Hamm, Luc; Cazaillet, Olivier; Loisel, Pierre-Etienne; Sauvaget, Patrick

ARTELIA - A one century long tradition of physical scale modeling

Hydrolink

ARTELIA - A ONE CENTURY LONG TRADITION OF PHYSICAL SCALE MODELLING

BY LUC HAMM, OLIVIER CAZAILLET, PIERRE-ETIENNE LOISEL & PATRICK SAUVAGET

Laboratoire Dauphinois d'Hydraulique was created in Grenoble in 1917 to support the industrial development of hydroelectricity in the French Alps. Since the first river physical scale model with rigid bottom which was implemented in 1923, continuous progress was made and experience accumulated to model with increasing accuracy water and sediment transport processes thanks to physical scale models.

ARTELIA inherited this tradition and operates presently a 10,000m^2 laboratory to perform its consulting engineering activities: in this facility, about 25 physical scale models are constructed every year to carry out engineering studies including the design of harbor protection structures, barrages and hydropower production equipment, canal locks, pumping stations, bridges and flood culverts in river valleys, etc. Long term sediment transport processes and morphological evolution of coastal inlets and rivers is also a specialty of the laboratory which has been applied to prestigious sites such as the Mont Saint-Michel Bay, the Loire river estuary or the Seine river estuary to design the extension of Le Havre harbor. Environmental integration of development projects is a constant preoccupation to which physical scale models contribute deeply.

From model to reality

The basic aim of hydraulics scale modeling is to build a model of a natural site - possibly including man-made development projects -at a reduced scale that adequately reproduces all the main physical processes involved, such as fluid discharge, water surface elevations, flow patterns, sediments dynamics, and forces on structures. The sophistication of the physical model l varies with the design or study objectives.

A physical model is a three dimensional tool that is very helpful for engineers and scientists to understand the relationships between the various components of a particular design, how various structures of a whole scheme interact, or to imagine new solutions. However, in a broader sense, the usefulness of a physical model can be seen in four areas: (1) technical: to ensure an appropriate and efficient design; (2) economic: improve project optimization and cost savings; (3) safety: lower risk for both the hydraulic structures and the potentially impacted populations; and (4) communication: convey concepts and designs to technicians, residents, non-governmental and governmental organizations and others, as necessary to aid in the understanding and acceptance of the project and of its hydraulic impacts.

Most physical modeling studies can be easily justified from an economic standpoint. In most cases the cost of physical model design, construction and tests is typically only a small percentage of the total project costs and the benefits are in many cases very high (e.g., simplifying and optimizing the design, improving safety, reducing total project costs).

