

hydrolink

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HYDRAULIC LABORATORIES SPECIAL

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**DEEP IMPACT: THE FUTURE
OF PHYSICAL MODELLING**
**LARGE-SCALE TSUNAMI
PHYSICAL SIMULATOR**
THE RØDSAND LABORATORY

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DEVELOPMENTS IN HYDRAULIC LABORATORIES

BY ANGELOS N. FINDIKAKIS

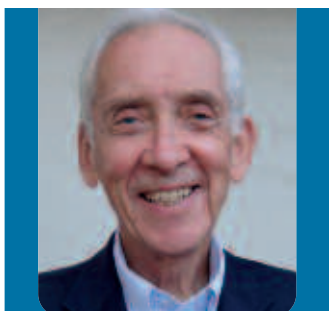
Rapid developments in computer technology and electronics over the last half century have changed drastically our daily lives and provided new powerful tools to all branches of science and engineering. Hydraulic engineering practice and research have been no exception. For example, laptops performing several orders of magnitude more floating point operations per second than the Cray 1 supercomputer introduced forty years ago, are used today routinely to run numerical models that solve a broad range of hydraulic problems. The credibility of the results of such models depends on the extent of their validation with field or laboratory data. In most cases, the collection of field data is quite costly and time consuming, which makes the use of laboratory data a more attractive option for model validation.

In addition, physical models in hydraulic laboratories offer the possibility to conduct tests under controlled conditions and can provide new insights into basic processes that help advance the understanding of the underlying physics. Using the tools offered by today's technology researchers and practitioners are able to analyze complex flow problems and processes, which has resulted in two trends in the evolution of hydraulic laboratories, the use of increasingly more sophisticated instrumentation and the design of inventive experimental facilities for the study of special flow problems.

The instrumentation used in hydraulic laboratories has evolved as rapidly as the hardware that led to the widespread use of numerical analysis models. Advances in electronics and laser and acoustic instrumentation make it possible to acquire rapidly and accurately high resolution data. For example, acoustic profilers can measure velocities several times per second using bins smaller than one centimeter. Special instrumentation makes it possible to extend velocity profiles to within a few millimeters from the bottom. Particle image velocimetry using digital cameras and special image processing algorithms allows calculating the surface velocity field over entire areas. In sediment deposition and erosion studies the use of underwater laser scanners makes it possible to record changes over large parts of the bottom by collecting millions of points per hour with sub-millimeter accuracy.

Hydrolink takes a look at the progress in data collection and processing methods from physical model tests through a series of articles on the capabilities and recent work of twelve hydraulic laboratories around the world.

On the subject of velocity measurements, Sinfotek of Beijing describes the development of a system using multiple synchronized cameras to capture the evolution of the velocity field over large areas in physical models, which is now used in several hydraulic laboratories in China. Articles contributed by HR Wallingford in the UK, Northwest Hydraulic Consultants in Canada and Aiden Research Laboratory in the USA discuss the use of advanced instrumentation in sediment deposition and scouring tests, and address the challenge of scaling issues in physical models of sediment transport models. Past approaches to the scaling of sediment transport that relied on distorted models had several limitations.



Angelos N. Findikakis
Hydrolink Editor

Today, the use of very fine particles of lightweight polymers in combination with surfactants that reduce surface tension effects seems to provide a solution to this problem.

Studies of erosion and deposition of different types and size sediments in natural channels are discussed in articles that describe the work at the hydraulic laboratories of Colorado State University and the University of Tennessee at Knoxville in the USA. Besides advances in instrumentation, creative designs of experimental settings have made it possible to study in the laboratory flow processes in the ocean. For example, the University of Western Australia has built several recirculating water tunnels, referred to as the 'O-tubes', with the ability to have either steady or

different types of oscillatory flow in it. The O-tubes have been used to study scouring and the self-burial of pipelines on the ocean floor, as well as other problems of subsea structures.

An example of a quite unique facility is the large rotating platform at the Laboratory of Geophysical and Industrial Flows in Grenoble, France, used to model geophysical flows, taking into account the rotation of the Earth and the presence of density stratification and variable bathymetry. Among other experiments this platform has been used recently to study the generation of internal waves by tidal currents on submarine ridges, and the contribution of the evolution of such internal waves to the vertical mixing in the ocean.

Another very interesting new experimental facility is the Large-Scale Tsunami Physical Simulator at the Central Research Institute of Electric Power Industry, in Japan. This facility can generate different size inundation tsunamis and has special instrumentation to measure the pressure distribution on vertical walls as well as the debris force on structures from scaled logs and vehicles. Tsunami waves generated by landslides have also been studied in one of the large basins of the Coastal Engineering Laboratory of the Technical University of Bari in Italy. The facilities of this laboratory are also used for a broad range of coastal studies including the effect of waves on dispersion and the interaction of jets and waves.

An interesting concept is that of the field laboratory in Rødsand, a non-tidal lagoon in southern Denmark. The laboratory consists of one buoy station and three instrument platforms in the lagoon used to test different types of equipment and collect data for the development of numerical models. Data communication units on the platforms and remotely controlled water samplers facilitate project management and data retrieval.

Because of space limitations, articles on three more laboratories will be published in the next issue of Hydrolink. They describe recent work at the Water Resources and Hydropower Research in China, CEDEX in Spain and Artelia in France.



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Cover picture: The wave-overtopping facility
of the Hydraulics Laboratory at Colorado State
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PRESIDENT'S ANNUAL MESSAGE

Dear Colleagues,

The past few months since I assumed the office of President have been a deep immersion in the diversity of IAHR activities. The sterling efforts of Roger Falconer as past President and the former IAHR Council should be recognized as setting the foundation for many new initiatives that will contribute to the vibrancy of the Association. Initiatives include the launching of the new Journal of Ecohydraulics (JoE) with our publishing partner Taylor & Francis and the creation of a new Technical Committee on Flood Risk Management under the leadership of Professor Larry Weber. JoE will be formally launched in May 2016 at a Technical Symposium sponsored by the China Institute of Water Resources and Hydropower Research (IWHR) in collaboration with IAHR. The leadership of founding Editors Dr. Chris Katopodis and Dr. Paul Kemp and the wing of our Ecohydraulics Committee chaired by Francisco Capel will ensure JoE has a strong start with several seminal papers expected in the opening issues.

The expansion of the Secretariat into IWHR in Beijing is proving to be a great success and Secretary General Dr. Jing Peng has recruited a talented staff and this enhanced support structure for our Divisions and Technical Committees means that 2016 will be a record year for IAHR specialist events and activities. A complete list is on the Calendar of the IAHR website and spans *Hydroinformatics* in Incheon (Korea) to *River Flow* in St Louis (USA). *RiverFlow2016* will include inaugural activities of the Flood Risk Management Technical Committee. Our regional conferences will be held in Liège, Belgium (Europe), in Lima, Perú (Latin America) - expected to be the biggest IAHR event of 2016; in Colombo, Sri Lanka (Asia Pacific); and our recently established IAHR MENA (Middle east and North Africa) Committee is sponsoring the third Arabian Coast Conference in Dubai organized by the Dubai Municipality in November.

There have been several memorable activities during the past few months since I took over the helm. On October 27th, Hohai University, one of



IAHR President Peter Goodwin addresses 30 000 people during the Hohai University centenary celebration

the elite global institutions dedicated to water research and a longstanding IAHR member, celebrated its 100th Anniversary. The ceremony was attended by almost 30 000 people and cultural displays were reminiscent of the opening of the Beijing Olympics. I was privileged to be invited to highlight the long collaboration between Hohai University and IAHR. At the same event, Professor Xu Hui, President of Hohai University hosted a *Chinese-Foreign University President's Forum on Internationalization and Innovation-Oriented Talents Cultivation*. Both IAHR Executive Director, Dr. Christopher George, and I were able to participate and explore how IAHR strategic directions align with many major Universities. Congratulations Hohai University on a spectacular event and good luck with a second century of success!

Professor Donatella Termini hosted the 2015 Yalin Memorial Colloquium in Italy. This international meeting sponsored by the IAHR Fluid Mechanics Committee included a remarkable plenary lecture by Professor Vlad Nikora, Editor of our Journal of Hydraulic Research, and created a stimulating retreat environment for early career researchers to engage in substantial technical debate with some of the top researchers in the field of sediment transport and turbulence. This carefully structured approach proved to be an excellent way to explore technical issues and establish international collaboration for research and publications. Further north in Europe, UNESCO-IHE hosted a retirement symposium for Professor

Arthur Mynett, Vice President of IAHR on 27 November. The symposium marked a remarkable career and included stimulating talks by Dr. Dick Yue of the Massachusetts Institute of Technology (USA) describing the OpenCourseWare experience that has transformed higher education and Dr. Vlado Babovic who described emerging techniques for managing uncertainties in Hydro-science. In February following the annual Executive Committee meeting in Madrid I held important talks with Tomás Sancho and Teodoro Estrela of the World Council of Civil Engineers with whom IAHR is closely collaborating in initiatives such as the Journal of Water Engineering and Research and RIBAGUA to bring scientific innovation into practice.

These are just a brief sampling of activities that demonstrate these are exciting times for IAHR. On behalf of the Council and the Secretariat, I would like to emphasize that IAHR is **your** professional association. We welcome and embrace your ideas to foster innovation in hydro-science and engineering and to build our international network of researchers and practitioners. You can follow IAHR events and activities throughout the year through our NewsFlash World eZine and by signing up to our new and improved social media feeds.

Sincerely,

Peter Goodwin
President

DEEP IMPACT: THE FUTURE OF PHYSICAL MODELLING

BY DAVID TODD, JAMES SUTHERLAND, JOHN HARRIS & RICHARD WHITEHOUSE

HR Wallingford's Fast Flow Facility, one of the world's largest marine test facilities, was opened in October 2014. Now, one year on, this versatile facility is setting the pace in physical modelling.



Dr David Todd is a marine scientist at HR Wallingford with responsibility for running the Fast Flow Facility. He holds a PhD in sediment transport and

has worked with the Fast Flow Facility since before it opened.



Dr James Sutherland is a Technical Director at HR Wallingford with 25 years' experience of nearshore hydrodynamics, sediment transport (including scour

around coastal structures and coastal erosion) beach management and wave forces on maritime structures. He is Vice Chair of the IAHR Coastal & Maritime Hydraulics Committee.



Dr John Harris is a Technical Director at HR Wallingford, a Chartered Engineer and a Chartered Marine Scientist with specialist skills in

numerical hydrodynamic modelling, turbulence and sediment transport.



Professor Richard Whitehouse is a Chartered Geographer and Technical Director at HR Wallingford with responsibility for the Fast Flow Facility. His

main focus is on sediment transport and geomorphology in river, estuarine, coastal and subsea environments.

Physical modelling has been a mainstay of HR Wallingford since the laboratory was established in the 1940s. In the beginning, waves were made in a large, outdoor basin by two men pushing a wave paddle between two points and a foreman with a stopwatch blowing a whistle to maintain the correct period. As you can imagine, tests were short in duration!

Almost 70 years later, enter the Fast Flow Facility. This new standard in physical modelling was developed to take physical modelling at HR Wallingford into the future. An extremely versatile facility, the Fast Flow Facility enables the production of fast currents and large waves in deep water, allowing physical model tests to be run at larger scales than would otherwise have been possible – deeper, faster, bigger. The first year of operation has seen a suite of commercial operations undertaken investigating novel scour protection, tidal turbine systems and, most recently, extensive testing of a number of offshore wind related structures for Danish Oil and Natural Gas (DONG) Energy. In addition to this, the facility has been home to exciting collaborative research with world-leading academics and private, company-funded research designed to keep HR Wallingford at the cutting edge of scientific developments.

Physical modelling has developed greatly during HR Wallingford's history, but no change has been as great as that seen in the last 25 years with the advent of personal computers, laser and acoustic instrumentation. Fifteen years ago, scour experiments relied upon one or more scientists moving touch-sensitive bed profilers around a structure to make measurements of scour development. This method allowed 8 radials of approximately 125 points to be made in a 30 minute period – a total of approximately 1 000 points per half hour. More recently, HR Wallingford has made use of terrestrial laser scanning systems in our large wave basins to allow greater, more repeatable

coverage that is less subject to human error. However, this technique requires the facility to be free from water as reflections from water surfaces cause errors in the measurements. This technique, therefore, while perfect for tasks like identification of breakwater armour movement, was not suitable for the new Fast Flow Facility.

The 4 m width of the Fast Flow Facility main channel allowed us to install a fully programmable x-y traverser system, which moves instruments up and down the flume to precisely known locations. We now deploy underwater laser scanners within the flume that are capable of recording approximately five million points with sub-millimetre accuracy in half an hour – five thousand times what we were capable of just 15 years ago. The laser scanners are able to cover a large area with good temporal resolution, providing data that is comprehensive in its coverage, representative of the experiment being undertaken, repeatable (as the exact position of each point is known) and less subject to human error. In addition, as these laser scanners are fully submersible, there is no need to stop testing or drain the facility as scans can be undertaken while experiments are ongoing.

Bathymetry measurements are not the only aspect of physical modelling that has changed drastically in the last 25 years. Flow profiles used to be restricted to a few points in the water column and were measured using propeller meters. However, with the acoustics revolution resulting in instruments such as the Nortek High Resolution Aquadopp – capable of bins as small as 7 mm and sampling rates of up to 8Hz – flow profiles can now be estimated across most of the water column (with blanking distances immediately below the instrument and immediately above the bed) both quickly and accurately.

The areas immediately sub-surface or above the bed can be sampled using the Nortek

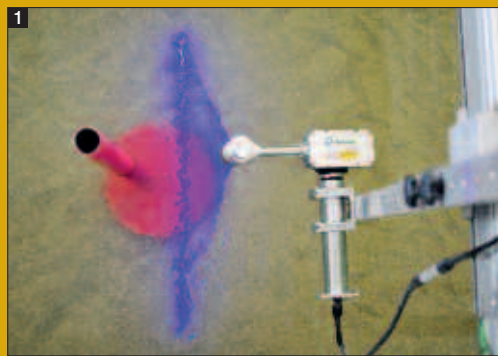


Figure 1 - Underwater laser scanner profiling the bathymetry around a suction bucket pile



Figure 2 - Aquadopp installed in Fast Flow Facility



Figure 3 - Wave gauges, suction bucket pile and Vectrino (on right) prior to a scour test



Figure 4 - Vectrino II ADV deployed in the Fast Flow Facility

Vectrino II – an acoustic instrument capable of measuring the three components of velocity in a 30 mm section at 1 mm intervals down to approximately 3 mm above the bed at sampling rates of up to 100 Hz. Such high sampling rates allow the investigation of turbulence and wave characteristics.

