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Hydrolink

ADVANCES IN PHYSICAL MODELING OF MOBILE BED SYSTEMS AT ALDEN DURING THE PAST 15 YEARS

BY DANIEL GESSLER

To help predict the effect of channel modifications on sediment transport and deposition, engineers have long used scaled physical models. If used properly, modeling can provide very helpful information for resolving sediment problems at riverine water intakes. During the past 15 years, there have been significant advances in physical modeling of sediment transport at Alden, further reducing the risk of building expensive solutions that may not work. This article considers advances in four areas: low density materials available for modeling sediment, instrumentation available for physical models, computer models that are coupled with physical models, and field data collection.

Scaling and Sediment Selection

In a physical model, the particle size scales with the model length scale; in a 1:100 scale model, the sediment should be 100 times smaller than in the prototype. This presents challenges when modeling sand bed rivers where the model sediment must have a diameter on the order of microns. When impractically small model sediment is required, based on scaling criteria, coarser sediment can be used, but with a lower sediment density.

Historically, mobile bed models at Alden and elsewhere were constructed with coal beds. Coal has a specific gravity of about 1.4 where sand has a specific gravity of about 2.65. However, coal particles tended to be coarser than sand and resulted in physical models dominated by bed load. Further, these models frequently required tilting (enhanced slope or distorted) to obtain any sediment transport at all. Tilted models have significant scaling problems. Einstein (1967) and Gessler (1971) both demonstrated the following limitations to distorted models:

1. Distorted models can only be designed for one discharge
2. The hydraulic time scale differs from the sediment time scale, by a large amount (factor of 10 or more) for only a small (2:1) distortion
3. The suspended concentration in the model differs significantly from the prototype, compromising model results
4. Local scour and deposition cannot be modeled, because the angle of repose in the model does not have the distortion of the model

Einstein and Chien (1956), Einstein (1967) and Gessler (1971) indicate that distorted models are a compromise which should be avoided when possible. The cost of a distorted model can be significantly less than that of an undistorted model and testing schedules can also be shorter. As such they have become popular with some engineers. However, results are purely qualitative and in some instances have resulted in the construction of sedimentation counter measures that exacerbated (rather than mitigated) sedimentation problems.

Alternative Model Sediment

A wide range of approximately spherically shaped particles with specific gravities as low as 1.05 and particle sizes as small as 60 to 100 microns have become available in the past 10 to 15 years. Polymers and other materials can be made to a specific density. Through grinding, it is possible to obtain a defined grain size distribution. Physical models can now be constructed with less or no tilting and distortion, reducing scaling problems. The use of lightweight sediment can introduce operational challenges with surface tension and getting the sediment to sink; however, these are readily addressed with surfactants that reduce surface tension without changing other properties of the water. Lightweight sediments should be used when appropriate to minimize scale effects from model distortion. Figure 1 shows a sediment bed being installed on an underlying fixed bed model.

Instrumentation

One of the most significant advances in model instrumentation has been with the use of laser scanners such as the one on the yellow tripod in Figure 2. Historically, after a model test, the static water level in the model was slowly lowered to establish contour lines at the water/bed interface. The contour lines were surveyed and a contour map of the beginning and ending riverbed conditions were produced. The laser scanners now in use at Alden can automatically measure the horizontal and vertical position of millions of

