# HYDRAULIC MODELS--INDISPENSABLE TOOLS OF THE DESIGNING ENGINEER

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Alvin J. Peterka
Hydraulic Engineer

Bureau of Reclamation
Denver, Colorado

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Over 300 years ago, Galileo said, "I have met with fewer difficulties in discoveries relating to the movement of heavenly bodies, notwithstanding their astonishing distances away, than in investigating the motion of flowing water taking place before my very eyes."

Galileo's observation is still true today. Despite the many recent advances in the field of hydraulics, much remains to be done to develop the knowledge required to design adequate hydraulic structures at minimum cost.

To provide simple, workable hydraulic structures which will perform as intended, and which contain a known factor of safety, two kinds of hydraulic knowledge are required. First, the kind found in textbooks on hydraulics or fluid mechanics. This knowledge is essential in that it defines the behavior of the water in general terms of mechanics. Usually, the conditions under which the behavior is analyzed are ideal. Water has no viscosity, there is no disturbing skin friction factor, there is no turbulence to create a bouncing water surface, and no air is entrained in fast moving flow. In short, the problem and its solution are ideal and occur only in textbooks. For example, the discharge over a weir may be expressed as $Q = CLH^{3/2}$ Discharge equals the length of weir times the head on the weir to the three-halves power times a "coefficient." Because of the many effects, or departures from the ideal, contained in "C," it has been called the coefficient of ignorance. Naturally, the coefficient is dependent on the kind of weir, the velocity of approach, the exit conditions, and many other factors. How do we determine the coefficient? By building various types of weirs, measuring discharge, head and length, and calculating "C." Thus, before one of the simplest formulas can be used, experimental hydraulics has played an important part in completing the known factors. Experimental hydraulics, therefore, is the second type of knowledge required to design a satisfactory hydraulic structure. Because of the many "coefficients" required to define precisely the behavior of flowing water, the hydraulic laboratory is an essential part of any organization devoted to the design of hydraulic structures.

In the example given, the word coefficient was used as a specific term. However, the word may be used generally to mean any unknown factor in a hydraulic problem--and the list of unknowns is almost endless. As time goes on, the list becomes longer, not shorter. This is so because of the more difficult problems which are attempted, the more demanding performances required of modern hydraulic structures, and the continuing battle to reduce costs in the face of rising prices. Larger and more costly projects require better and more dependable hydraulic structures to prevent loss or damage to a sizeable investment. Greater coverage by a single project and more numerous projects make it necessary to reduce maintenance costs to a minimum.

Hurry-up construction programs make it necessary to use less experienced design engineers so that foolproof hydraulic design procedures and design data are required to put hydraulic design procedures on a more business-like basis. No longer should hydraulic works be used solely because they have been used over a long period of time. No longer can poor or doubtful structures be condoned as part of the process of learning what is good and what is bad design practice.

In the past decade, hydraulic laboratory procedures have improved to the point where practically any hydraulic problem can be solved in a reasonable length of time and at reasonable cost. Even small structures have been the subject of hydraulic tests and have been successful even from the point of view of cost. By spreading the development charges over a number of structures, the unit development cost has been reduced to less than that of larger one-of-a-kind structures. From the point of view of the hydraulic laboratory engineer, therefore, there is no excuse for building untried or doubtful designs in the field.

Hydraulic laboratory investigation may be divided into two classes--the first, studies aimed to obtain basic data from basic parts of a structure such as the "C" just discussed; and the second, studies of entire structures in which overall effects are evaluated in terms of structure performance. In the first class are included factors such as roughness coefficients for pipes or flow surfaces, head losses through bends or transitions, and discharge coefficients for weirs, gates, and valves. From these basic data, the performance characteristics of a prototype structure may often be calculated. The success of these operations is usually dependent on the ability of the engineer to include and accurately evaluate <u>all</u> the factors influencing performance. This is not always possible, however, and structure designs based on calculations alone account for some of the structures which have been built on the basis that they "should work" but do not.

In the second class, the entire structure is reproduced and the performance of all or any part of the structure may be observed and photographed. In these studies, the model or hydraulic testing device acts as an integrating machine to include all the possible factors which affect the performance. Results are limited only by the skill of the hydraulic engineer in providing a suitable test facility. The advantage of this type of testing is that even inexperienced engineers can see and evaluate the developed structure and, assured by the experimenter that the field structure will perform as well as the laboratory version, can proceed with confidence and enthusiasm. Some of the most complicated structures, as well as some of the simplest ones, have been developed in this manner.

Studies in the second class are often believed to be of little value for future use on other installations. Experience has shown, however, that after several similar studies have been made, covering a range of heads, discharges, etc., it is often possible to generalize the design so that a structure may be designed to fit any installation without the need for individual model tests. Or, the several individual studies may provide the insight necessary for running a series of tests which will provide data useful in generalizing the design. Here again, the skill of the hydraulic engineer will determine the ultimate value of an individual or series of individual model tests. Proper interpretation of results is the most important single aspect of hydraulic model testing.