These instruments have all been utilised successfully during the first year of operation in the flume. The most recent commercial work, undertaken for offshore wind developer DONG Energy, has involved exploring alternatives to the traditional monopile foundation. Well understood and heavily utilised in shallower near-shore regions, as offshore wind moves into deeper water, larger monopiles are required which must be installed at greater depths. These factors are resulting in monopiles slowly becoming less viable as foundation structures. Because of this, developers are designing and testing alternative foundations in order to reduce costs and keep offshore wind competitive within the energy market place.

Even in deeper water, offshore wind farms are often sited in areas affected by strong tidal currents in combination with steep, near breaking waves. These conditions can result in scour, posing a risk to the stability of turbine foundations, cables and cable crossings, while protection and mitigation works come at a high cost. Optimisation works for scour protection

are still developing. Often, scour protection designs have been tested with dominant wave conditions only due to the limitations of the test facilities. To cover real exposure conditions for the North and Irish seas for example, the ability of the Fast Flow Facility to reproduce design conditions of combined waves and currents under true live bed conditions, with mobile sediment and at a large scale is of significant importance for an optimised and yet robust scour protection design.

For deep water applications, a new suction bucket jacket foundation design has been refined by DONG Energy as an alternative to the traditional monopile. This new structure required physical model testing to determine how the structure interacts with, and impacts upon, the local hydrodynamic conditions and the surrounding seabed. HR Wallingford has been carrying out physical model testing of scour response to optimise the design of the suction bucket jacket and mitigate scour development.

Key to this testing was the ability to run both fixed and live bed conditions in the Fast Flow Facility, allowing investigations into the potential depth of scour and the stability of rock armour of various sizes and gradings. Gathering information on the size and extent of protection that is required under differing hydrodynamic

conditions is vital to the survivability of the scour protection.

An underwater laser scanner was utilised to measure the bathymetry before, during and after each test, providing details of the development of scour both temporally and in extent. Current profiles, collected using the Aquadopp HR profiler and Vectrino II Acoustic Doppler Velocimeter (ADV) have provided a record of the hydrodynamic conditions run in the facility. Twin-wire wave probes located at different points along the flume provided detailed wave spectra, while a High Definition (HD) underwater video camera was used to provide real-time visual feedback of scour development and armour stability.

Physical modelling techniques have changed markedly over the last quarter century with the advent of new measurement capabilities allowing greater coverage of test areas, both temporally and spatially. The Fast Flow Facility was built to be the future of physical modelling at HR Wallingford, with its first year proving a huge success as it utilises the latest technology to deliver large-scale commercial and research projects. Progress within the facility also shows no sign of slowing, with the in-house development team set to release a set of rapid calibration wave probes and a jacking system for the wave paddle in the next few months. ■

NORTHWEST HYDRAULIC CONSULTANTS – USING EXPERIMENTAL METHODS TO ADVANCE SEDIMENT MANAGEMENT SOLUTIONS AT HYDROELECTRIC FACILITIES

BY BRIAN R. HUGHES

As existing hydroelectric facilities age, and as new facilities are developed, the management of sediment both upstream and downstream of these developments is repeatedly identified as a critical parameter in the project life cycle. For over 50 years specialists at Northwest Hydraulic Consultants (NHC) and Lasalle|NHC have been utilizing in-house hydraulic laboratories, together with advanced numerical methods, analyses and field investigations, to assist clients throughout North and South America and elsewhere in developing techniques to effectively manage sediment at their projects.

The Problems

The management of sediment accumulation and passage at hydroelectric projects is an ongoing and increasing problem around the world. The most prominent problems

associated with sediment accumulation, passage and scour at hydroelectric facilities include loss of storage, restricted flow to the intake, damage to equipment, and degradation downstream of the project often leading to loss of habitat.

Many of today's large hydroelectric projects were built with a dead storage capacity designed to trap sediment for a period of approximately 50 years. Since many of these facilities are now approaching their design life, it is expected that the problems associated with upstream sediment accumulation will become more pronounced in the coming years. Smaller, run-of-river facilities which were designed with minimal storage but are often located on steep, sediment-laden rivers are potentially subject to annual sediment volumes that must be diverted away from the intake by some means.

As a reservoir fills with sediment, water depths are reduced and sediment transport capacity within the reservoir increases. This results in more sediment reaching the intake, which can restrict the volume of water entering the intake during periods of lower flows and can increase abrasion damage to the turbines and other mechanical equipment. The resulting impacts on performance, operation and maintenance can have a huge impact on the economic and technical viability of the project. In 2009 it was estimated that the total yearly loss resulting from sediment accumulation in reservoirs was reaching almost US\$20 billion (ICOLD 2009), and this number is expected to continue to increase as the world's reservoirs continue to fill with sediment.

The Tools

Numerous examples are cited in the literature where reservoirs have filled with sediment well in advance of time predictions made during the project design, requiring development of remedial sediment management measures at existing facilities. Similarly, new projects are being developed each year that must consider sediment management measures in their



Brian Hughes holds a Bachelor's degree in Civil Engineering and a Master's degree in Water Resources, both from the University of British Columbia. He has over 25 years of experience in modelling and hydraulic design having worked on a variety of hydroelectric developments, spillway projects and sediment transport investigations. Since joining Northwest Hydraulic Consultants in 1988, Brian has participated in over 200 physical and numerical model studies. He is a Principal of NHC and the Director of the firm's physical modelling operations.

Figure 1 - Sediment accumulation within a hydroelectric reservoir in the Western United States



designs. Tools available to analyze and develop sediment management measures include drawing on the experience of sedimentation specialists, implementing field investigations and monitoring systems, applying advanced numerical analyses, and conducting reduced-scale experiments in a hydraulic laboratory. In many cases, two or more of these tools are required to arrive at a technically feasible solution.

NHC and Lasalle|NHC have operated hydraulic laboratories in Canada and the United States for over 50 years. While the laboratories have formed the foundation for many studies related to sediment management at hydroelectric facilities, the capabilities and expertise of the firms' senior specialists, together with advancements in numerical analyses and field investigations, have all played important roles in the development of practical and effective solutions for managing sediment at these facilities. Reservoir sedimentation and scouring processes, where 3D effects are important,

usually require the use of a physical (scale) model. The biggest challenge in conducting reduced-scale experiments to address sediment management issues is the scale effect associated with simulating the scour and deposition processes occurring in the field. Nonetheless, NHC and LaSalle|NHC have adopted experimental methods using fine sands, low-density model sediments and distorted scale models to study a range of sediment-related problems commonly found at hydroelectric projects.

The experiments conducted at NHC often include both a “comprehensive model” and a larger-scale “section model”. The comprehensive model represents a relatively large area of the reservoir and downstream channel, and is used to assess the general sedimentation patterns and behavior of both suspended and bedload sediments approaching the project. Typical scales for comprehensive models of this type generally fall between 1:40 and 1:100. The section model of the intake structure or desanding facility is then used to provide a detailed evaluation of their performance and refine their designs to make them more efficient

at preventing sediment from entering the penstock. Examples of comprehensive and section models are illustrated in Figures 2 and 3. In addition to laboratory experiments, NHC often apply advanced numerical methods and field investigations to gain a better understanding of the processes that are occurring in the field. These methods are applied both during the design stage for assessing the performance of new facilities and during the operation stage if sediment management problems have developed since the facility was constructed. The results of the numerical analyses and field investigations are often used as input parameters for a physical model used to confirm their findings.

Numerical methods utilized by NHC include 1-, 2- and 3-dimensional models, with both hydrodynamic and morphologic capabilities. Recent studies conducted by NHC include assessing the morphologic impacts downstream of a proposed hydroelectric development in western Canada using Telemac 2D (Figure 4), and assessing the efficiency of a proposed sediment bypass tunnel at an existing hydroelectric development in the United States (Figure 5). Field

monitoring studies have included the installation of turbidity meters and bed level sensors upstream of the intake for a run-of-river project, to provide real-time information critical to power-house operation.

Finally, in-house specialists in sedimentation and geomorphology use the information generated from these tools to develop solutions designed to mitigate the problems associated with sediment accumulation.

The Solutions

Having developed the necessary tools, NHC has worked with clients on establishing solutions for both existing and proposed hydroelectric facilities, ranging in capacity from less than 1 MW to over 2000 MW. The solutions have been as varied as the problems themselves. For small, run-of-river developments they can include (i) field monitoring to guide operation, (ii) controlling the sediment source, (iii) incorporating sediment guide walls or sediment vanes upstream of the intake, and (iv) periodic dredging or sluicing of the accumulated sediment. For larger developments the solutions can also include incorporating sediment bypass

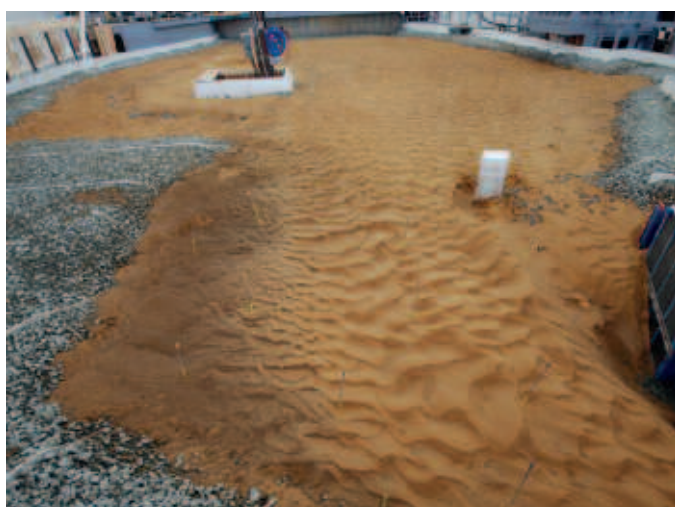


Figure 2 - Comprehensive mobile-bed model using low-density model sediments

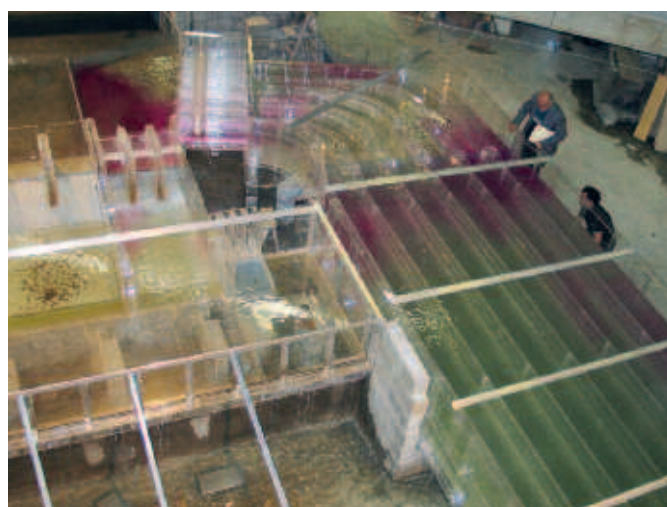


Figure 3 - Detailed section model of a desanding facility for a project in India

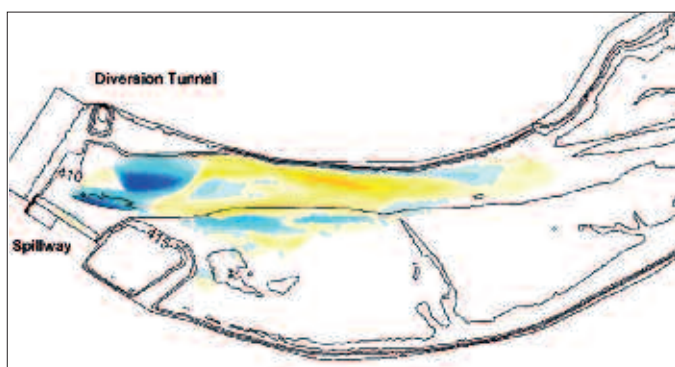


Figure 4 - Prediction of morphologic changes downstream of a proposed hydroelectric project in Canada using Telemac2D

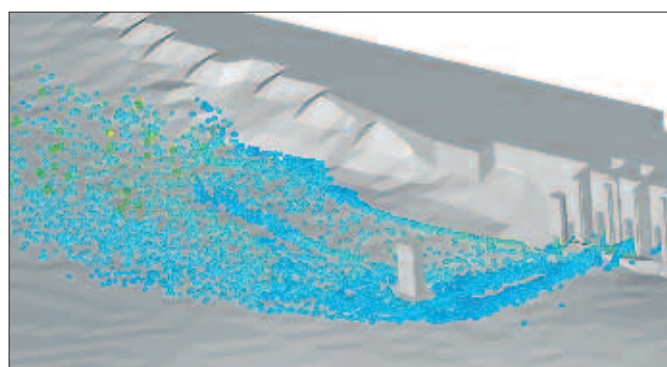


Figure 5 - CFD particle tracking used to assess the efficiency of a proposed sediment bypass tunnel at an existing hydroelectric project

and/or desanding facilities. In many cases the preferred solution may include two or more of these components.

Examples of these solutions include a small run-of-river development in Western Canada where turbidity meters and bed level sensors were installed upstream of the power tunnel intake. Information from these sensors is used by the operators to assess when the power intake should be shut down to protect the turbines and when the sluicing facilities should be operated to remove accumulated sediment from the headpond. For a much larger project, field monitoring sensors, sediment sluicing facilities and a desanding facility were all incorporated into the design to manage very high sediment loads at the intake. In this case, NHC conducted extensive field investigations, numerical model analyses and mobile-bed physical model studies to arrive at a practical and effective solution.