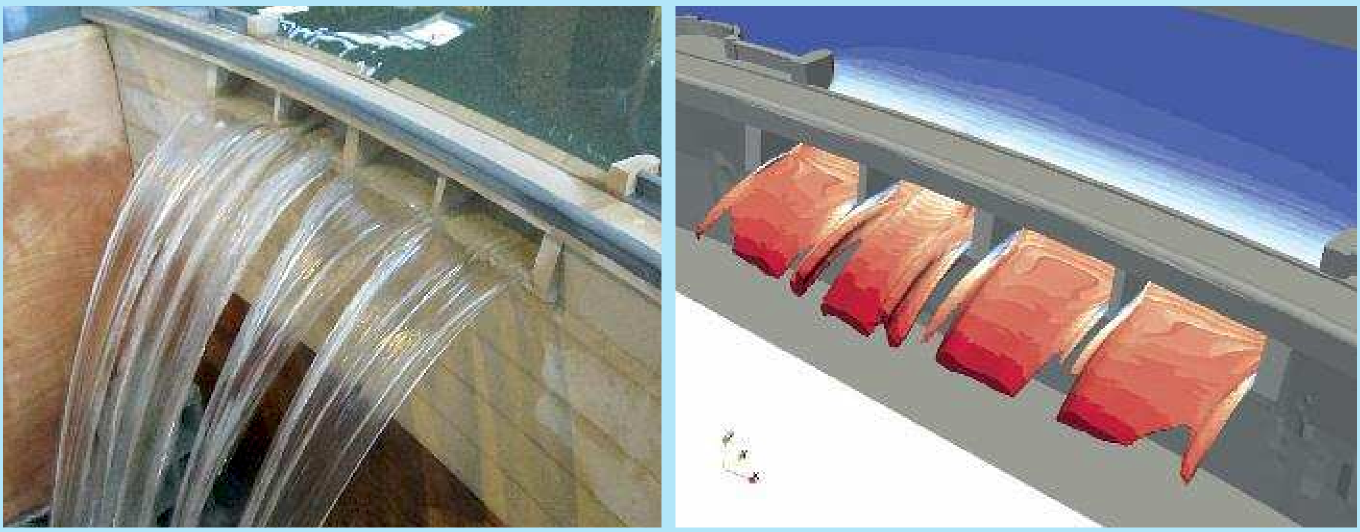


Figure 1. Comparison of CFD and physical modeling of the flood spillway of Cammazes dam (ARTELIA R&D study)

Figure 2. Scale modeling of dam rehabilitation projects with upgrading of flood spillways

Figure 3. Scale model of a 30 m lift lock with 5 saving basins and of hydropower scheme surge shafts

Figure 4. Scale modeling of sedimentation in reservoirs (Jirau dam, Karnali dam, Inga headrace canal)

It is important for engineers, project managers and owner/operators to understand the type of problems for which a physical scale model is a useful and, sometimes, unique tool. The field of scale model use is wide:

- Hydraulic structures studies and river engineering
- High dams and run-of-river dams
- High lift height and complex lock
- Storm water hydraulic structures
- Pumping stations
- Coastal and harbour engineering
- Sediment transport studies, both aiming at forecasting morphological evolution of natural sites under various constraints and at studying the stability of man-made equipment, for a wide variety of water bodies: torrents, rivers, dam reservoirs, estuaries, deltas, coastal shorelines, lakes, etc.
- Environmental studies, with the specific case of gravity-driven flows (thermal and salinity plumes)
- Navigation training (Ship handling training using manned models)

There is a close and complementary link between the numerical and the hydraulic scale modeling approaches. In some cases a numerical model and a physical scale model can be coupled and operated simultaneously in the time loop to reproduced globally physical processes. More commonly, the two approaches contribute to different objectives of a global project. As an example, a large scale numerical model will be used to analyze processes at geographical scale and will also supply boundary conditions to a physical scale model which, in turn, will allow to study precisely narrow field hydraulics and to supply parameterization useful to the numerical model.

To illustrate this close interaction between physical and numerical approaches, let's mention the R&D study carried out by ARTELIA in 2014-2015 on the comparison of both tools for the estimation of the discharge capacity of the free surface flood spillway of Cammazes dam (France), as shown in Figure 1 (Loisel et al., 2015). This comparison led to very satisfactory results, although it was shown that the Computational Fluid Dynamics (CFD) model always needs a trusted calibration point to reach the same level of accuracy as the physical model.

Hydraulic scale modeling of dams and hydropower hydraulic works

ARTELIA has always been involved in the field of hydropower and has developed an expertise in the design of the complex hydraulic works which are often encountered in such projects like Piano Key weirs, Fusegates, labyrinth weirs, shaft spillways, vortex shaft as well as more conventional spillways and dissipation basins which are always crucial structures for the dam safety. An increase of scale model studies is observed in hydraulic laboratories due to the dam ageing and the necessary upgrading and rehabilitation, and also as a consequence of the strengthening of regulations in many countries.

Unsteady flows, varying very rapidly, are observed in the surge tanks with complex shapes of hydropower schemes or in high lift locks with various saving basins. It is possible to reproduce these flows in scale models thanks to

Figure 5. Scale models of pumping station (with surface air core vortex), stepped drop shaft and vortex drop shaft on a urban drainage network

the improvement of the laboratory equipment operated in few milliseconds with perfect simultaneity.

Sedimentological models are probably the most sophisticated scale models. Various models of this type have been recently built by ARTELIA to study the Jirau reservoir flushing operation (Brasil, Energia Sustentavel do Brasil), the INGA 1 & 2 headrace canal sedimentation and cleaning (Democratic Republic of Congo, SNEL) the future Upper Karnali Hydrpower Project (Nepal, GMR), the recreation of a natural delta of the Rhône river in Lake Geneva (Switzerland).