Hydraulic Laboratory work in the Bureau of Reclamation has been in progress for about 30 years and has covered a wide variety of problems. Hundreds of hydraulic flow problems have been solved and no problem has ever been tackled without finding a solution. Naturally, some solutions have been ideal, some satisfactory and a few have been compromised. In every case, however, some good was accomplished, and in all cases a better insight to the problem and its ultimate solution was obtained. In all cases, the purpose of the investigation was to improve performance and provide safe and dependable operation; but often, monetary savings resulted which more than paid for the investigation. In fact, savings in design and construction costs in the Reclamation program have amounted to millions of dollars.

In all hydraulic flow problems, flow control is the key to successful performance. Water flowing under controlled conditions is rarely a problem--uncontrolled water is always a problem and often leads to disaster. To illustrate a few of the flow control problems encountered in Reclamation engineering, the cycle of water in passing from a cloud to the earth and back to a cloud may be followed. Rain falling upon the earth produces runoff, which passes through fields, farms, creeks, rivers and into the ocean to be returned by evaporation into a cloud. Nature has solved, or is still solving, the flow problems in this natural cycle.

When man interrupts this process to use the water in a profitable manner, real trouble begins. Tilled soil produces an erosion and silt problem. Hydraulic model and field tests have been made to prevent or reduce the passage of sediment into canals and farmers ditches. The canals used to transport water from regions having excess water to arid regions introduce flow problems at checks, turnouts, curves, and drops. All of these have been investigated and helped by hydraulic model tests.

Storage dam outlets and energy dissipators have been investigated, as have control valves, gates, spillways, penstocks, turbines, pumps and tunnels. Siphons, both conventional and inverted, in the field as well as in the laboratory, have been investigated and improved. Rescue devices have been developed for humans and animals that might fall into the swift waters of a canal. Fish ladders, fish traps, and fish screens have been investigated to aid in handling migrating fish. Ice prevention devices to reduce ice pressure against high dams, automatic flow-control and measuring devices, improved flow-control valves for extremely high heads, riprap sizes for protection of channel banks and bottoms, cavitation prevention or control devices along with correct design procedures, wave height suppression, vortex control and prevention devices, and many others have been developed.

In the course of improving designs in current use, new concepts on handling flow problems have been originated and developed. In many cases, these eliminated the "old ways" and introduced modern structures. For example, because a hydraulic jump is a good energy dissipator, it was used downstream from a hollow jet valve installation, resulting in a long basin having a relatively rough water surface. The structure was satisfactory, but it was evident that a better structure would be desirable. Hydraulic laboratory experimentation showed that when the valves were tilted downward and the jet was passed between converging walls, then allowed to expand.

suddenly, the basin length could be reduced by 50 percent. The water surface in and downstream from the basin was comparatively smooth, resulting in less extensive riprap bank protection and smaller rock sizes. In comparison, the earlier structure is considered unsatisfactory.

Even the hollow-jet valve mentioned in the example is an improvement over an "old design." When cavitation problems and the difficulty of dissipating a solid jet appeared to be too complicated, the long-used needle valve was modified in the laboratory to produce the now used hollow-jet valve. This valve is cavitation-free, weighs two-thirds as much as a needle valve, requires only routine maintenance and discharges an annular jet which is more easily handled in a stilling structure. Another recently developed structure is the impact-type stilling basin used to replace larger energy dissipators. This dissipator, contained in a box-like structure, will handle relatively large volumes of water moving at velocities of up to 30 feet per second. Hundreds of these basins have been built by the Bureau of Reclamation and several State Highway Departments have shown interest in using them on culverts and drains.

In recent tests made for the Bureau of Public Roads, the basin was adapted for use within a short length of standard corrugated metal pipe. First tests over a limited range of flow conditions indicate that the device may prove to be useful without being costly. Another example of a new concept is the culvert-type wave suppressor developed and generalized in the laboratory. Waves originating in stilling structures sometimes reduce the capacity of canals or flumes by reducing the freeboard at near maximum flows. A wave-free surface would increase the capacity of the structure without the need for raising the height of the concrete lining.

Laboratory studies showed that when the flow was passed through a flat-roofed culvert, wave heights were reduced considerably. For a roof length, about four times as long as the flow depth, the downstream water surface fluctuation was only 10 percent of the wave heights upstream from the suppressor. Field tests have shown the suppressor to work as predicted in the laboratory. The list of similar developments made in the Hydraulic Laboratory, in close cooperation with design engineers, is quite long and covers a wide variety of subjects.

In fact, more than 500 reports are available to Bureau of Reclamation engineers to help them in their design problems. Most of these engineers agree that hydraulic models and hydraulic investigations are essential in providing safe, workable, hydraulic structures at the least cost. The knowledge that the structures they are designing are the best possible, and that the structures will operate as intended, gives them added confidence--an essential attribute of any successful engineer.



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