The Next Steps

As existing hydro projects continue to age and as new projects are developed, the need to effectively manage sediment at these facilities will continue to increase. At the same time, the experience of specialists and the capabilities of investigative tools will continue to improve, and



Figure 6 - Intake facility that includes field monitoring sensors, sediment sluicing facilities and a desander

the solutions will continue to evolve. NHC and LaSalle|NHC will continue to advance their capabilities and expand their "toolbox" to assist clients with developing solutions related to sediment management – whether a 0.5 MW development on a small stream or a 2000 MW development on one of the world's largest rivers. Advances in numerical analyses and in the capabilities of real-time field sensors may

reduce reliance on large-scale physical models; however, specialised skills and experimental capabilities for site-specific investigations and the development of innovative solutions will continue to be in demand for several decades to come. ■

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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

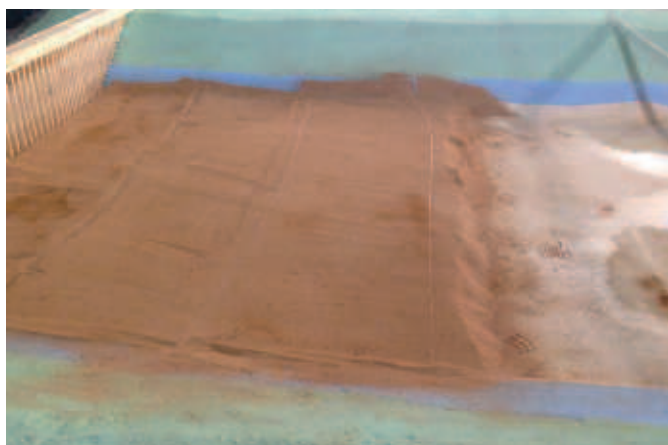


Figure 1 - Lightweight sediment being installed in a physical model

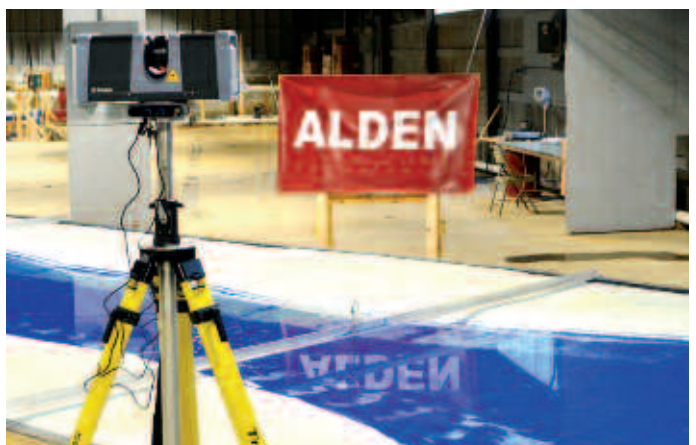


Figure 2 - Sub-millimeter scanner in use on a model to determine scour and deposition. Scanner is on the yellow tripod and the river bed is blue



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 de-

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

termining 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 signifi-

cant 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. ■

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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

THE HYDRAULICS LABORATORY AT COLORADO STATE UNIVERSITY

BY ROBERT ETTEMA & STEVEN R. ABT

An illustrious history along with the availability of extensive facilities, a capacity to deliver remarkably large water discharges, and an array of instrumentation, make Colorado State University's (CSU) Hydraulics Laboratory a national and international resource for tackling fundamental and applied aspects of water engineering. The lab's earliest activities date back to the 1880s work of the pioneering hydraulics engineer of the American West, Elwood Mead (for whom Lake Mead on the Colorado River is named). Its current activities address a wide range of contemporary as well as enduring research topics, and link closely to the university's extensive programs of graduate education in water engineering, science and management. As with all vibrant laboratories, the hydraulics laboratory at CSU continuously develops its facilities and instrumentation in response to evolving research needs and opportunities.

Background

The history and potential of CSU's hydraulics lab quickly drew the attention of noted hydraulician Hunter Rouse, who in 1940 began a lengthy connection with the lab. Though his

name is primarily associated with the University of Iowa's hydraulic lab, Rouse spent considerable time at CSU and produced a handy book (Rouse 1980) describing the historic influences and people that led to the lab's prominence. In his customary concise, matter-of-fact manner Rouse documents some of Mead's contributions, along with those by many other well-known engineers who contributed to the lab's growth in productivity and stature; e.g., Ralph Parshall, Emory Lane, Maurice Albertson, Daryl Simons, Ev Richardson and Hsieh-Wen Shen; to name just a few people. Subsequent articles, including those by Bhowmik et al. (2008), Simons (2004), and Julien and Meroney (2003), recount the work of other notable engineers whose principle contributions to hydraulic engineering were made while at the lab. The lab's facilities also drew the interest of talented scientists, such as the acclaimed geomorphologist Stanley Schumm.

Setting

The physical and educational aspects of the lab's setting give it strategic advantages shared by few other hydraulics laboratories. Since 1962 the lab has occupied a major part of CSU's



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Steven Abt is an Emeritus Professor of Civil and Environmental Engineering at Colorado State University. He graduated as a civil engineer from Colorado State University in 1973, and subsequently a PhD. Degree in 1980 from the same institution with specialization in river mechanics. He worked as a Professor, Director of the Hydraulics Laboratory, Director of the Engineering Research Center and Research Associate Dean of the College of Engineering at Colorado State University. He has over 35 years of experience performing scaled physical model studies, revetment testing and evaluation, sediment transport processes in gravel-bed rivers and hydraulic structure-near prototype experimentation. He has published extensively in the field.

Figure 1 - An aerial view of CSU's Hydraulics Laboratory at Horsetooth Reservoir

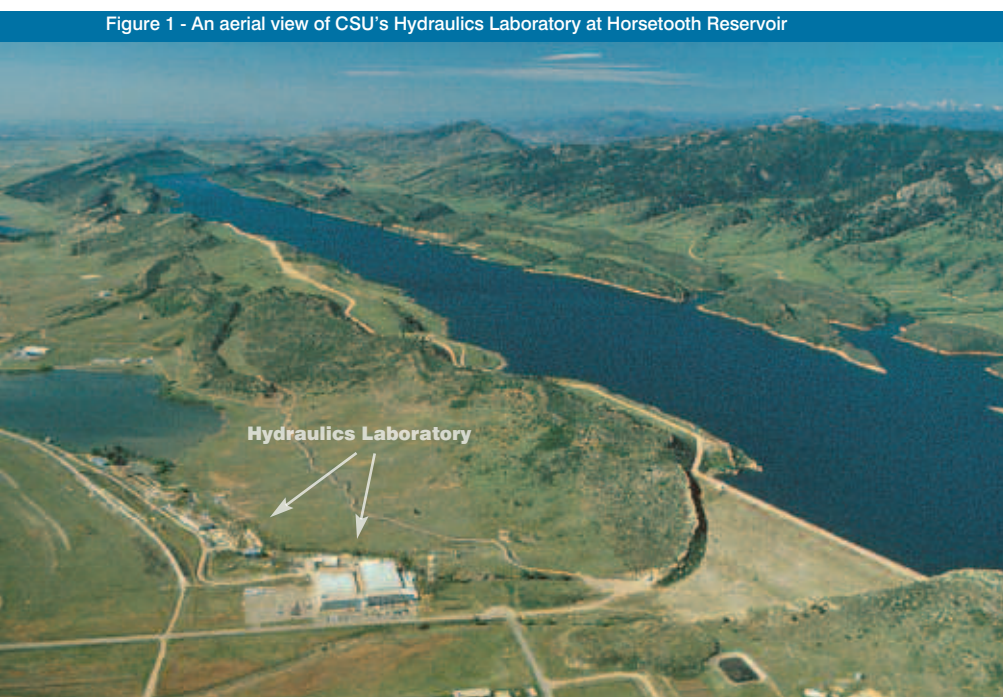




Figure 2 - The 8 m by 33 m flume used to model a system of grade-building structures placed in a mobile-bed model of a braided alluvial channel



Figure 3 - Wave-overtopping of a grassed, soil slope placed in the wave-overtopping facility

Engineering Research Center (ERC), located below Soldier Canyon Dam of Horsetooth Reservoir in Fort Collins. Figure 1, an aerial view of the ERC, indicates the lab's physical setting. This setting is ideal for a hydraulics laboratory as it provides a large water discharge capacity (up to 5 m³/s) at a very large head (107 m). Moreover, the reasonable centrality of Fort Collins within the USA, and its closeness to Denver International Airport, make the lab readily accessible.

The lab serves faculty and students involved in CSU's broad, water-related graduate programs (see, for example, <http://www.engr.colostate.edu/ce/degreeinfo.shtml>). The programs connect contemporary technologies in water-related areas of civil and mechanical engineering and the geosciences. They include hydraulic and hydrologic systems and infrastructure, fluvial engineering, fluid mechanics, environmental and ecological hydraulics, coastal hydraulics, and groundwater, and are well-known for interdisciplinary studies involving water-resources planning and management. The programs emphasize the application of advanced laboratory and field instrumentation and methods, computer technologies and numerical modeling to practical water engineering as well as to the enlightened management of environmental and ecological systems. Today these programs have nearly 200 graduate students. Over the years the programs have led innumerable graduates to careers in water engineering.

Facilities

The large space and water discharge available to the lab enable it to operate substantial permanent physical facilities and have the flexi-

bility to construct large-scale, near-prototype size, project-specific facilities. Additionally, the lab has a well-equipped machine and instrument shop to support the facilities and build experiment set-ups and instrumentation. These attributes enhance the lab's ongoing capacity to undertake a wide range of fundamental as well as applied research projects. The lab's permanent features include a comprehensive system of fourteen pumps connected to a network of sumps (volume of 1,223 m³). Individual pumps range in capacity from about 1.5 m³/s at a head of 6 m, to about 0.017 m³/s at a head of 15 m. Portable pumps of various capacities are used for experiments involving flow recirculation. The pumps connect to a fleet of flumes, although some flumes are fitted with their own pumps for flow and sediment recirculation. The fleet includes a versatile flume 8 m by 33 m in plan area, and 1.3 m deep. Figure 2 shows its use in a current study involving braided channels (Ettema et al. 2015). A large recirculating flume, 2.4 m by 60 m by 1.3 m deep, is capable of recirculating water at a discharge of 2.8 m³/s and gravel-size sediment. This latter flume is fitted with a wave-maker in order to conduct various studies on the combined effects of wave and current action. The main lab building houses four other tilting flumes and has ample room for temporary experimental installations and hydraulic models. A 40.7-hectare outdoor area adjoins the main lab facilitating large-scale model and full-scale prototype experiments. Additionally a further lab building exists for testing hydro-machinery equipment (its 1m-thick concrete floor averts flexural vibration) and is at times used to house hydraulic models and large-scale experiments. A large flume and a wave-overtopping basin are

presently in frequent use. The flume, 18 m by 6 m by 2.4 m, includes a 3.3 m-deep recessed section. Since 2010 CSU has operated the largest wave overtopping test facility in the world (Figure 3). This facility, its need prompted by the damage wrought on New Orleans by Hurricane Katrina, is operated using a computer system that simulates waves larger than 2 m in height waves. The waves spill water down over 12 m-long, 2 m-wide "trays" that simulate levees made of soils specific to any region (Thornton et al. 2014). Various types of grass are grown in soil trays placed in a large greenhouse purpose-built for the over-topping facility. A companion over-topping facility consisting of a concrete head box, chute and tailbox is used for studying the erosion of soils and erosion countermeasures located on steep slopes.

Concluding Remark

By virtue of its physical and educational settings, and the talents of the many people associated with it, CSU's Hydraulics Laboratory is well-positioned to continue as a national and international resource for water engineering and related sciences. ■

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HSL – A PREMIER LABORATORY FOR STATE, REGIONAL AND GLOBAL RESEARCH IN HYDRAULICS AND SEDIMENTATION ENGINEERING

BY THANOS PAPANICOLAOU, ACHILLEAS TSAKIRIS, CHRISTOPHER WILSON & BENJAMIN ABBAN

The recently established Hydraulics and Sedimentation Laboratory (HSL) at the University of Tennessee at Knoxville (hsl.engr.utk.edu) constitutes a premier facility for conducting innovative fundamental and applied research in environmental fluid mechanics, sedimentation engineering and watershed science. With state-of-the-art facilities and equipment, HSL aims to provide knowledge and address hydraulic engineering problems, while promoting at the same time the adoption of adaptive strategies towards addressing contemporary and future challenges at the state, regional, national and international levels.

Research with Depth and Breadth

The research conducted at HSL has three distinct but interconnected main thematic areas, namely:

1. Coarse-grained stream hydraulics, stream restoration, sediment transport processes
2. Cohesive soil/ sediment transport dynamics and source tracing
3. Ecological and biogeochemical processes in watershed and estuarine environments.

Hydraulics and Sediment Transport Processes in Coarse-grained Channels

The main thrust of the research activity at HSL is focused on the study of fundamental environmental fluid mechanics, hydraulics and sediment transport mechanics in coarse-grained streams. The improved fundamental knowledge gained from HSL research is oriented to the solution by a suite of practical engineering problems, thus assisting practicing engineers and other stakeholders effectively manage the environment in coarse-grained streams (Fig. 1). The spearhead of the research in this theme is focused on developing educated mountain stream restoration practices, with most prominent the understanding of the role of large boulders and similar structures (Fig. 2) in modifying the near-bed turbulent flows and controlling sediment transport patterns with implications to fish habitat, water quality and sediment management. Furthermore, our research in this

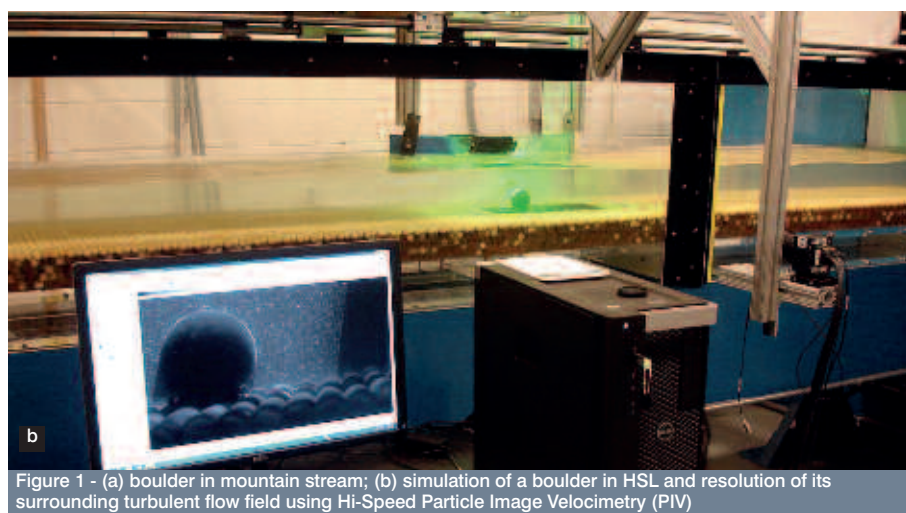


Figure 1 - (a) boulder in mountain stream; (b) simulation of a boulder in HSL and resolution of its surrounding turbulent flow field using Hi-Speed Particle Image Velocimetry (PIV)

theme goes hand-in-hand with the worldwide transition in analyzing bedload transport from an Eulerian to a Lagrangian perspective. Work in HSL concentrates on investigating coarse bed granular dynamics and grain-to-grain interactions, as well as diffusion processes. Along the same lines, research at HSL also focuses on scour around stream restoration and other hydraulic structures placed in coarse-grained streams, a topic which has received minimal attention in the past. For undertaking this research, HSL has two 10-m long, 0.60 m wide, water-recirculating flumes with adjustable slope up to 5%, one of which also allows sediment recirculation (Fig. 3). A plethora of measuring equipment is available for making high quality flow and sediment transport rate measurements, including a state-of-the-art Hi-Speed Particle Image Velocimetry (PIV) system, a 2D Laser Doppler Velocimeter (LDV) system, several 3D Acoustic Doppler Velocimeters (ADV), geophones, micro-pressure transducers, Radio Frequency Identification (RFID) sediment particle tracking equipment and, sonar bathymetric devices among others. The HSL also offers space, electromechanical infrastructure and unique expertise for constructing physical models.