Scale modeling of industrial or urban hydraulic structures

Numerous scale models of industrial or urban hydraulic structures are also studied in ARTELIA's laboratory, such as "classical" pumping stations, but also urban drainage networks, drop shafts. The local constraints in the cities due to the limited available space often lead to complex and unique hydraulic design that fully justify the need for a scale model validation study.

Trends in physical scale modeling applied to maritime hydraulics

In the maritime part of the laboratory, the trend in the classical wave stability studies for port and coastal structures is toward larger models covering about 1,000m2 in wave tanks due to either larger scale (shift from 1 in 60 towards 1 in 40) or very large layouts. A good example of this trend is provided by a recently completed model built in a wave tank 30 m by 40 m at a scale of 1 to 38 to study the protection of the Guggenheim Abu Dhabi museum by four

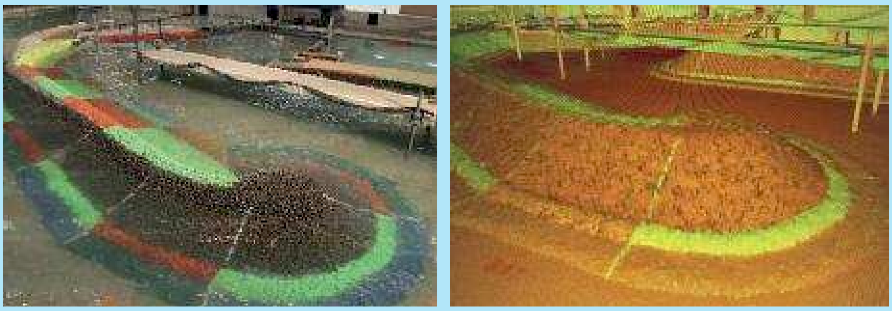


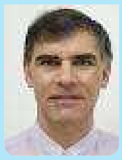
Figure 6. 3D laser scanning to follow morphological changes of a breakwater

Figure 7. 6-components strain gauge balance for measuring wave loads on a gravity-based structure (GBS) concept for offshore wind turbine development

Luc Hamm **is technical director of the Maritime and Ports branch of ARTELIA. After graduating as a civil engineer in Paris, he received a Ph.D in mechanics of geophysical environment from University of Grenoble and more recently an accreditation to supervise research in fundamental science from University of Caen Normandy. His main field since 1980 is waves, hydrodynamics, sediment transport and morphodynamics and their applications to coastal and estuarine environments and to port and coastal engineering with emphasis on physical and numerical modeling.**

Olivier Cazaillet **is a hydraulics engineer, working as project director for Artelia Eau & Environnement (formerly Sogreah) in the fields of dam hydraulic structures, development projects for rivers, delta and estuaries, morphodynamics and sediment transport, inland waterways, large irrigation canals, water resources and in protection schemes against hydrological and sedimentological risks. He managed the Hydraulics Laboratory of Sogreah during 6 years and specialized in sedimentological scale model.**

Pierre-Etienne Loisel **is a hydraulic engineer and project manager at ARTELIA. He has been working on hydraulics of rivers and structures since 2007, starting for one year as young expatriate in Oman. He has been developing a sound experience in scale modelling since 2009, by managing more than 20 projects. Mr LOISEL has been a member of the French dam committee since 2012 and published 5 papers for international congresses.**



Patrick Sauvaget **has 36 years of professional experience in the field of numerical modeling applied to the water environment. After obtaining an engineering degree in Hydraulics (INPG, Grenoble, France), he passed a master's thesis in civil and environmental engineering (University of Iowa, USA) and a PhD thesis in fluid mechanics (INPG, Grenoble, France). He is presently head of the Hydraulics department of Artelia Eau & Environnement, Grenoble, France. He acted as project leader or project director of water and environmental studies in various domains: hydraulics and water quality in rivers, coastal hydrodynamics, flood risk management, water resources management, water distribution, etc.**

detached breakwaters (Perrin et al., 2016a). The museum is built on a landmass retained by a vertical seawall with varying top elevations. One of the challenges of the study was to limit wave overtopping and negative wave pressures on the seawall while minimizing the visual impact of the detached breakwaters.

New technologies are also used in such stability models like a robotized total station for model construction and for quality control, and 3D laser scanning for monitoring morphological changes in breakwaters (see figure 6).

