Theory of Hydraulic Models

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Preface

The present book concerns the design of hydraulic models. Theory cannot cover all the complications that are encountered in practice, so that almost every major project in the field of hydraulic engineering undergoes a 'model test' where, on a small scale model, the flows and their consequences corresponding to various versions of the scheme may be observed, and the relevant quantities measured. As a result of these observations and measurements, the most effective and rational design of the scheme can be determined.

A hydraulic model is a precision device for the experimental investigation of a hydromechanical phenomenon, which can give reliable information only if its scales are determined according to certain definite rules; that is, if it is designed correctly. If the design is not correct, then the model is wrong in principle. In that case, the employment of the most sophisticated instrumentation and measurement methods can only help to increase the accuracy of the wrong predictions. A small scale reproduction of a physical phenomenon can be a scientifically valid model only if a certain set of its measurable characteristics are related to their counterparts in the actual phenomenon, or prototype, by certain constant proportions which satisfy definite mathematical conditions. These constant proportions are referred to as scales, whereas the mathematical conditions which must be satisfied by the scales are called the criteria of similarity. It follows that the design and realization of a true model of a phenomenon can only be achieved if the similarity criteria of that phenomenon are known. These can be revealed by the mathematical relationships (usually differential equations of motion) describing the physical nature of the phenomenon under investigation. However, the accuracy, and thus the reliability of the results determined by this method, depend entirely on the reliability of the mathematical relationships used, and if the phenomenon has not been formulated mathematically then its criteria of similarity simply cannot be

determined. This is an ironic situation, for a model is of greatest use in those cases which cannot be formulated theoretically.

Another, and considerably more effective way of determining the criteria of similarity is the dimensional method. Here, the criteria of similarity are supplied from dimensional study of the characteristics themselves and not from the mathematical relationships (containing the characteristics involved). In other words, the criteria of similarity are supplied by the dimensional method without the risk of misinterpretation of the physical nature of the phenomena (which might be inherent in mathematical relationships). The dimensional method has been the subject of considerable controversy and it has taken a long time for it to be accepted that it is not a 'dangerous tool which can often give erroneous results', but that it is a tool which, like every other mathematical tool, always gives correct results if correctly used and which gives erroneous results if erroneously used. After the appearance of the works of Bridgeman, Birkhoff, Langhaar, Comolet, Sedov, and others, in the last three decades, it has also been generally accepted that the theory of dimensions is not a set of trivial rules with no other use than to determine the exponents of a power product, but that it is what may be called the 'theory of experimental research'.

The application of the criteria of similarity to the design of hydraulic models is, in practice, frequently impeded by serious difficulties of a physical or technical nature. The fact that the prototype and its model are on the same planet implies that they are both subject to the same force of gravity, or that the scale of the acceleration due to gravity g is necessarily equal to unity. Similarly, the utilization of the prototype fluid (water) in the model means that the scales of fluid density and viscosity are also equal to unity. It is often very difficult, and sometimes impossible, to satisfy the criteria of similarity by using such 'unadjustable' values of the characteristics mentioned. In such cases the model cannot be designed according to the exact principles of the theory of models, and it is up to the knowledge, experience, and even intuition, of the experimenter to decide what would be the 'next best thing' to do in order to design a reliable model. These drawbacks do not, however, mean that the derivation of exact criteria of similarity is merely an academic exercise and thus that it might be possible to design a model without having any information on the principles of the theory of models (see Chapter 2). One can never know for a particular similarity problem how nearly an adopted practicable solution approximates the correct solution if the latter is unknown. Therefore, whether applicable or not, the exact solution should always be first determined, and then, if it proves to be impracticable, used as a frame of reference to judge the degree of correctness of the adopted solution.

I would like to express my thanks to Professor E. M. Wilson, the Editor of this Series, for his comments which have improved the text considerably. I am also grateful to Mr. C. H. Russell, the Director of the Hydraulics Research Station, Wallingford, for reviewing the manuscript and offering a number of valuable suggestions. My appreciation is extended to my colleagues, Professor A. W. Peterson and Dr J. W. Kamphuis, who were so helpful during the preparation of this work. Finally, I would like to thank my wife Cherrilyn for typing this difficult manuscript.

KINGSTON, Ontario
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M. S. YALIN

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