Cohesive Sediment Transport and Dynamics

A key topic of HSL research is the erosion of cohesive stream banks (Fig. 2), a process



Thanos Papanicolaou, Professor and Henry Goodrich Chair of Excellence in Civil and Environmental Engineering at the University of

Tennessee, Knoxville is the Director of the Hydraulics and Sedimentation Laboratory. Since receiving his M.Sc. and Ph.D. degrees in Civil and Environmental Engineering from Virginia Tech, he has been actively involved in experimental fundamental and applied research in environmental fluid and sediment transport mechanics, as well as in numerical modeling of riverine and watershed transport processes. Having authored over 100 articles in 42 different discipline journals, he is currently the Director of the Tennessee Water Resources Center, as well as the chief Editor of the Journal of Hydraulic Engineering, ASCE.



Achilleas Tsakiris was appointed as the manager of the Hydraulics and Sedimentation Laboratory after completing his M.Sc. and Ph.D. studies at the

University of Iowa in 2014. His research interests include fundamental hydraulics and interaction between sediment, structures and flow turbulence, modeling as well as fluidization of cohesive sediment. He is also actively involved in sensor development for surrogate bedload transport and bridge pier scour monitoring.



Christopher Wilson is the field coordinator for HSL. He holds a B.S. in Biology/Ecology from Rhodes College and a Ph.D. in Geological Sciences.

Additionally, he has worked at the USDA-ARS National Sedimentation Lab before joining the team. His research interests include examining the movement of water, soil, and carbon through the Earth's critical zone through source tracking of radionuclides and other hypopedological properties, as well as studies related to bank erosion, soil health, and evaluating conservation practices.



Benjamin Abban is a researcher at HSL. He holds an M.Sc degree in Civil Engineering from the University of Cape Town. His research inter-

ests include upland erosion processes, watershed dynamics and scaling laws, knick-point development and migration, and local scour around bridge piers and abutments. He is also interested in computational modeling of river networks, as well as the use of various sensor technologies such as Radio Frequency IDs and laser scanning systems for monitoring land surfaces changes and sediment fluxes.

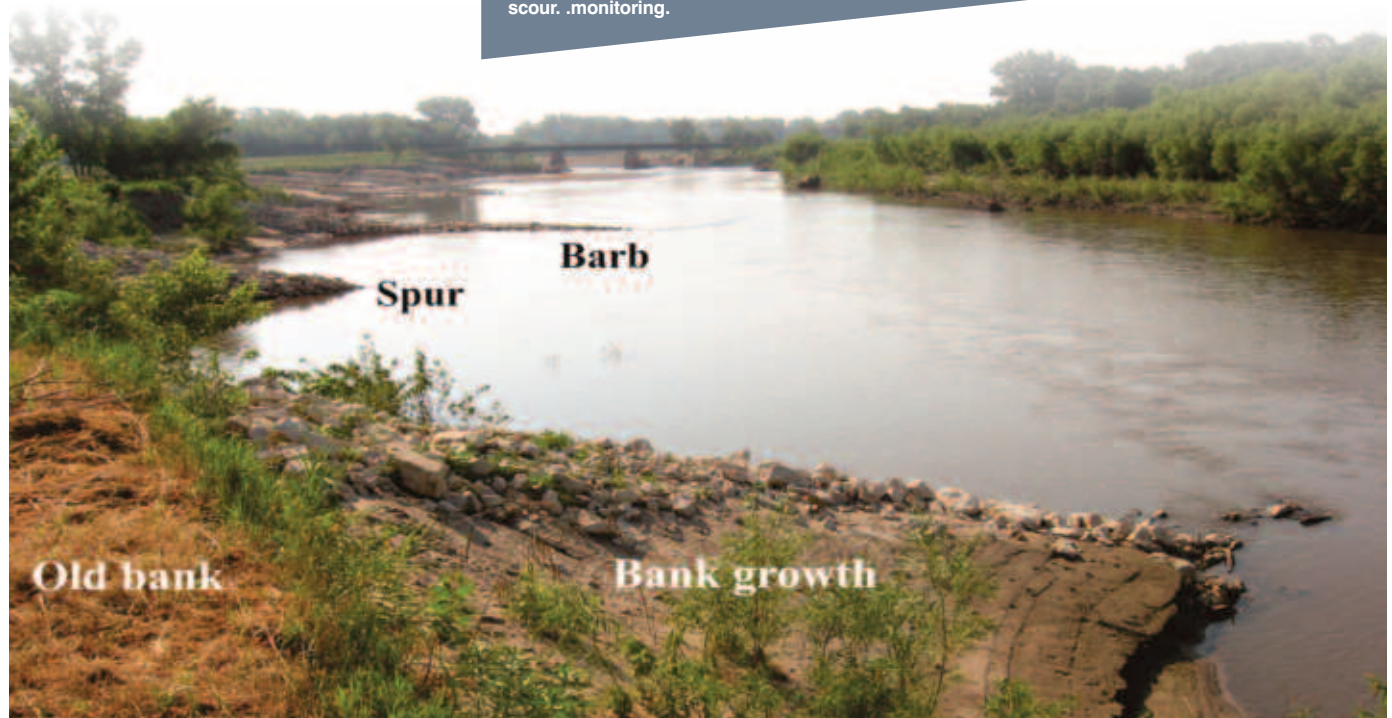


Figure 2 - Placement of hydraulic structures (barbs and spurs) for protecting river banks from erosion and preventing loss of agricultural land

encountered world wide with important implications on lateral stream migration, safety of bridge, highway and other infrastructure, water quality and loss of arable land. Research at HSL concentrates on isolating the different mechanisms of bank erosion and quantifying the erosional strength of different soils, as well as the effects of soil properties, temperature changes and vegetation. In doing so, we seek to develop predictive relationships for bank erosional strength suitable for use by practicing engineers and planners. Instrumental to the study of cohesive bank erosion at HSL are a prototype conduit (Fig. 3) and a mini-open channel mobile flume which has been designed in-house specifically for estimating the critical erosional strength of bank materials in the laboratory or in situ. Within the framework of cohesive sediment transport, work at HSL also focuses on the phenomenon of fluidization and the resulting piping within soils that arises from pore water pressure variations in the soil. Fluidization is applications in fluid mud management in harbors, estuarine dynamics, dam seepage and gas (methane or gas hydrates) upwelling in lakes and dam reservoirs. HSL offers the capability and technical expertise for replicating the fluidization and piping phenomena in the controlled laboratory environment thus allowing isolation of the underlying physical mechanisms. A wide array of measurement equipment, such as miniature pressure transducers, high-definition imaging and image analysis and a microscope lens assist in making detailed measurements of pore water pressure and observations of the soil structure.

Source Tracing and Nutrient Cycling

Research at HSL is also focused on understanding the source and transport of sediment and nutrients (e.g., nitrogen and phosphorus)

Research at HSL focused on understanding the source and transport of sediment and nutrients in intensively managed landscapes

in urban and agricultural watersheds and particularly in intensively managed landscapes. Through this understanding, we sought to inform the decisions of land managers, farmers and other land stakeholders towards a more sustainable agriculture. For this type of research, HSL has a mobile rainfall simulator unit capable of performing in-situ experiments (Fig. 4) simulating natural storms for studying the movement of soil at the plot or watershed scales. The mobile unit is complemented with an array of equipment for measuring suspended sediment concentration, infiltration, bed microtopography, moisture, erosion depths, pressure and temperature. Furthermore, HSL is equipped with a gamma sourcing facility that allows tracing sediment with radioisotopes including ^{210}Pb , ^7Be , and ^{137}Cs . Under the lead of Prof. Papanicolaou, Dr. C.G. Wilson coordinates the field experimental campaigns and the radionuclide tracing, which are complemented with numerical modeling supervised by B. Abban. This research is enhanced with the study of carbon cycling in the landscapes for gaining insight into the fertility of soil.

New Initiatives and Worldwide Networking
Constantly adjusting and adapting to contemporary challenges, HSL seeks to expand its research capabilities in parallel with the three main research thematic areas. As part of this effort, HSL is applying knowledge gained by

research on Critical Zone dynamics for studying sustainable ways of producing food, water and energy. Along the same lines, HSL plays a key role worldwide in developing new generation of sensing technologies for developing “smart” infrastructure and for supplying newly developed numerical models with accurate and actual data. A key step in this direction is the development of an automated, remotely operating system based on RFID technology for automated monitoring of scour around bridge piers and other hydraulic structures.

In these new initiatives, HSL is partnering and collaborating with many institutions in the public and private sectors nationally and internationally. HSL is building connections with other laboratories in Australia, New Zealand, India and Europe, with the United States Bureau of Reclamation (USBR) and the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) laboratories, and with the United States Army Corps of Engineers (USACE) and the United States Geological Survey (USGS) southeastern region to address significant environmental problems such as the hypoxia and the BP Horizon disaster problems in the Gulf of Mexico. In addition HSL is developing a partnership with the Tennessee Valley Authority on water and dam operations as well as with ORNL on biogeochemical cycles and hydropower energy. ■



Figure 3 - Perspective view of HSL with the 2 experimental flumes (left and top right) and the conduit erosion flume (bottom right)



Figure 4 - Rainfall simulator unit deployed in situ for studying upland erosion in an agricultural field



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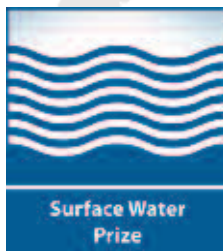
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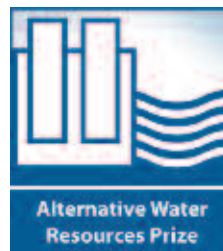
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LEGI: FUNDAMENTAL FLUID MECHANICS FOR THE BENEFIT OF THE ENVIRONMENT AND INDUSTRY

BY JOËL SOMMERIA, THIERRY MAITRE & JEAN-PIERRE FRANC

The Laboratory of Geophysical and Industrial Flows (LEGI) (www.legi.grenoble-inp.fr) in Grenoble, with over 100 employees, conducts leading-edge research in the field of fluid mechanics. Both environmental and industrial flows are investigated together with their interactions. Various advanced methods are used, including theory, experiments, numerical modeling and the development of innovative measuring instruments. In recent years, new facilities and capabilities have been developed such as the Coriolis platform, the test bench for water turbine models used in the field of marine renewable energies and the PREVERO cavitation tunnel for cavitation erosion investigations.

The Coriolis platform

The Coriolis platform (Fig. 1), 15 m in diameter, is the largest rotating platform in the world dedicated to fluid dynamics. Its main activity is the experimental modeling of geophysical flows, taking into account the rotation of the Earth, in the presence of density stratification or topography. The large size provides an approach to the inertial regimes that characterize ocean dynamics, with little influence of viscosity and centrifugal force. Laboratory experiments can thus provide support to model ocean dynamics and interpret observed fluid process under simplified and well-controlled conditions.

The platform has been rebuilt in 2014 on the model of the old platform built in 1960, with many improvements. The total weight of the platform is 150 tons and it supports an extra load of 150 tons of water, corresponding to water height of 1.1 m in the cylindrical tank, 13 m in diameter. Its rotation period can be set with high stability between 10 and 1 000 s. The tank can be filled with homogeneous or density stratified water. Stratification is made by filling the tank with a computer-controlled mixture from two ancillary tanks (90 m³ each) with specified salinity and temperature. Model sediments made of plastic particles can also be used.

Various devices can be employed to produce turbulence, such as towed grids and topography models to reproduce boundary layers and wakes of the natural environment. Thermal convection can be sustained by heating with up to 20 kW.

Particle Imaging Velocimetry (PIV) systems provide time resolved velocity fields in both horizontal and vertical planes of up to 3 m × 4 m in size, with a relative precision of 2%. The laser sheet can scan a volume, providing three-dimensional three-component velocity fields, a quite unique feature for such large-scale

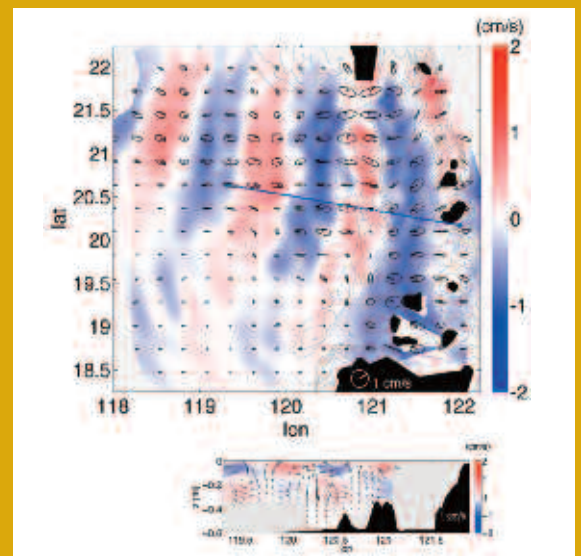


Figure 1 - The Coriolis platform (left), with an example of the velocity field obtained by PIV in a scaled model (horizontal scale 1/100 000) of tidal currents in the Strait of Luzon (right). The ellipses indicate the trajectories of the main (barotropic) tide while the colors represent the excited internal waves (baroclinic tide) also seen as a vertical cut in the bottom right (from Mercier et al. 2013 [1])

systems. Other imaging laser techniques can be used such as LIF (Laser Induced Fluorescence). Local probes are also available, like ultrasonic velocimeters, salinity and temperature sensors. Mechanical displacements and data acquisition are computer controlled. The installation is also appropriate for Lagrangian studies, tracking various flow tracers or particles.

Recent projects involve the generation of internal waves by tidal currents on submarine ridges (see Fig. 1). Those can evolve into solitary waves with intense currents in some regions of the world, a process which contributes to the global vertical mixing of the ocean. Other projects model the mixing of fresh and salty water in a river estuary or a fjord. More fundamental studies of turbulence in a density stratified and rotating medium are also performed. The general mechanisms of energy dissipation and mixing in oceanic currents are thus investigated, with particular interest in the evolution of coherent vortices like the 'meddies', lenses of Mediterranean water persisting at 1 000 m depth in the Atlantic Ocean. As part of the ERC (European Research Council) project WATU (Wave TURbulence), surface waves are studied in the context of wave turbulence, which is the long-term random behaviour of interacting waves of moderate amplitude in an enclosed basin. For this project, the full space-time fluctuations of the free surface shape and flow velocity is obtained by a 3 camera stereoscopic system. Extensions of these studies to

internal gravity waves obtained at a density interface or in a continually stratified medium are under way.