Measurements of forces and pressures applied to fixed structures are another important growing activity covering both breakwaters and renewable marine energy. Measurement of the impact pressures on a crest wall, induced by breaking waves, was performed on the old 19th century breakwaters of Artha and Socoa in a wave flume at a scale of 1 in 30 (Garcia et al., 2016). Measurements of such impulsive loads require high sensitivity piezoelectric pressure sensors and a very high sampling frequency, chosen in this case at 10,000Hz. Sensors, with a resonant frequency ≥60kHz, resolution of 0.69Pa and low frequency response ≥0.5Hz, were chosen to allow reliable measurements.

Figure 7 presents the case of a gravity based structure (GBS) concept for an offshore wind turbine development tested in a wave tank to get wave loads and pressures induced by extreme waves (wave height of 12 m with a period of 13 s in a water depth of 25 m). Such measurements constitute also a reference dataset for numerical modeling (Thilleul et al., 2014).

Another example is the site of Civitaveccia in Italy with measurements of hydrodynamic forces on the existing crest wall of a recently built vertical breakwater as illustrated by figure 8.

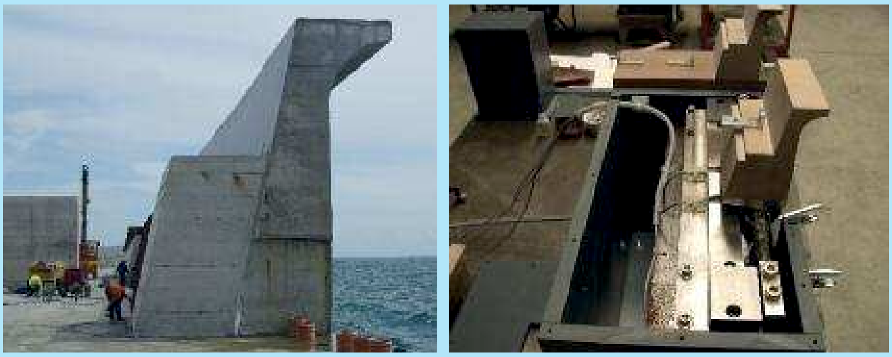


Figure 8. 3-components strain gauge balance for measuring wave loads on the crest wall of the vertical breakwater of Civitaveccia (Italy)

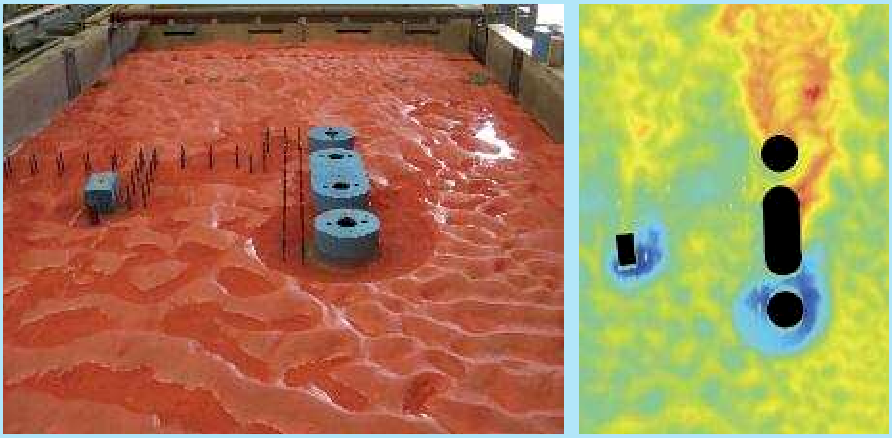


Figure 9. Erosion-sedimentation patterns around bridge piers measured by photo-scan surveying technique

