary

Basic technologies in water resources engineering are described in the initial part of this chapter. Hydraulics provides knowledge on the prediction of water stage and of flow velocity under various conditions. Hydraulics also provides tools for design of hydraulic structures in river training works and hydropower production. Hydrology provides techniques to determine design rainfall or design discharge, which is a key factor for the safety level of flood protection projects. Hydrological data are quite important to quantify existing water resources potential, for instance, a reservoir project for irrigation, drinking water, and hydropower production. Maritime hydraulics provides a technical basis for port and harbor construction, protection of beach erosion, and maintenance of waterways, under wave action.

Surge of environmental concern gave impacts in water resources engineering. Environmental hydraulics emerged and became a popular branch of hydraulics.

Environmental hydraulics clarified diffusion and dispersion problems, stratified flows in reservoirs and estuaries, eutrophication in reservoirs and lakes. As eco-compatibility becomes important, eco-hydraulics and eco-hydrology develop in water resources engineering. Global warming affects the grand design of water resources planning and water resources potential. In this sense global warming needs to be understood not only on a global scale but also at regional and local scales.

Statistical data are summarized for catastrophic floods and drought. Tendency is seen that the number of people killed is reducing chronologically for similar intensity of natural hazards as warning system and counter-measures progress. Major facilities for human water use are also summarized. Water ethics is necessary for sound management of water resources because we need to consider not only human benefits but also to conserve ecosystems for sustainability. Equity and value of environment are new fundamental components in water resources engineering in the 21st century.

1. Introduction

Water resources engineering is related to vast areas in analyses on abundance, scarcity, and conservation of terrestrial waters. In this chapter the development of technology is briefly traced and actual projects and facilities to satisfy human needs are described. In the final part key factors for future development in water resources engineering are discussed.

Fluid mechanics provides a mechanical basis to water resources engineering. The main principles utilized are principles of mass conservation, momentum conservation, and energy conservation. To derive a mathematical solution, there is not only the application of basic principles or basic mathematical equations but also initial or boundary conditions. Because water resources engineering is concerned with waters in the hydrosphere of the earth, much knowledge is needed about earth sciences to determine boundary conditions in real problems in water resources engineering. The requirement of familiarity with earth sciences shows distinction of water resources engineering from fluid mechanics which has been developed in other areas of engineering, for instance, fluid mechanics in mechanical engineering, in aeronautics, in chemical engineering, and so on.

Traditional branches of water resources engineering are classified into hydraulics for rivers, hydrology for rivers, and maritime hydraulics.

1.1. Hydraulics for Rivers

Although all great civilizations in Egypt, Mesopotamia, India, and China resorted to water resources development works, the science of hydraulic engineering remained at infant stage till the modern science greeted its birth through the Renaissance. Hydrostatics was then developed during Renaissance. The dynamics of water movement was formulated through the book published by Daniel Bernoulli in 1738.

Hydraulics has been developed through empirical formulae. Epoch-making books that summarize the existing knowledge in an exhausting manner were edited by Weisbach in

1844 and Forchheimer in 1914. They are the pioneers who made efforts to merge theoretical fluid mechanics with empirical hydraulics. The core part of hydraulics for rivers is open channel hydraulics. Open channel flow has a free water surface where the atmosphere directly connects with water. Water depth and flow velocity are the main variables in the analyses by river engineers and a one-dimensional approach has been a traditional development. This is partly because rivers are long enough compared with dimensions in a section and partly because one-dimensional analysis is the only tractable way for a mathematical approach.

The resistance of a surrounding boundary of a stream is explained by the Manning or Chezy formula, in which resistance to flow is proportional to the square of the sectional average of the flow. These empirical formulae are widely used by hydraulic engineers.

For the majority of design purposes in river engineering in steady state analysis the important parameters are spatial variations of velocity and depth. River flow is more complex and as a typical example of unsteady flow there is the tidal flow in estuaries and floods. Near the peak of a flood temporal variation becomes very slow and hence a quasi-steady analysis is still applicable to study these peak flow features. One of the characteristic features of flood flow is that the discharge in a rising limb of the hydrograph is larger than that in a falling limb for the same water stage.