The test bench for marine water turbine models

The marine water turbine facility (Fig. 2a) was built in 2005 in the frame of the HARVEST - Hydroliennes à Axe de Rotation VERTICAL STabilisé - project aiming at developing a new concept of cross flow (Darrieus) marine current energy converter^[3]. Compared to axial turbines, Darrieus type turbines present several possibilities for marine applications. They are insensitive to the flow direction avoiding the need of yaw and variable pitch devices. Moreover, Darrieus turbines can be piled up on a same shaft allowing the use of the same generator for the entire turbine column. The length of the columns can be adjusted to fit the water depth. However, unlike axial flow turbines and more largely the majority of hydraulic turbines, cross flow turbine blades develop dynamic stalls leading to complex vortical and turbulent flows. Because these flows are challenging for the numerical modelling, the turbine facility has been used following two goals: optimizing the turbine design by using several scaled models and checking the ability of numerical modeling to calculate accurately the torque and the flow field.

The test section, shown in Fig. 2a, has a rectangular form (length x width x height = 100 x 70 x 25 cm³) and is placed downstream a convergent duct in order to obtain a uniform inflow. A small turbulence level of 1% is



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Thierry Maitre is Associate Professor at the Ecole Nationale Supérieure de l'Eau de l'Energie et de l'Environnement (ENSE3). He has been working at LEGI since 1997 on turbomachinery and more recently on new concepts of marine and river currents energy converters.



Jean-Pierre Franc is senior researcher at the French National Center for Scientific Research (CNRS). He has been working at LEGI since 1982 on various topics including cavitation, two-phase flows and heat transfer.

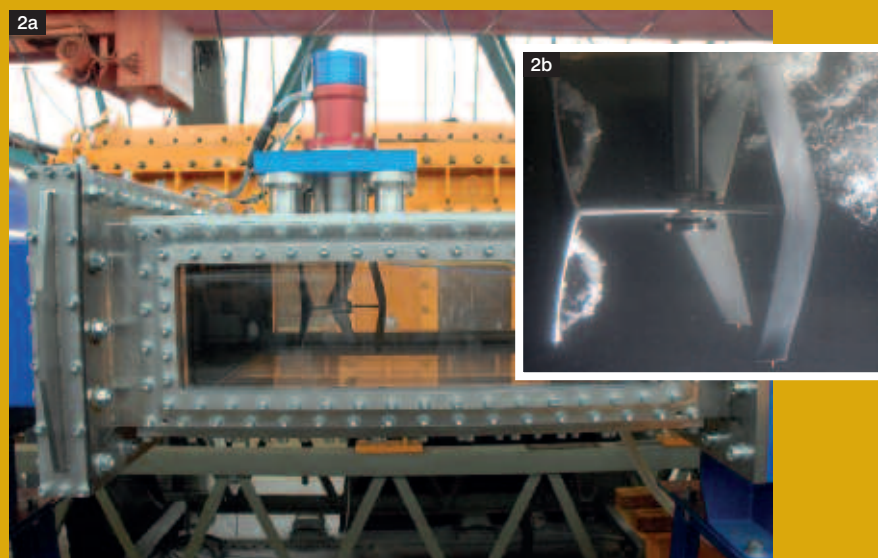


Fig. 2a - Test section for Darrieus turbines
Fig. 2b - Cavitating vortex

achieved thanks to honeycomb devices placed upstream. The flow rate is up to 0.5 m³/s allowing a velocity range from 1 to 3 m/s. The lower and the two lateral walls of the test section are made of altuglass to allow flow visualizations and PIV / LDV measurements. The upper wall is made of aluminum in order to support the experimental apparatus. The measurement platform (in blue on Fig. 2) is mounted on the superior wall by means of four piezoelectric sensors giving the instantaneous hydrodynamic forces applying on the turbine. The torque is measured via a frameless permanent magnet servomotor kit mounted above the platform. It includes an electrical synchronous generator (red cylinder in Fig. 2a) used to drive the turbine at the desired rotational speed and a resolver giving the angular position (blue cylinder in Fig. 2a). A proportional-integral regulation imposes a constant rotation speed by controlling the electric current and consequently the instant-

neous torque applied on the turbine. The tunnel can be depressurized to allow cavitating flow conditions. In the case of water turbines, the cavitation risk is weak and cavitation is essentially used to visualize the strong vortices shed by the blades (Fig. 2b).

The straight blade design (Fig. 2b) has been used for numerical modelling validations. It has been shown that the URANS (Unsteady Reynolds Averaged Navier-Stokes) method leads to accurate predictions of mean torque and power at nominal operating point [3]. PIV measurements performed locally around rotating blades have shown that the dynamic stall is correctly captured by the numerical prediction even if phase shift is observed. Cross-flow turbines recently developed at LEGI [2] are currently commercialized by the start-up company Hydroquest.

The PREVERO facility for cavitation erosion research and material testing

The PREVERO facility (Fig. 3) was built in 2003 in order to investigate cavitation erosion. It is a hydrodynamic tunnel whose main feature is that it can be pressurized up to 40 bars (4 MPa). As a result, velocities as high as 90 m/s can be reached, which leads to cavitating flows of high aggressiveness. The flow rate can be changed in order to vary the flow aggressiveness and then investigate the effect of flow velocity, which is known to be of primary importance in cavitation damage. The operating pressure can also be changed in order to vary the cavitation number and the extent of cavitation. The power of the pump is 80 kW. The test section is

axisymmetric and made of an axial nozzle of 16 mm in diameter followed by a radial divergent of 2.5 mm in thickness where cavitation bubbles are produced. The sample to be eroded is 100 mm in diameter. It is facing the nozzle and exposed to bubble collapses.

Velocities as high as 90 m/s can be reached, which leads to cavitating flows of high aggressiveness

Various types of erosion tests can be made including pitting tests and mass loss tests. Pitting tests are short duration tests generally conducted on metallic alloys whose surface is finely polished in order to easily identify cavitation erosion pits. Pits are small plastic deformations of micrometer size that each result from the collapse of a single cavitation bubble produced in the test section. Measurement of pit shape (depth, diameter...) and pitting rate allows the flow aggressiveness to be quantitatively characterized. In particular, a special technique has been recently developed in order to determine for each pit the impact load that is responsible for it.

Mass loss tests can also be conducted. They are long duration tests from which the kinetics

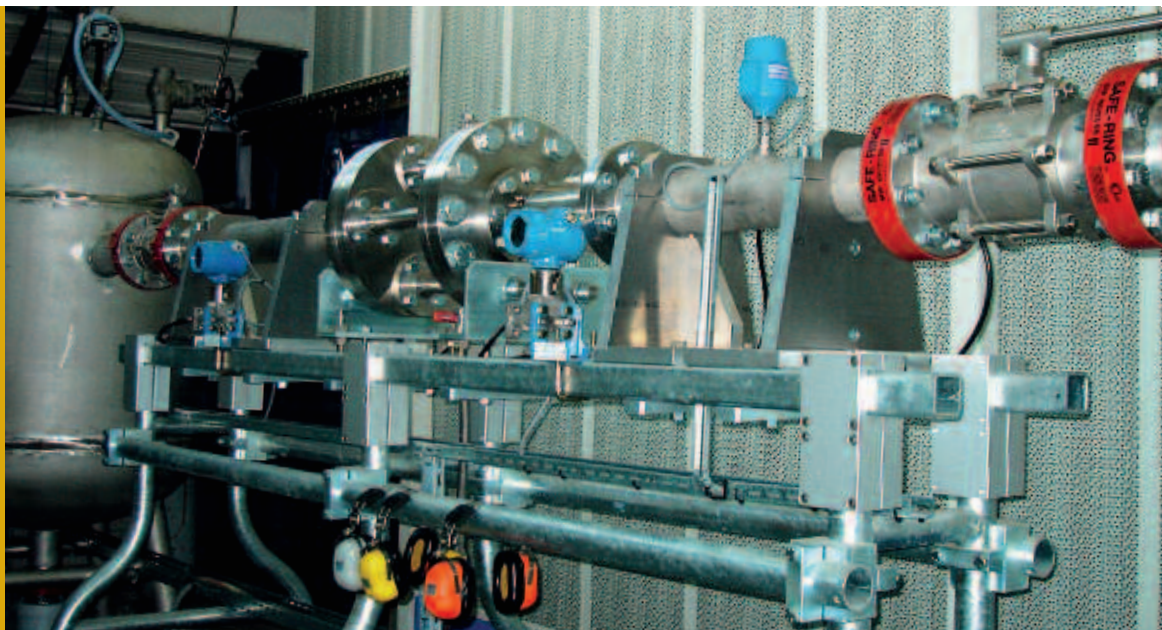
of erosion can be determined. Typical mass loss curves are determined that show the evolution of mass loss as a function of exposure time. Major parameters can be deduced such as the duration of the incubation period and the eventual erosion rate that both characterize the material resistance. Any type of material can be tested including conventional metallic alloys and new materials such as compliant [4], coated or composite materials.

In addition to the experimental approach, LEGI develops together with the Laboratory of Sciences and Engineering of Materials and Processes in Grenoble (SIMAP) (www.simap.grenoble-inp.fr) a numerical method for predicting cavitation erosion damage. The method is based on FEM (Finite Element Modeling) simulations of the response of the material to the repetitive impact loads generated by the bubble collapses. The approach includes a damage criterion to compute material removal due to cavitation [5]. Such a predictive approach, still under development, represents a breakthrough in comparison to correlative techniques used so far in cavitation erosion. ■

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Fig. 3 - The PREVERO facility for cavitation erosion research and material testing



OCEAN-STRUCTURE-SEABED MODELLING IN UWA'S RECIRCULATING 'O-TUBE' FLUMES

BY L. CHENG, S. DRAPER, H. AN & D.J. WHITE



Figure 1 - Examining scour around the model pipe in the test section of the Large O-tube

The University of Western Australia (UWA) is home to a set of recirculating water tunnels, referred to as the 'O-tubes'. These flumes have been developed at UWA to allow simulation of ocean-structure-seabed interactions using realistic metocean and geo-technical conditions. The large, small and mini O-tube flumes allow seabed flows to be simulated at a range of scales, including full scale modelling of small subsea pipelines and scour and sediment transport around infrastructure.

O-Tube concept

Many physical modelling facilities have been developed to study offshore structures, including open channel flumes, U-tube flumes, and oscillating water tunnels. However, each of these facilities have limitations for studying ocean-structure-seabed interaction problems in storm conditions, such as that experienced on

Australia's North West Shelf (NWS). Open channel flumes, for example, are limited to wave velocities below which wave breaking occurs, whilst the use of a driven trolley in an open channel allows higher velocities to be achieved but is impractical for large regions of mobile bed. U-tubes allow higher velocities to be achieved, but with limited flexibility (due to

the requirement to operate at or near resonance). Piston driven water tunnels offer more flexible control but are limited by the stroke of the piston.

Because of these limitations an alternative flume configuration, known as an O-tube, has been developed at the University of Western Australia. This flume comprises a horizontal fully enclosed circulating water channel, with a rectangular test section and an impeller-type pump driven by a motor. With this arrangement currents can be introduced easily and wave velocities are limited only by the pump characteristics and not by wave breaking, resonance of the water mass or the stroke of a piston.

Three O-tubes have been constructed at the University of Western Australia (see Table and Figures 1-3). The mini O-tube (MOT) was constructed first to prove the concept, followed

quickly by the large O-tube (LOT). The different scales of O-tube are suited to different purposes. The LOT is capable of modelling small pipelines at full scale, with 1:1 scale flow conditions. The MOT and Small O-tube (SOT) require less sediment to fill and nourish the working section compared with the LOT. This allows small scale tests and sediment-specific erosion testing to be undertaken using prototype sediments gathered from the field.

O-Tube measurement and control hardware

The LOT, SOT and MOT all use similar drive and control systems, varying only in scale and power. Flow is forced around the LOT with an impeller driven by a brushless 580 kW AC motor. The rotational speed of the motor is controlled by a Variable Frequency Drive (VFD) and can be controlled from a desktop computer via a signal that is transmitted digitally over a local wireless network. The internal control software on the VFD includes safety interlocks that limit motor acceleration and rotation speed. The SOT and MOT use smaller drives operating on the same principles.

Flow conditions including steady current, sinusoidal oscillatory flow, random oscillatory flow and any combination of the above conditions can be generated. These flows are achieved by controlling the propeller to run at a steady, oscillating or irregular rotational speed. Detailed studies of motor speed-flow speed relationships, flow asymmetry, turbulence intensity and secondary flows have been undertaken in all of the O-tubes (Luo et al. 2011, An et al. 2013, Cheng et al. 2014 and Mohr et al. 2016a).

An important component of the LOT facility is a 200 mm instrumented model pipe mounted on an actuator system to record the applied horizontal and vertical forces. The pipe is also equipped with a network of surface pressure cells to record the hydrodynamic load around the pipe circumference. The actuator system prevents model pipe movements in unrealistic degrees of freedom such as roll and yaw. The feedback system can provide neutral horizontal and vertical control, allowing the pipe free lateral movement in response to the natural balance between hydrodynamic loading and soil resistance, and free vertical movement as if acting under self-weight.