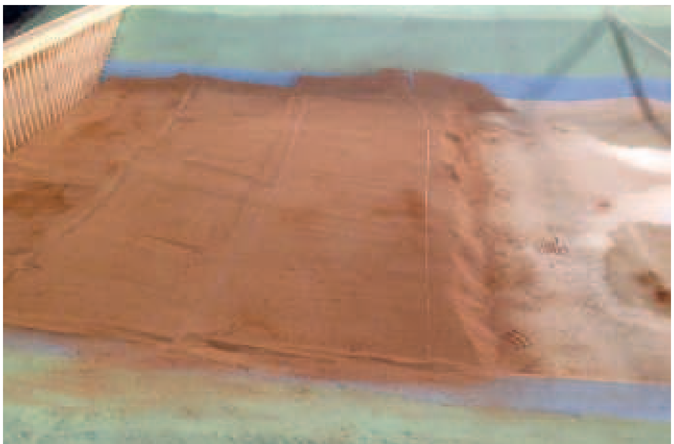

Figure 1 - Lightweight sediment being installed in a physical model

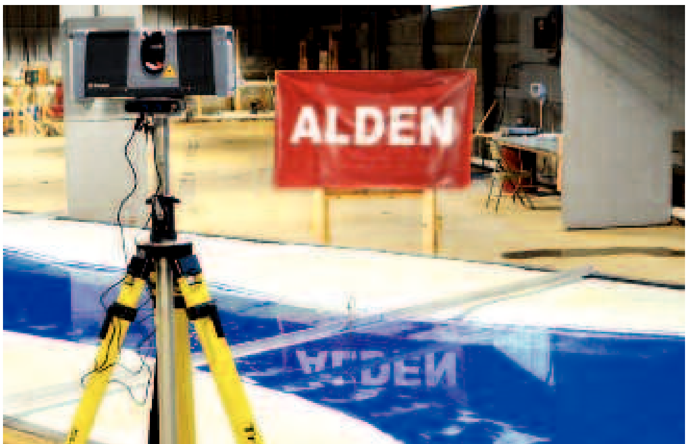

Figure 2 - Sub-millimeter scanner in use on a model to determine scour and deposition. Scanner is on the yellow tripod and the river bed is blue

About Alden
Alden (Alden Research Laboratory, Inc.) was founded in 1894, and is an acclaimed leader in solving flow-related engineering and environmental problems. The firm has 95 employees and over 150 000 sq feet of indoor lab space on a 32 acre campus in Holden, MA, and an additional 25 000 square feet of laboratory space in Redmond, WA. Alden provides engineering, physical and computational flow modeling along with environmental and flow meter calibration services. For more information, please visit www.aldenlab.com

Dr. Gessler **is a registered professional engineer and has over 25 years of experience in numerical and physical modeling and generally oversees the numerical and physical hydraulic modeling activities at Alden. He is responsible for hydraulic modeling using computational fluid dynamic (CFD) models and one and two dimensional hydraulic models, including sediment transport models. In addition to working on numerical models, he provides technical expertise on physical models involving sediment transport. Dr. Gessler also manages Alden's Colorado office, and strives to provide engineering recommendations and valuable engineering options for the projects in which Alden is involved. He is a Vice President and prior to joining Alden, he worked as a Research Scientist and Assistant Professor at Colorado State University.**

points on the riverbed, creating a point cloud that defines model surface. The scanners have sub-millimeter accuracy (e.g. the Trimble FX 3D scanner) and are now used in conjunction with data processing software to define changes in river bed elevation to less than 1 mm model scale. The scanner can automatically scan all of the surrounding environment to a distance of 50 meters or more depending on the scanner.

Numerical Models

One of the least intuitive but equally significant advances in physical modeling is numerical modeling. One limitation of physical models has been the time consuming effort of accurately determining three dimensional flow patterns and eddies. Three dimensional numerical tools are now used to compliment physical modeling efforts. While three dimensional models have significant limitations for predicting changes in bed elevation associated with sediment scour or deposition, the models are extremely valuable for visualizing flow patterns that may be difficult to measure directly in a physical model. The additional cost of a parallel numerical modeling effort is typically offset in a savings in the physical model and additional insight that is gained about the physical model. Every proposed physical model study at Alden now considers the potential benefits of a parallel numerical modeling study. Figure 3 shows CFD results that are superimposed on the physical model in a hybrid CFD – physical model study.

Field Data

The fourth pillar of physical modeling is field data. The most significant advances in field data collection have been the ability to measure water velocity and bathymetry. Historically, point velocity measurements were made to determine the time averaged velocity at a single point. Measuring water velocity at a range of depths and locations in a large river was time consuming and frequently cost prohibitive. The development of Acoustic Doppler Current Profilers (ADCP) has revolutionized velocity measurement. Widely used now for over 20 years, the method measures the instantaneous water velocity from a moving boat and is able to acquire both the horizontal and vertical velocity profile across the width of the river. ADCP velocity data has significant spatial fluctuations and multiple passes combined with statistical methods must be used to analyze the data.

Bathymetric data vastly improved with the use of Differential Global Positioning Systems (DGPS) during the past 15 years. When combined with echo sounders and shipboard navigation systems, thousands of linear feet of bathymetric data can now be collected and processed in a single day with a previously unachievable precision. Figure 4 shows a pontoon boat equipped with modern bathymetric survey and ADCP velocity measurement equipment.

Summary

Technology has revolutionized physical modeling of mobile bed rivers in the past 15 years. Major improvements have been realized in the materials used for simulating the river sediment and laser scanners used for measuring a model river bed to an accuracy of 1mm or better. Combining physical models with three dimensional numerical models can help visualize the flow patterns responsible for the depositional patterns noted in physical models. Field velocity measurements were revolutionized by ADCP systems and DGPS-based surveying systems have improved the bathymetry used in models. ■

References

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Figure 3 - Computational Fluid Dynamics (CFD) model results superimposed on a physical model for a combined CFD – physical model study

Figure 4 - One of Alden's boats for field measurement equipped with DGPS navigation, bathymetry and velocity measurement equipment