As the resources of electronic computers expanded, numerical simulation became familiar in research and practice and two-dimensional and three-dimensional schemes became available.

River hydraulics provides knowledge of the prediction of water stage and of flow velocity under various conditions, for instance, flow behaviors during flood and backwater curves upstream or downstream of weirs and dams. Such information is vital for design of various hydraulic structures. Flow behaviors in irrigation canals are also analyzed by hydraulics. Detailed velocity estimation along a bank is needed for design of, for instance, revetment works, groins, and so on. In order to operate hydraulic structures we also need hydraulics. Hydraulics is used for the estimation of the discharge from a sluice or other type of gate, and the pressure force exerted on structures. Hydraulic prediction is also necessary for stable maintenance of river channels. As described above river hydraulics provides a mechanical tool for river basin management.

1.2. Hydraulics for Pipe Flows

This branch of hydraulics has been developed in association with water supply, sewerage works, and hydropower generation. Basic equations used for analyses are the same as those for open channel flows but boundary conditions become different because pipe flow has no free surface.

One characteristic feature of a pipe flow is high pressure caused by a transient flow. Under steady conditions pipes are exposed to hydrostatic pressure but when a valve is shut down in a pipe network the momentum of flowing water is changed, which generates additional pressure. In the case of large amount of flowing water utilized for hydropower generation and when operation is initiated or terminated, large amount of momentum change produces a very high pressure in the conduit system. The phenomenon or associated high pressure is called the water hammer. Steel structures may be made strong enough for excessive pressures but protection such as a relieving open surge tank may be used. Management of pipe systems and treatment of water is crucial in the event of pollution such as Cryptosporidium and Giardia organisms. They are harmful germs for human health. Chlorination and ozonation is effective to kill them but higher chlorine concentration of chlorine and ozone has a side effect to produce other harmful chemical compounds. In order to solve this dilemma we need risk analysis in present day planning for permanent potable supplies.

1.3. Fluvial Hydraulics

A fundamental nature of natural streams is a boundary that is composed of movable materials, that is, sediment mixture. Morphological characteristics give not only a beautiful diversity to rivers from the standpoint of landscape but also a wide variety to riverine habitats to support biological diversity of the ecosystem. Fluvial hydraulics provides the fundamental knowledge to understand river morphology.

The sediment mixture is formed mainly by weathering of mountain slopes; then it may be moved momentarily or during certain flow conditions. Fluvial hydraulics deals with processes and mechanisms of sediment movement from its source to destination, that is, river mouth to the sea. In fluvial hydraulics analyses of erosion and deposition are central themes. Examples of problems are, erosion at mountain slope and banks, scour around bridge piers, degradation of the riverbed, deposition in reservoirs, and so on.

The sediment components are classified into three, namely, wash load, suspended load, and bed load. Wash load is a very fine component that originates in a river basin and is transported to the sea by a flood and it is not a component of a riverbed. Suspended sediment is the component that loses contact with the bed for long time after it is picked up into suspension by a flow. Bed load is sand, silt, gravel and rock detritus, mainly carried by a stream along its bed. Prediction of sediment transport rate has long been a major target of fluvial hydraulics and uses a probabilistic theory as a new approach to trace the motion of sediment.

The configuration of rivers is neither flat in the vertical plane nor straight in the horizontal plane. Bed forms are categorized by typical scales of a stream. Ripples and dunes are called small-scale bed forms. Sizes of small-scale bed forms are explained in terms of grain size of riverbed and water depth of a stream. Bars are a medium scale deviation and the size of them is related with stream width. A meander is a large-scale deviation of river course in plan view and related to a stream reach. In a reach a couple of riffle-pool systems are seen in actual streams. Fluvial hydraulics explains the mechanism of how a configuration is formed and a classification chart of rivers with controlling factors has been established.