Table 1 - Key characteristics of UWA's O-tube flumes

		Large O-tube (LOT)	Small O-tube (SOT)	Mini O-tube (MOT)
Year commissioned		2010	2014	2008
Working section dimensions	Length, L (m)	17	3.0	2.0
	Width, W (m)	1.0	0.3	0.2
	Height, H (m)	1.4	0.45	0.3
Maximum steady current (m/s)		3	4.5	1.5
Typical oscillatory flow	maximum velocity, U_m (m/s)	1 – 2.5	1 – 3	0.5
	Period, T (s)	5 – 13 s	4 – 10 s	6 s

Figure 2 - General arrangement of the large O-tube (LOT) at UWA's Shenton Park campus



In addition to the actuator controlled model pipe, the O-tube laboratory is equipped with various measurement devices. Flow measurements within the O-tubes are made using Acoustic Doppler Velocimeters (ADV) and an electrical-magnetic sensor. A two-dimensional Particle Image Velocimetry (PIV) system can be

used for flow visualization, whilst an acoustic echo sounder and contact image sensors are used in various configurations for continuously detecting scour around subsea structures. A laser scanner and infra-red profiler have been adapted to scan three-dimensional scour profiles. Each of these devices can be used

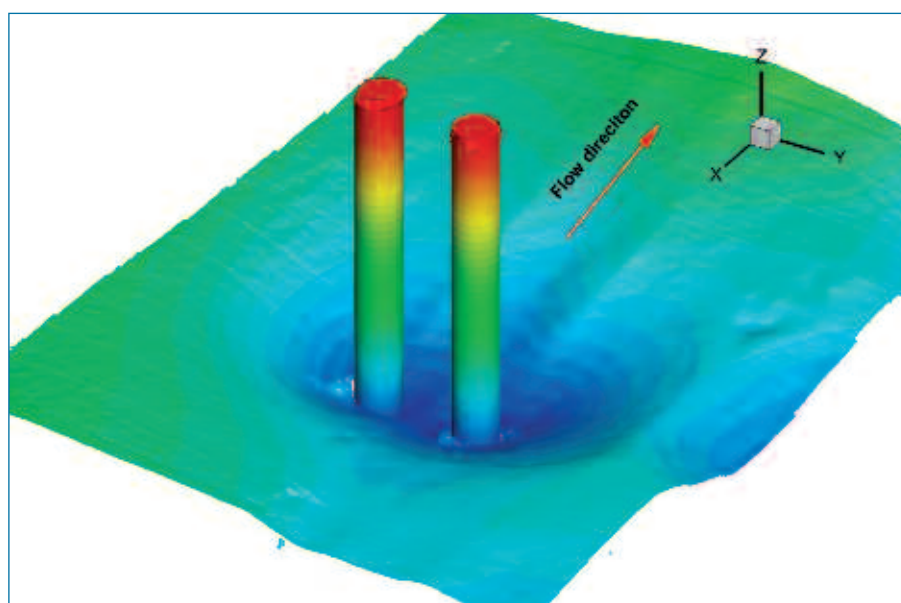


Figure 3 - A scour profile around two vertical piles recorded using the infra-red 3D camera.



Liang Cheng is a Winthrop Professor at The University of Western Australia and a "1000-Talents" Professor at Dalian University of

Technology in China. Liang got his BE from Tsinghua University in Hydropower Engineering (1983) and PhD from Dalian University of Technology in Hydraulics (1990). Liang has more than 20 years' experience in research areas covering vortex-induced vibrations, local scour, flow/structure/seabed interactions and computational fluid dynamics (CFD) modelling. Liang has published widely in these areas and has been working closely with industry on consulting and contract research projects.



Scott Draper is a senior lecturer at The University of Western Australia (UWA). He completed a DPhil at the University of Oxford, UK, in

2011 working on tidal stream energy. At UWA Scott now works more generally in offshore fluid mechanics, applied to both the oil and gas and marine renewable energy industries. His research work focuses on: scour of subsea infrastructure at the seabed; the optimization of arrays marine renewable energy devices; and wave kinematics and statistics. Scott has written over 50 peer reviewed papers and presents public lectures to industry and the wider community.



Hongwei An is a lecturer and DECRA Research Fellow at the University of Western Australia.

He finished his PhD

degree in 2010 from UWA and since then he has been working at UWA in the offshore hydrodynamics area. His research interests include flow-structure interaction, subsea structure stability, scour and sediment transport through both physical model tests and numerical simulations.



David White holds the Shell EMI Chair of Offshore Engineering at the University of Western Australia. He completed

MEng and PhD degrees at Cambridge University before holding a University Lectureship in Cambridge until 2006 when he moved to UWA. His specialism is offshore geotechnics and his research has led to >250 publications that feature in many industry guidelines, shaping engineering practice. He is a Fellow of the Royal Academy of Engineering, the Australian Academy of Technological Sciences and Engineering and the Institution of Engineers Australia.

berms on solid and erodible seabed; stability of concrete/steel mattress on the seabed; erosion properties of various sediments, and estimation of hydrodynamic force on offshore structures. This work has been captured in over 20 academic publications, including multiple high impact journal publications in Coastal Engineering and the Proceedings of the Royal Society (An et al. 2013; Draper et al. 2015; Mohr et al. 2016b). Full details of the publications can be found on the UWA website (such as <http://www.web.uwa.edu.au/people/liang.cheng>).

Research outcomes from the O-tube have contributed directly to the oil and gas industry, through industrial and contract research projects. Experimental work in the O-tubes has already supported engineering design of more than 10 developments in locations including offshore Western Australia, the North Sea and Indonesia. This work has resulted in significant cost savings to the operators. The O-tube facilities also enable new fundamental research. In the last five years the team have received four Australian Research Council Grants from their Discovery and Linkage schemes. The O-tube facilities have also been used to support student research, including 5 PhD projects and more than 40 final year undergraduate and master degree projects at UWA.

Acknowledgements

Development of the O-tube flumes at UWA has been funded by Woodside, Chevron, the Australian Research Council and UWA Strategic Funds. The technician team has been making a great contribution to the research work. The technician team (Mr. T. Brown, Mr. J. Breen, Mrs W. Sun, Mr. A. Duff and Mr. P. Hortin) is acknowledged. Mr. Y. Wu is acknowledged for processing some photographs used in this paper. ■

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synchronously to extract more comprehensive data, which enables an improved understanding of fundamental ocean-structure-seabed interactions.

Research activities and research outcomes

Significant research efforts have been devoted to pipeline on-bottom stability and seabed mobility at UWA over the past five years, supported by the Australian Research Council (ARC) and industry partners Woodside and Chevron through the STABLEpipe Joint Industry Project (JIP). Model tests in the LOT have highlighted the strong influence of seabed mobility on pipeline stability. The processes of scour and self-burial have been observed and quantified in controlled conditions, leading to

new calculation methods for design purposes. Based on the STABLEpipe JIP, a new design guideline for the stability design for subsea pipelines has been prepared (DNV 2015). This work is a team effort involving det Norske Veritas (DNV) and provides methods for assessing pipeline stability that account for scour and sedimentation over the duration of the pipeline operating life.

Besides the stability of subsea pipelines, a wide range of research topics related to various subsea structures have been investigated using the O-tube facilities. These include local scour around pile foundations and caissons, both with and without protection; local scour around wave energy devices; onset of tunnel scour under subsea pipelines; stability of rock

LARGE-SCALE TSUNAMI PHYSICAL SIMULATOR

A NEW TYPE OF EXPERIMENTAL FLUME FOR RESEARCH ON TSUNAMI IMPACT

BY NAOTO KIHARA

For tsunami disaster prevention and mitigation in coastal areas, it is important to assess the safety margins or failure probabilities of coastal structures against tsunamis by predicting the tsunami loads and the response of the structures. Data obtained from large-scale experiments on tsunami impact are useful for the development of evaluation technologies. A Large-Scale Tsunami Physical Simulator was designed for large scale experiments with realistic tsunami inundation flows, and was installed at the Central Research Institute of Electric Power Industry.

Tsunami impact and experiments

The tsunami caused by the 2011 Tohoku earthquake struck a wide area of the northeastern coast of Japan. The earthquake and tsunami resulted in more than 15 000 deaths, over 2 000 missing people, and the destruction of a large amount of infrastructure. For disaster prevention and the mitigation of tsunami damage in coastal areas of Japan, it is necessary to assess the fragility of coastal structures against tsunamis. In the fragility assessment of a coastal structure, the loads due to probable tsunamis, the response of the structure to the loads, and the capacity of the structure are predicted, and then

the safety margin or failure probability is evaluated. The tsunami loads and the response of structures are predicted by combining numerical models and empirical equations. Data obtained from large-scale experiments on the fragility of structures against tsunami impact are useful for the verification of numerical models and empirical equations. Furthermore, the performance of tsunami prevention structures can be confirmed through large-scale experiments. Laboratory experiments on tsunami impact have conventionally been carried out using flumes with four types of wave generators:

piston-type wave generators, pump wave generators, pneumatic wave generators, and gate-rapid-opening generators, i.e., dam break flows. As experienced with the 2004 Indian Ocean tsunami and the 2011 Tohoku earthquake tsunami, tsunami inundation flows have complex waveforms with a long duration. It is difficult to reproduce and control such a realistic tsunami inundation flow on a large scale using these generators because of limitations of the stroke length of the wave-generating paddles, the performance of pumps, the length of flumes, and the degree of freedom in the control of the flows.

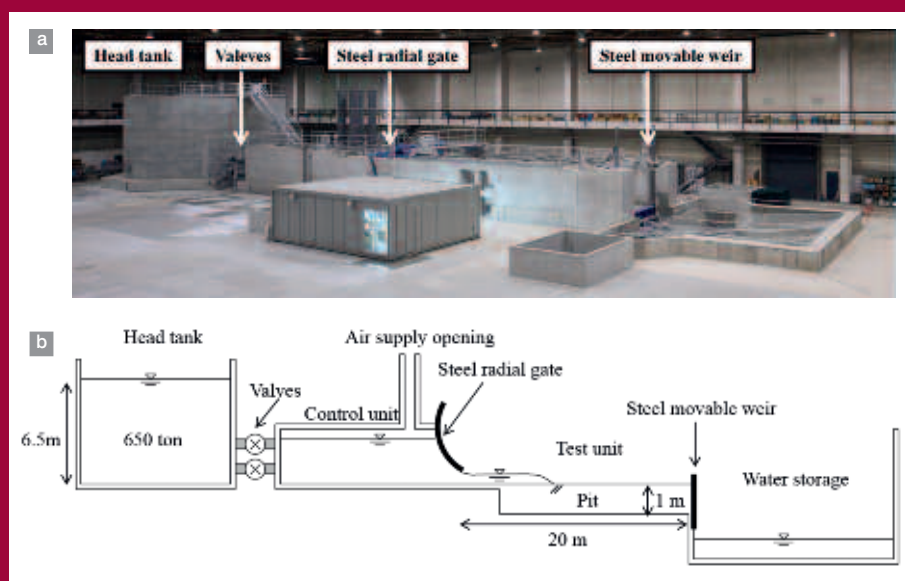


Figure 1 - The photograph (a) and the schematic view (b) of the Large-Scale Tsunami Physical Simulator

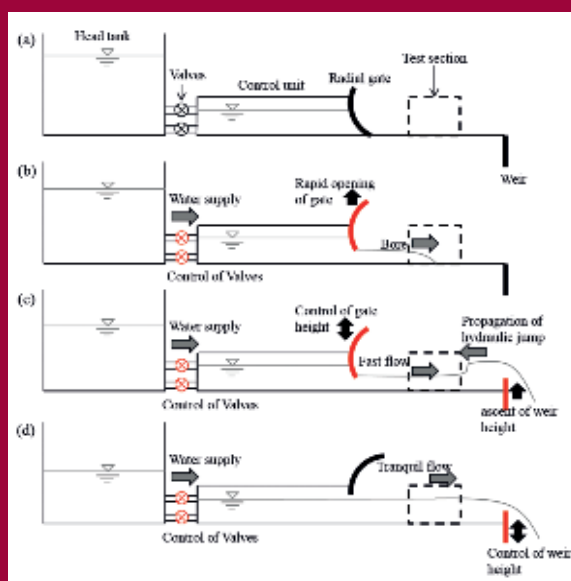


Figure 2 The schematic diagram of the method used to control the flow. (a modified version of Fig. 1 in Ota et al. [2013])

Our main research target is fragility assessment in areas of inundation. Thus an important requirement for experimental facilities is the generation and control of realistic tsunami inundation flows. A new experimental facility, called “the Large-Scale Tsunami Physical Simulator” installed in the Central Research Institute of Electric Power Industry (CRIEPI), Japan, was designed to be able to generate and control various types of local tsunami inundation flows on a large scale.

Design of the Large-Scale Tsunami Physical Simulator

Figure 1 shows a photograph and schematic view of the Large-Scale Tsunami Physical Simulator. This facility is composed of a head tank, a control unit, a test unit, and a water storage tank. The maximum water volume of the head tank is 650 m³, and its maximum depth is 6.5 m. The control unit is a closed rectangular channel. The test unit is an open channel made of reinforced concrete that is 20 m long, 4 m

wide, and 2.5 m high. To observe measurements from the lateral face of the channel, four acrylic observation windows, 0.9 m × 0.9 m in size, were installed in the side wall. There is a pit of 1 m depth beneath the bottom of the test unit for use in scouring experiments. Eight valves are mounted on eight pipes that connect the head tank and the control unit. A radial steel gate separates the control unit and the test unit, and a moving steel weir separates the test unit and the water storage tank. To control a tsunami-like inundation flow in the test section, the apertures of the eight valves and the heights of the gate and weir are controlled by computer. A schematic diagram of the method used to control the flow is shown in Figure 2 (Ota et al., 2013). A tsunami bore is generated by rapidly opening the radial gate like a dam break flow. The inundation depth of the bore is controlled by the height of the gate. The velocity of the bore is controlled by the water depth in the control unit. The velocity and depth of a fast flow are controlled by the height of the gate and the valve aperture. A tranquil flow is controlled by the top height of the weir and the valve aperture. This tsunami generation method makes it possible to reproduce “inundation tsunami”-like flows in the test section.

Experiments on tsunami impact

After the facility was installed, some experiments on tsunami impact were carried out, and two of them are briefly described hereafter. The first experiment was on tsunami wave pressure loading on a seawall (Kihara et al., 2015). In this experiment, a vertical seawall with 1.5 m height



Naoto Kihara started working at Central Research Institute of Electric Power Industry in 2006 after receiving a doctor's degree in science at Kyoto University. In the first five years of his career he carried out research on ocean waves, seasalt transport in the atmosphere, and tsunamis. After the 2011 Tohoku earthquake and tsunami, his main area of research became the tsunami impact and fragility evaluation of coastal facilities against tsunamis. He was the leader of the team that designed and installed the Large-Scale Tsunami Physical Simulator.

and 0.3 m width was set on the flat bottom in the flume. We measured vertical profiles of the pressure on the front of the seawall in inundation flows with periods longer than 80 s (Figure 3). This experiment showed in detail the characteristics and types of tsunami wave pressure profiles in terms of their change with time. The second experiment was on the force of debris collision (Takabatake et al., 2015). The debris used in the experiment were wood logs and an actual mini vehicle. A vertical steel plate, which was designed to be able to measure the collision force, was set in the test unit. The debris were initially set upstream of the plate and allowed to drift in the bore, and collide with the plate. The experiments with the mini vehicle showed that the relationship between the impact speed and the collision force was nonlinear and that the axial stiffness depended on the impact speed. These experimental results provide useful knowledge for the design and fragility assessment of tsunami prevention structures. ■

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Figure 3 The experiment on tsunami wave pressure loading on a seawall

A LARGE SCALE SYNCHRONOUS VELOCITY MEASURING SYSTEM BASED ON THE PTV TECHNOLOGY

BY JUN ZHENG, MINGXUAN REN, XIHUA WANG AND ZHAOSONG QU

The technology of Particle Image Velocimetry (PIV) can be used to measure simultaneously and instantaneously velocities over an entire field. Fujita (1998) used the PIV technique to measure velocity distributions in a wide range of conditions. Since the PIV algorithm is complicated, the time required to calculate the measured velocity distribution is large, which makes real-time measurements of broad velocity distribution fields hard.

