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Merging Field & Laboratory Bridge Scour Data

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Abstract

Highway engineers are struggling with a major effort to assess and evaluate our nation's bridges for scour. Advanced technology is urgently needed to make a meaningful impact on this effort. This paper describes a need to focus laboratory and field research studies on a better understanding of the bridge scour processes.

Introduction

The State Highway Agencies of the United States are in the midst of a major effort to assess the nation's 485,000 bridges over water for susceptibility to scour related failures. Hydraulics engineers have long recognized the need to get more field data and establish better procedures for predicting bridge scour but the major impetus for the current effort was brought on by several catastrophic failures - especially, the Schoharie Creek failure in 1987 and the Hatchie River failure in 1989.

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Bridge Scour Assessments

Highway agencies have completed most of the first stage of the assessment process which is to screen bridges and to place them in categories of low risk, scour susceptible or unknown foundations. The target date for this stage to be complete is April 1992. Worst case estimates of bridge scour are acceptable at this stage of the process but more accurate technology is needed for the more detailed evaluations that will be done for the bridges that fall in the scour susceptible category.

Projection of the screening results available to date indicates that approximately 55% of the bridges are in the low risk category, 25% are in the scour susceptible category and 20% have unknown foundations or not readily accessible foundation plans. The 25% that are in the scour susceptible category represents approximately 121,000 bridges that will require more detailed evaluation to determine which are scour critical and will require some remedial action either in the way of monitoring, repairing or closing. January 1997 is the target date for completing these evaluations.

The detailed evaluations are costly when the number of bridges is considered so it behooves this nation to develop the best possible technology to support these evaluations. The detailed evaluations generally cost $10,000 to $15,000 per site, so there is substantial national investment that could exceed $1 billion at stake just for the evaluations without considering the cost of whatever remedial action is necessary to safeguard the traveling public from those bridges that are considered to be scour critical.

Based on a relatively small number of evaluations that have been completed, it appears that approximately 11% of the scour susceptible bridges are actually scour critical. The wide range of remedial actions that could be used for the scour critical bridges makes estimating the cost of this aspect highly speculative. Costs in the range of $200,000 per site are not unlikely so there could easily be another $2 to $3 billion cost for remedial measures associated with the scour critical bridges.

Laboratory and Field Scour Studies

To make a contribution to these major obligations that will impact our nation over the next decade, a research program must be timely and focused on the practical aspects of the scour process. A good balance and exchange of information between field and laboratory experiments is essential.

In the past, most of the scour research has been conducted in the laboratory and a number of prediction equations have been developed based primarily on lab data. Engineers are generally somewhat skeptical of equations that are based strictly on small scale laboratory data and a premium value is placed on verification with field data.

The current research effort in this country is heavily oriented toward the collection and analysis of field data. There are 14 state highway agencies studies and one FHWA national study involved in the collection of regional and detailed scour data over a period that spans from 1985 to 1997. The total cost of all of these studies is approximately $5 million or 0.15% of the expected cost of the evaluations and remedial measures.

While these studies will surely generate very valuable information and insight about bridge scour problems, they can not completely replace the laboratory investigations that can be controlled to isolate various parameters. In fact more field data will probably create an even greater push for laboratory experiments that help define the influence of the vast number of variables that are evident in the field.

Some answers are best attained with field data and others are readily attained with laboratory experimentation. The challenge for those in the research community is to bring this information together in a timely manner.

Field data are essential for verifying the similitude assumptions that are made in applying lab results to full scale conditions. In particular, there are problems associated with modeling bed materials in small scale experiments. The ratio of flow depth/D_{50} often appears as a secondary parameter in the analysis of laboratory results but when results are extrapolated to full scale conditions this parameter can become a dominant factor. To resolve this dilemma carefully selected field measurement sites are needed so that they become an extension of laboratory results.

The effects of gradation of bed materials on bridge scour can best be studied in a laboratory experiment but field observations are needed to identify the range of gradation that needs to be tested. At least three field studies (Copp & Johnson 1987, Crumrine 1991 and Miller 1992) have suggested, all be it with rather weak data sets, that scour equations with a correction for gradation predict scour depths that agree best with measured depths.

Nevertheless, it is very difficult to isolate the effects of this parameter unless other parameters can be held constant while this one is varied. Parallel laboratory studies currently underway at Colorado State University and field studies currently underway by Pennsylvania State University and by USGS can be very productive if there is an eager exchange of technical information among researchers.

Field observations are very important in focusing the proper presentation of results. Laboratory researchers are inclined to overlook the predominance of stratified soils being a limiting factor in bridge scour depths. While fundamental studies might give adequate techniques for dealing with various types of bed materials, prediction equations derived in the past have not been formulated to account for different layers of soils that are encountered in the scouring process.

Analysis of Laboratory Data

One of the most difficult questions in merging laboratory and field data is the question of similitude. Can the small scale lab results be scaled to prototype conditions? Do the dimensionless ratios often used in the analysis of laboratory data accurately reflect the process that was observed or do they sometimes mask the most pertinent trends? While some researchers have successfully developed very compact representations of complicated phenomena by judiciously selecting the proper dimensionless ratios to develop relationships, others have misrepresented data with spurious relationships by failing to scrutinize dimensionless ratios used in the analysis of data. Some of the problems introduced by analysis of dimensionless ratios include:

1. a bias may be introduced when the equation is rearranged to solve for scour depth rather than the ratio which includes scour depth;
2. the range of ratios may not be the same in both the laboratory and field;
3. the range of prototype data that can be used is unknown;
4. information can be lost and spurious information can be introduced in analyzing data using ratios.

An alternative is to scale laboratory variables rather than dimensionless ratios to prototype conditions. Three important advantages have been described (McCuen, Leahy & Johnson 1990), (McCuen & Snyder 1986) for considering this alternative in analyzing scour date. First, and most importantly, the actual laboratory data can be analyzed, rather than analyzing ratios. This will provide a clear picture of the effect of each individual variable on the scour depth; rather than the effect of a ratio containing the variable on a ratio containing scour depth. Through this type of analysis, relationships that were hidden by the ratios may be seen in the individual parameters. Second, bias will not be introduced since we are not calibrating an equation for ds/b or ds/y then solving for ds. Third, the appropriate range of prototype parameter values for use in the developed equation can be determined by scaling according to the model data ranges. The use of scaling is particularly simplified if an undistorted model is assumed.

There is clearly one major disadvantage to using scaling rather than dimensionless ratios. Each of the parameters in the equation must be varied in order to include them in such an analysis; however, since much laboratory work has already been done, this does not pose a formidable problem.

Conclusions

The United States is facing a major challenge in the assessment and evaluation of all of the existing bridges over water for vulnerability to scour failures. Worst case techniques are available for the first stage assessment and categorization of bridges, but technology is lacking for the more detailed evaluations that will be needed to determine where and when resources need to be spent on major remedial measures for bridges that are found to be vulnerable to scour.

A relatively ambitious field data collection program has evolved to help meet this challenge. To be successful this program must be complemented by selective laboratory studies and there must be an aggressive exchange of data between researchers.

While dimensional analysis has served the hydraulic engineering profession well over the years, there are some pitfalls in the traditional technique of analyzing dimensionless ratios to scale laboratory results to prototype conditions. A viable alternative, that will enhance the merger of laboratory and field observations, is a technique of scaling individual laboratory variables, rather than sometimes poorly selected dimensionless ratios. This alternative technique leads to clearer physical relationships for processes that are observed in a laboratory and more accurately shows where additional data must be collected to develop more accurate models.

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