1.4. Engineering Hydrology

Hydrology deals with a water cycle on the earth. Evaporation driven by sunlight from the ocean surface, forests, and so on provides sources of vapor and rainfall. Rainfall on land converges into a mountain stream due to gravity and flows down an alluvial fan and to river mouth.

The time taken by the process in which a raindrop has to reach the ocean, varies very widely . A raindrop that infiltrates to the ground takes much longer time to appear in a stream or a spring due to slow motion in the ground. Furthermore, a component that penetrates into a deep aquifer does not contribute to a stream.

That water only appears again in the solar cycle if the water is pumped up through a well. Rain drops trapped in a small depression may directly evaporate from such a depression.

Hydrology that is devoted to water resources engineering is usually called engineering hydrology. A technique that correlates rainfall with stream discharge is called runoff analysis. The runoff process is considered to be a response function of a river basin to rainfall. In flood protection projects design rainfall or design discharge is adopted to determine the safety level of the project. The probability of occurrence of a maximum annual flood is usually resolved and a safety level is prescribed by a return period of a maximum annual flood, such as for instance, a one hundred year flood. The return period for the design flood of big and important rivers is usually bigger than one hundred years, perhaps as great as five hundred years or one thousand years.

In urban areas expansion of impervious zones by urbanization has much influence on flood hydrograph. The impacts of urbanization on a hydrograph are two fold. One is an increase of peak discharge due to the decrease of infiltration to the ground and the other is a shorter time of arrival of a flood peak. This is caused by the convergence of urban storm water into a sewer network and rapid transport inside a sewer network.

Hydrological data are quite important to quantify existing water resources potential, for instance, a reservoir project for irrigation, drinking water, hydropower, and so on. Many dams have been constructed and operated for a single purpose or multiple purposes of water use. In a multiple purpose dam the cost allocation needs to be resolved among water users and a flood control sector. Operation rules are determined to assist in a compromise of conflicts among different users of a reservoir and to accomplish objectives of the project.

In many parts of the world groundwater is a vital water resource. An unconfined aquifer is defined as an aquifer where a free surface exists. In a confined aquifer flows occur under a pressurized condition. Near the ground surface, water partially fills up voids in the subsurface. This zone is formed by spatial variation of infiltration of rainfall and is called an unsaturated zone. A saturated zone is formed under a phreatic surface.

Movement of groundwater is quite slow; therefore, once groundwater is contaminated cleaning of contaminants takes a long time. Contamination of groundwater is mainly caused by chemical compounds and waste disposal from industries. Environmental rules to regulate disposal of materials are enacted gradually and remediation techniques for contamination are being developed.

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Biographical Sketch

N. Tamai is the Professor of River Engineering at Kanazawa University and Professor Emeritus of the University of Tokyo. He was born in 1941 and graduated from the University of Tokyo with B.S. in Civil Engineering in 1964. In October 1966 he joined the University of Tokyo as a research associate. He obtained the degree of the Doctor of Engineering from the University of Tokyo in 1972. He was Professor of the University of Tokyo between July 1983 and March 2002.

He has experiences as a research assistant at the University of California, Berkeley, as a visiting researcher at the University of Stuttgart, the University of Karlsruhe, the University of Western Australia and the Swiss Federal Institutes of Technology, Lausanne, and as a visiting professor at the Swiss Federal Institutes of Technology, Lausanne and the University of Stuttgart.

His research area was initially mixing problems in environmental hydraulics and shifted to river mechanics, for instance, flows in compound channels and meandering channels, and coherent eddies in geophysical flows. In recent fifteen years he extended the area into environmental river engineering including evaluation of fish habitat, interactive process between vegetation and river works, prediction of human impacts on hydrological cycles, and economic evaluation of environmental flows.

He was Chairman of the Section on Education and Professional Development in the International Association of Hydraulic Engineering and Research and now serves as the Chairman of one of three Divisions of IAHR.

He published more than 300 papers with co-workers. He is the single author of four books and editor in chief of six books. He has been serving as a technical expert in many committees of governments and public organizations.