A branch of the PIV technology is Particle Tracking Velocimetry (PTV). Because of its simple algorithm and fast computation, it is more practical to use PTV to measure the velocity distribution over large fields in hydraulic model experiments. A velocity distribution measuring system developed based on PTV, has been used in physical model experiments (Xingkui Wang, 1996). The images recorded and stored on video tape, are processed after they have been collected, and then the required calculations and analysis are performed by the system. This makes it hard to use this approach for real-time measurements. The development of monitoring cameras has made it possible today to obtain real-time measurements of the velocity distribution over large areas (Mingzhong Yu, 2002). However, the data transmission of the cameras is limited by bandwidth, and it is not possible to synchronize the collection and transmission of data from multiple cameras. Consequently, the method of collecting images introduces cumulative errors leading to incorrect results when velocity measurements over large areas are combined. Beijing Sinfotek Technology Co., Ltd (Sinfotek) has developed a large-scale synchronous velocity measuring system based on the PTV technology. The system can obtain quickly and accurately the flow field in a model test, as well as the flow velocity distribution on cross sections, and the velocity history at single or multiple points. The system has solved the problem of multi-camera collecting images simultaneously, and has improved the synchronization of collecting images greatly. (Sinfotek Open Patent No.: CN100487372C). In order to

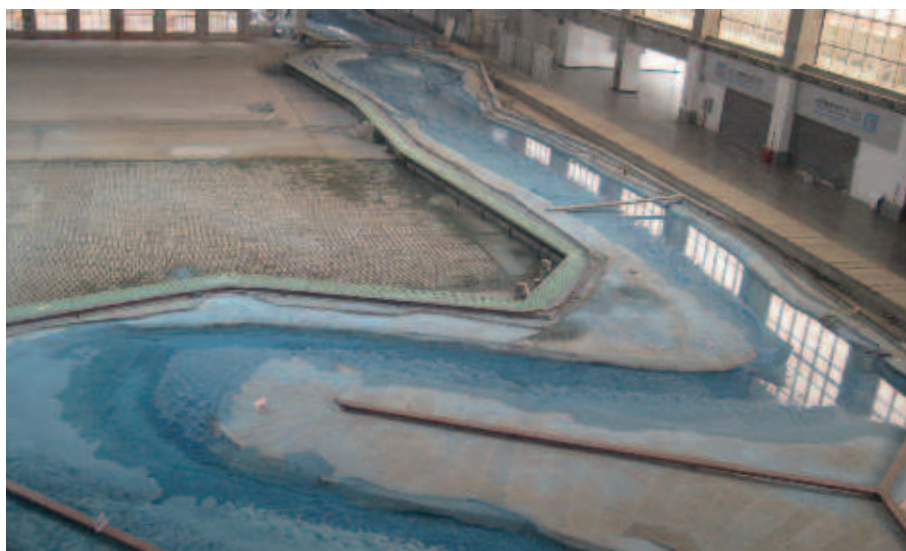


Figure 1 - Yangtze River flood control model

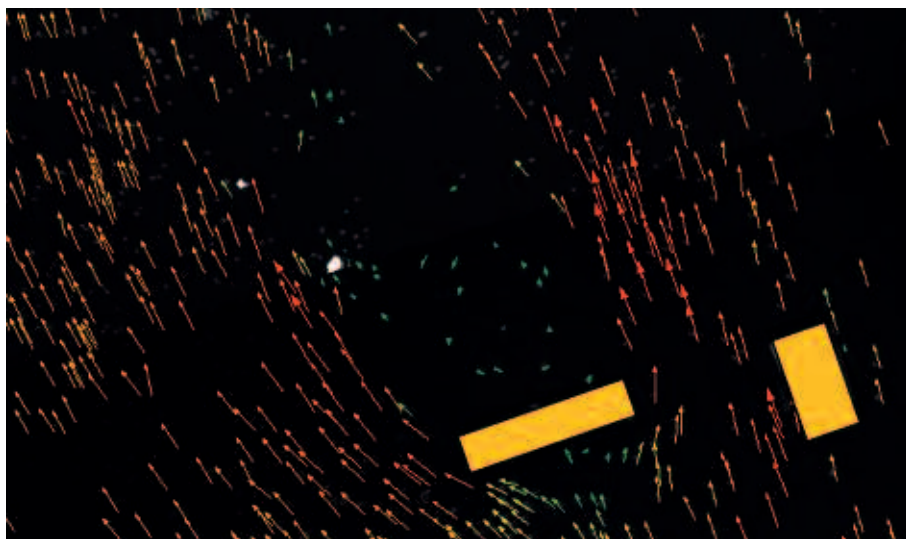


Figure 2 - Flow field result of engineering design scheme

measure the velocity distribution over large areas the system was further improved by using Local Area Network (LAN) technology. The system has been used widely in hydraulic model experiments in many scientific research institutes and universities.

Key Technology

Acquisition Terminal

The system uses high-resolution Charge Coupled Device (CCD) cameras for image

acquisition. Cameras are installed above the hydraulic model. The vertical distance of each camera from the model is determined by the range of measurements. When the camera is installed at a fixed height above the model, the number of cameras can be calculated based on the size of model and the vertical distance from the camera to the model.

The system uses optical fiber and cable to sample images, and then transfers the images to a computer for processing.

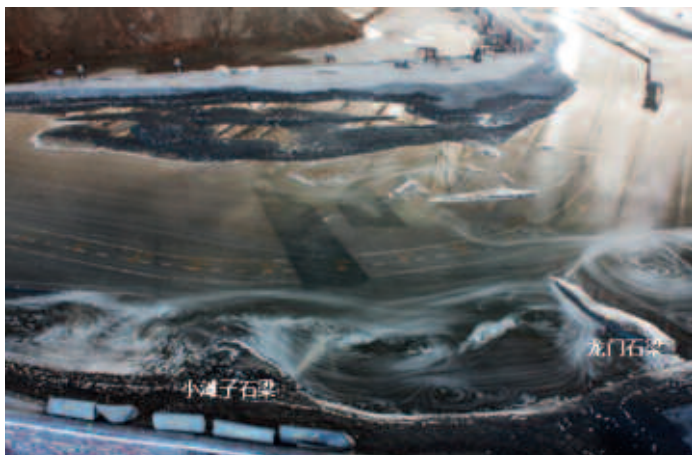


Figure 3 - The real scene of bend model test

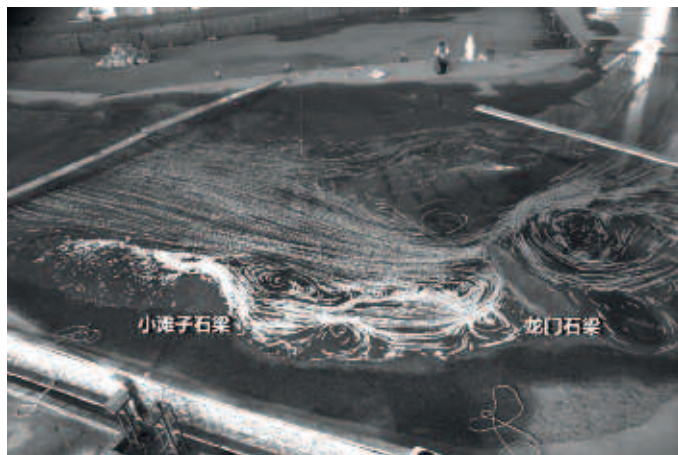


Figure 4 - The flow field measurement result of bend model test

Software Algorithm

The software system uses image processing to recognize individual particles and extract their coordinates. Then, the system processes sequences of images matching individual particles. The coordinates of matched particles are used to calculate their velocity. The system uses the method of adaptive threshold to achieve image segmentation, the purpose of which is to recognize individual particles. The pixels belonging to different particles are divided into groups, one group per particle. Each group contains a few pixels. The center coordinate of a particle is calculated based on the coordinates of all the pixels in a group.

Local Area Network (LAN) Extension

It is very difficult for a standard system (16 cameras) to meet the needs of large models. In this regard, the system is expanded using a LAN.

With this expansion, the system can measure the velocity distribution over large areas. The expanded system consists of a number of standard systems. The standard systems communicate with each other via 1 or 10 Gigabit LAN. All the standard systems aggregate into one network edition system. Any of the standard systems can play the role of "server" or "client". The "server" sends instructions to the "client", receives the velocity data from the "client", and then merges and saves the velocity data. The "server" also has other functions, such as, real-time monitoring of each channel of the "client" adjusting the threshold of each channel setting parameters and so on.

In order to make the system more integrated, the "client" and the "server" are packaged in a cabinet. To perform simultaneous velocity measurements the operator only needs to

control a "server", which controls the entire system.

Application

The system has been widely used in hydraulic model experiments for rivers and harbors, as well in various flume experiments. Many universities and research institutes in China, such as Tsinghua University, Yangtze River Scientific Research Institute, Nanjing Hydraulic Research Institute and Wuhan University, have used the system.

Conclusion

The technology of Particle Image Velocimetry, a non-contact and high-precision velocity measurement technique, is widely used in

hydromechanics. A system developed based on the technology of PTV has been applied to real-time measurements of the velocity distribution over large areas. The system has solved the problems of synchronization and expansion, which has improved greatly the accuracy of velocity measurements, and expanded the scope of its applications. ■

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Dr Jun Zheng started working in Sinfotek in 2008, in charge of different projects and research in areas related to water science, measurements of river hydraulics, sediment transport and fluid mechanics.



Dr Xihua Wang has more than 10 years of experience working in software development and algorithm research. Her interest areas are related to image processing, ultrasonic measurements and high performance computing.



Zhaosong Qu is the president of Sinfotek, a specially invited expert under the national "Thousand Talents Plan", and professor of Chongqing Jiaotong University. His research focuses on flow, sediment transport measurement of water and environmental science.



Mingxuan Ren is a Senior Product Manager of the hydraulic measuring system. He began his professional career in Sinfotek in 2007. His current fields of interest are image processing and the auto-control of flow and sediment movement.

THE RØDSAND LABORATORY – A WORKING LABORATORY IN THE FIELD

BY ULRIK LUMBORG

A joint effort has resulted in a field laboratory in Rødsand, in the southern part of Denmark. The area is now being used by a number of national and international partners to conduct cross-disciplinary research. Among the results of the work at Rødsand are an increased understanding of coupling between sediment dynamics and benthic biology.

In recent years there has been an increased focus on the islands Lolland and Falster in Southern Denmark because of the fixed immersed Fehmarnbelt tunnel between Denmark and Germany that is planned to be constructed in the near future. This focus has resulted in increased research activity, especially in connection with the environmental investigations prior to the construction works. In connection with these investigations the Rødsand lagoon was studied intensively as it was pointed out as a sensitive area during the construction phase. Rødsand lagoon is designated as a Natura 2000 area. Natura 2000 areas are part of a network of European nature protection areas aiming at the protection of specific nature types and endangered and protected species.

The Rødsand laboratory was established in 2009 as a result of ongoing activities in the area and the desire for coordination of the efforts to study the area. The laboratory has several purposes including:

- Study and exploration of the Rødsand area (land, lagoon and near-shore)

Figure 2 - Technician working on a survey platform in Rødsand lagoon. A total of three towers have been erected for easy mounting of monitoring instruments. The remotely controlled water sampler can be seen in the foreground

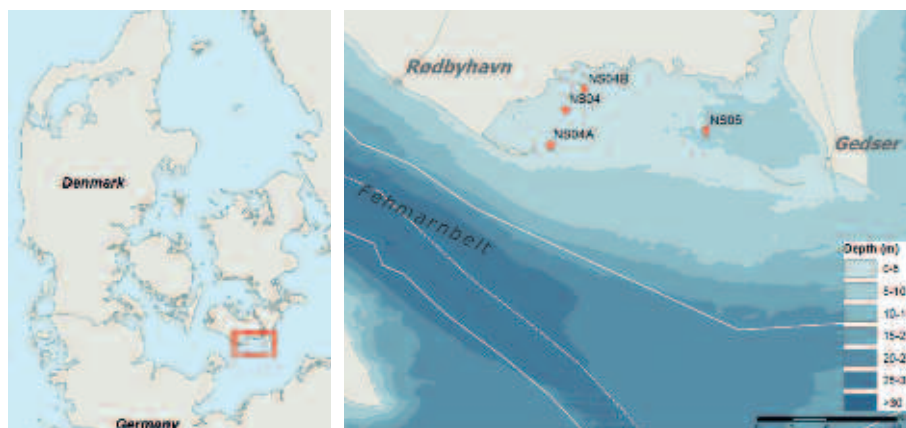


Figure 1 - Position of the monitoring stations

- Utilization of the area as a test for different types of equipment
- Utilization of the abundant field data for development of better numerical modelling tools
- Use of the area and its facilities for arranging courses, seminars and other activities

The Rødsand lagoon is a non-tidal lagoon in the inner Danish Waters (Figure 1). The area is located next to Fehmarnbelt and is protected by a coastal spit, as well as by two semi-submerged sand barriers. The lagoon is located north of the strait Fehmarnbelt. Water exchange with Fehmarnbelt takes place through three openings towards the South. The water level variation is forced mainly by water level changes in Fehmarnbelt. Fehmarnbelt itself is part of the inner Danish waters. These waters form a transition zone between the salty North Sea and the brackish Baltic Proper. Fehmarnbelt is responsible for 70-75% of the water exchange. The water level variations in the inner Danish waters are caused by meteorological changes rather than actual tides. Rødsand lagoon also has an opening towards the North, Guldborgsund which occasionally contributes to the water exchange.

The laboratory itself consists of a farm house with lodging facilities as well as a small laboratory and room for instrument testing and storage. In addition, three instrument platforms have been erected in the lagoon (Figure 2). These platforms are prepared with fuel cells and data communication units. This allows the users to fairly quickly install any instrument to the platform and to retrieve data online. When needed, the platforms are equipped with remotely controlled water samplers ensuring a water sampling programme that covers a range of weather situations. Additionally one buoy station has been established in the eastern part of the lagoon (Figure 1).

Monitoring the physical environment

A large data set has been collected partly in connection with baseline investigations prior to establishing the Fehmarnbelt fixed link and partly to support a collaborative research effort on bio-geophysical processes and landscape dynamics in a non-tidal coastal lagoon. Based on four online stations in the lagoon, the data set consists of numerous parameters including: hydrodynamics, suspended sediment concentrations, sediment grain size/floc size distributions, light attenuation coefficients, organic

content and local meteorological conditions. The data were collected with a series of high quality instruments.

Current speed- and direction were measured using RDI 600 and 1200 kHz kHz WorkHorse ADCPs. The Acoustic Doppler Current Profiler (ADCP) measures the current parameters in bins throughout the water column. The profiler is installed in a bed frame and measures using acoustics. In this way the currents are monitored without influencing the water movement. The instruments are ideal for monitoring over longer periods.

Water quality parameters were monitored using the WQM manufactured by WET Labs. The multi parameter probe measures pressure, conductivity, temperature, turbidity, fluorescence and dissolved oxygen. The instrument is efficient to monitor in areas where biofouling can be an issue. The instruments are manufactured in copper on which no fouling occurs. The window for fluorescence and optical backscatter is protected by a "bio wiper" also in copper. The bio wiper is only open when the measurement is taken. When the instrument is in sleep mode the wiper completely covers the window which can remain clean for a very long time.

Grain size distributions were measured using the LISST-100X manufactured by Sequoia Scientific. The instrument measures turbidity based on transmissometry and also the grain size distribution in 32 classes in the interval 2.5 – 500 μm . The instrument provides reliable measurements and is easily operated in marine waters.

Light attenuation was measured using LI-COR light meters. Using two instruments plus one above water the light attenuation can be computed. The instruments are reliable to use in marine water but suffers quickly from biofouling. All attached instruments were powered by a battery that was charged by solar panels combined with an EFOY fuel cell whenever necessary. The measured data were collected in a data communication unit on the platform and all data were transferred by a mobile internet connection. The data were collected in the DHI data management system DIMS and displayed on a web page in near real time for convenient data QA and inspection. The online data option was also used to decide when to trigger the remotely controlled water samplers, e.g. when turbidity was increasing the user could choose to start sampling with a fixed interval. The sampled data were documented by more than 200 water samples collected in a range of weather conditions.



Ulrik Lumborg started working for DHI in 2005 after finishing a PhD from University of Copenhagen on modelling of cohesive sediment dynamics. In the first years Ulrik focused on numerical modelling issues. After some years he became involved with survey work and has since studied a number of sites based on a combination of monitored data and numerical modelling. His main works during the recent years has been with the environmental impact assessment of the Fehmarnbelt fixed link as well as spill monitoring on dredging projects throughout Europe. Since 2012 Ulrik has led the Rødsand Laboratory.

The data collection programme was supplemented with grain size analyses of the bed material and mapping of benthic flora and fauna. The data set covers a period of nearly two years and allow for a range of studies on biology and sediment dynamics. The example provided in Figure 3 shows total suspended matter concentrations, the grain size as well as wind characteristics. It can be seen that the grain size distribution is correlated with the concentration and the wind in a rather complex manner. In general the mean grain size increases with increasing concentration, as floc formation is favoured in this situation. The median grain size is however also closely linked to the wind and can decrease with increasing

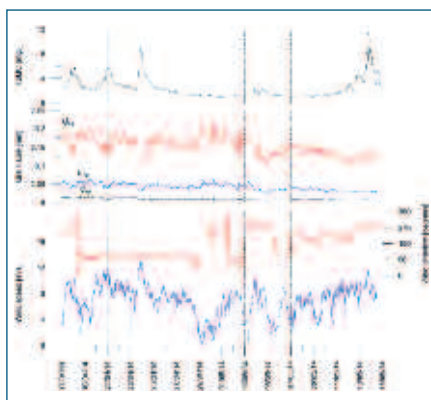


Figure 3 - Example of collected time series at station NS04 in the western part of Rødsand lagoon. Note that the grain size generally decrease on increasing sediment concentration. This is because of the relatively shallow water depth where waves are responsible for resuspension hence the increased concentrations. These waves also destroy flocs

wind due to floc breakup. As the monitoring area is fairly shallow the grain size is mainly governed by the wind. These findings are included in a larger research project on flocculation of fine-grained sediments.

Advancing the activities

The survey platforms and the house is now used by several parties including the University of Copenhagen which engages several PhD and Master Students. The laboratory has also recently been used by the Hydralab+ research project for a study of the coupling between sediment dynamics and benthic biology. This includes mapping of eelgrass distribution (cover, density, biomass, shoot length), deploying of small high-frequency pressure sensors to monitor wave height, monitoring turbidity, monitoring small scale sediment accumulation and erosion and sediment characterization. Subsequently, experimental sites within seagrass and un-vegetated sediment will be set up for quantification of bioturbation using tracers.

The collected data will be used to improve existing modelling tools. The overall characteristics of the sediment size distribution in the lagoon are diverse and depending on the interplay between wave activity and the water depth. Aggregate formation and floc stability vary with water depth and hydrodynamics, and sediment modelling must be able to consider variable settling and erodibility characteristics of both cohesive and non-cohesive material. Emphasis will be given to the development of a model that can handle both types of sediment. Another example of a new model development is a numerical model that covers both benthic biology and cohesive sediment. There is good evidence about how suspended sediment affects different sea grasses and fauna. How benthic biology affects the sediment dynamics has also been studied, e.g. how the sea grass beds are acting as sediment traps and how biofilms can stabilise the sediment bed. Based on these field studies an attempt will be made to construct a numerical model that takes into account both features.

After denoting Rødsand lagoon an actual field laboratory the basic research in the area has increased and is now used commonly for different interdisciplinary research activities. ■

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THE COASTAL ENGINEERING LABORATORY (LIC) OF THE TECHNICAL UNIVERSITY OF BARI – ITALY

BY MICHELE MOSSA

The *Coastal Engineering Laboratory (LIC)* of the *Department of Civil, Environmental, Building Engineering and Chemistry* of the *Technical University of Bari* was designed for advanced research and technical support to the Public Administration in coastal territorial management. The LIC was financed by the EU (European Union) and the Apulia Region (so-called *Programma Operativo Plurifondo Puglia* – D.R. 29/10/90 n. 6155, Structural Funds CEE-REG. CEE n. 20522/68 e 4253/88, Sottoprogramma 6, Misura 6.3). The construction of the laboratory was completed and started operating in February 2001.

The mission of the laboratory is to provide facilities for researchers, PhD and MSc-students, as well as to perform practical work and demonstrations in support of teaching at the University. It also has the potential for physical-experimental research in the fields of Maritime and Environmental Hydraulics.

The core activities of the LIC are managing, procuring and maintaining the facilities and equipment in the laboratory. These activities also include setting up, performing and processing of measurements in experiments, as well as developing the required numerical codes. Furthermore, the laboratory provides support to the design and construction of experimental facilities, specific installations, apparatus and equipment.

The laboratory has a total surface area of 30 000 m², a laboratory area of 12 000 m² and an office area of 500 m² of 5 000 m².

The laboratory has several wave basins and channels. The major experimental facilities at LIC are:

1. Two tanks used for three-dimensional physical models for maritime and coastal engineering research. The model area consists of two large basins; one (figures 1 and 2) used for coastal modelling and the other for offshore modelling (figure 3). The coastal model basin is 100 m long, 50 m wide and 1.2 m deep (figure 2), while the offshore model basin is 50 m long, 30 m wide and 3 m deep. The coastal model facility is equipped with a series of three-dimensional wave makers, having 6 modules, 8

paddles 60 cm wide, with maximum wave front length equal to 28.8 m and maximum height 30 cm.

As an example, the basin for off-shore physical models was used in a National Interest Research Program to analyse tsunami waves generated by landslides in water, the mechanics of wave generation and propagation, the development of forecasting tools and the real-time warning systems based on tidal measurements (for further details, please see Di Risio et al., 2008 and visit the following page of the IAHR Media Library: <http://www.iahrmedialibrary.net/stromboli-islandtsunami-1/>).

2. Two wave channels, which are 2.4 m wide, 50 m long and 1.2 m deep. They are equipped with a two-dimensional wavemaker with one module, 4 paddles, each 60 cm wide, providing a maximum wave height of 30 cm (figure 4). For further details, see for example De Serio and Mossa (2013).

3. Very large flume for sea currents

The very large flume (figure 5) consists of a rectangular steel channel, with base and lateral walls of 15 mm thick transparent glass material, connected and sealed internally with watertight

silicone rubber, able to prevent thermal dilatation. The base has a surface of 15 m by 4 m and the depth of the channel is 0.4 m. To create a current inside the channel, a closed hydraulic circuit was constructed. The water is supplied by a large metallic tank with a centrifugal electro-pump downstream which sucks the water into a 200 mm diameter steel pipe. The same water is then discharged into the upstream steel tank. A side-channel spillway with adjustable height made from different plates mounted together is fitted into the upstream tank. The water that overflows is directed into a pipe with a 250 mm diameter similar to that used for the water supply and parallel to it, and is finally discharged into the tank downstream of the channel. Two different electromagnetic flowmeters are mounted onto the two parallel pipes described above in order to measure the flow rate in the channel as the difference between the two discharge measurements. The upstream and downstream gates can be used to control the channel flow.

The very large flume is used to study different environmental problems such as wastewater ocean outfalls. While there are several studies in the literature on nonbuoyant and buoyant jets



Figure 1 - The basin for coastal physical models



Figure 2 - View of the LIC with the basin for coastal physical models

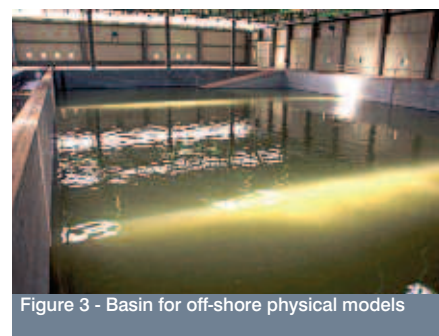


Figure 3 - Basin for off-shore physical models



Figure 4 - One of the wave channels



Figure 5 - The very large channel of the LIC

and their interaction with currents, few deal with jet-wave interaction. The majority of studies emphasizes the importance of a wave flow field in diffusion processes and the need for experimental tests to better understand jet-wave interaction dynamics and possibly confirm the validity of proposed mathematical models. Although stagnant ambient conditions are of interest, they are almost never present in real coastal environmental problems, where the presence of waves or currents is common. As a result, jets cannot be analyzed without considering the surrounding environment, which is only rarely under stagnant conditions. This study deals with this problem and, for example, shows experimental results of a turbulent non-buoyant jet discharged in a stagnant ambient and in the presence of a wave flow field in order to compare both conditions and to experimentally analyze the behavior of different flow regions. For further details on the interaction of jets with waves see Mossa (2004a; 2004b).

A problem investigated in the very large flume is the effect of corrugated and vegetated channel beds on buoyant or non-buoyant turbulent jets, vertically discharged into a crossflow. The main aim of this research is to study the background turbulence, generated by corrugated or vegetated channel bed surfaces, which affect the jet behavior (i.e., jet penetration, spreading, mixing performance, turbulent structures). For the interaction of jets with a vegetated crossflow, see for example Ben Meftah et al. (2015).



Michele Mossa is full professor of Hydraulics at the Department of Civil, Environmental, Building Engineering and Chemistry of the Technical University of Bari and Chief Scientist of the LIC (Coastal Engineering Laboratory). The main topics of Michele Mossa's research group are relevant with the Environmental and Maritime Hydraulics, examining the mechanisms of waves, sea currents, local erosion phenomena, buoyant and non-buoyant jets issued in steady or wave environment or in crossflow, also with macroroughness at the bottom (ripples or vegetation), channel flows and their local phenomena, such as hydraulic jumps. For further details, please visit the website www.michelemossa.it

4. Positive and negative buoyant jet systems

A physical model for the study of buoyant jets was constructed at the LIC. The channel flow permits to simulate sea currents interacting with buoyant jets issued in the same channel through diffusers with different number of nozzles. This channel includes a buoyant jet thermal-hydraulic system. The discharged heated water generating the turbulent buoyant jet is pumped into the channel through a round steel tube mounted at the bottom of the channel in the central longitudinal section.

A process computer and control software (that oversees all the system and stores the test data) can be used to control and manage the buoyant jet system. They can generate the desired jet temperature and flow rate issued into the very large channel (Figure 6). Recently another apparatus for the analysis of the dilution of salt jets was constructed.

The LIC has many advanced equipment and instrumentation for morphological and hydraulics analysis, such as: bottom propellers, Acoustic Doppler Velocimeter (ADV), Vessel-Mounted Acoustic Doppler Current Profiler (VM-ACP), micro whirls flow meters, pressure gauges, bottom profiler, densimeter, ultrasonic wave height meter, high-precision GPS transceivers, spectrometer, LDA (Laser Doppler Anemometer) system. Figure 7 shows the new LDA system.

In addition to the specific pieces of equipment and instrumentation discussed above, the laboratory is also equipped with software and data acquisition systems for the study of the



Figure 6 - Buoyant jet thermal-hydraulic system with the process computer

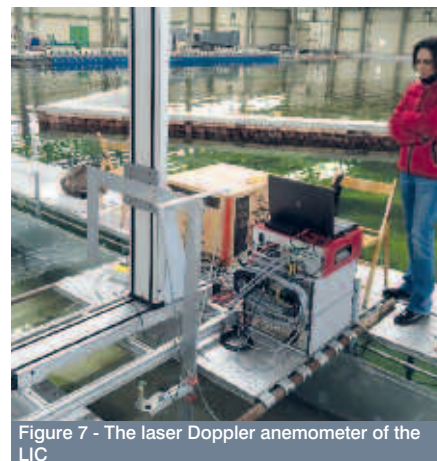


Figure 7 - The laser Doppler anemometer of the LIC

wave climate hindcasting and forecasting, wave propagation, storm and swell activity inside harbours, solid transport, beach evolution (also with remote sensing, see for example Bruno et al. 2016), circulation currents and pollutant diffusion.”.

The LIC hosts also equipment of the colleagues of the mechanical engineering department of the Technical University of Bari, such as a wind tunnel and an experimental apparatus to determine the performance of pumps and turbines.

The LIC staff includes many researchers, technicians and students whose hard work makes the laboratory a reference point in the field of Hydraulics, Maritime and Environmental Hydraulics. The LIC promotes relationships and cooperation with international universities and research institutions.

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