Studies of scouring at the toe of maritime structures are another field of activity presently driven by marine renewable energy developments subjected to combined wave and currents actions. They required an adaptation of our facilities to allow current generation in our wave flumes and basins. Such movable bed scale models cannot be in exact similitude with nature when natural sediments are fine to very fine sands. A long tradition in our laboratory is to use lightweight material instead of natural sand in order to represent correctly the initiation of sediment movement and facilitate suspended sediment transport. An example of this approach is the recent model of scour of bridge piers supporting a long causeway in Kuwait bay (Perrin et al., 2016b). An advanced image-based 3D modeling solution was implemented on this model by photographing the test zone from different viewpoints using a fix-lens camera (60 photographs), followed by spatially referencing (x, y, and z co-ordinates) the pixels composing each photograph using coefficients that were previously calibrated with 6 known benchmarks. A dense point cloud was then created from these 60 photographs and a 3D polygonal mesh representing the model was finally built on this basis. Quantitative evaluations of seabed morphology change can be obtained by comparing photo-scan surveyed seabed levels at the end of each test to the initial seabed levels. Figure 9 illustrates such a result for another bridge pier scour model. Such optical methods are also implemented for measuring the movements of moored floating structures by infrared stereoscopic cameras allowing motion capture. ■

References

Cazaillet, O. et Marcellin, L. 2009. Etude d'une écluse de 30 m de chute : apport des nouvelles techniques de mesure et d'instrumentation à la modélisation physique (Société Hydrotechnique de France, Colloque sur la modélisation physique, Lyon, novembre 2009)

Cazaillet, O. et Vermeulen, J. 2009. Théorie de la modélisation physique hydraulique en 2009 (Société Hydrotechnique de France, sur la modélisation physique, Lyon, novembre 2009)

Cazaillet, O., Derrien, S., Bazerque, L. Ribeiro, V., Pinto, P. 2013. Physical studies of the upgrading of existing Venda Nova Scheme, 81th ICOLD Annual Meeting - Seattle, USA - 12th to 16th August 2013

Cazaillet O, Loisel P.E., Alam S., Sharma G.S., Agarwal S., Samal H.P., 2013. Upper Karnali Hydroelectric Project – Sedimentological model studies. 81th ICOLD Annual Meeting - Seattle, USA - 12th to 16th August 2013.

Garcia, N., Cayrol, C., Marcol, C., Bonthoux, L. and P.G. Anquetin, 2016. Wave-induced pressures and hydraulic stability of the Artha and Socoa breakwaters, Saint-Jean-de-Luz (France). Accepted for presentation at the 6th Int. Conf. on the Application of Physical Modeling in Coastal and Port Engineering and Science (Coastlab16), Ottawa, Canada, May, 10-13, 2016

Jones, B.A. Cazaillet, O., Hakin, W.D. 2006. Safety measures adopted to increase spillway potential at Jindabyne dam in the snowy mountains . ICOLD, 22nd Congress, Barcelona, 2006.

Loisel, P.E., Schaguene J., Bertrand O., Guilbaud C., 2015. Comparative study between numerical and physical hydraulic modelling of flood spillway structures. ICOLD 25th Congress, Stavanger, Norway, June 17-19, 2015.

Loisel P.E., Valley P, Laugier F, 2013. Hydraulic scale model of Piano Key Weirs as additional flood spillways on the existing Charmine dam. 2nd International Workshop on Labyrinth and Piano Key Weirs, Paris – Chatou, France November 20-22, 2013.

Perrin, S., Keppers, C., Seifart, C., Cayrol, C., Johnson, T. and J. Gonçalves, 2016a. Optimisation of Guggenheim Abu Dhabi detached breakwaters by physical models.). Accepted for presentation at the 6th Int. Conf. on the Application of Physical Modeling in Coastal and Port Engineering and Science (Coastlab16), Ottawa, Canada, May, 10-13, 2016

Perrin, S., Keppers, C., Murphy, E. et S. Roux, 2016b. Small-scale physical modeling of scour at bridge piers with light-weight sediments. Accepted for presentation at the 6th Int. Conf. on the Application of Physical Modeling in Coastal and Port Engineering and Science (Coastlab16), Ottawa, Canada, May, 10-13, 2016

Ribeiro, V., Pinto, P., Bazerque, L., Cazaillet, O. 2012. Venda Nova III surge tanks: physical model studies, 11th International Conference on Pressure Surges, Surge Analysis, Lisbon, October 24-26, 2012

Thilleul, O., J-M Anfray, A. Gonzales, L. Guisier, P. Ferrant, 2014. Nonlinear wave loads in CFD on a gravity based offshore wind turbine foundation. Poster presented at the International Conference on Ocean Energy (ICOE 2014), Halifax, Canada, November 4-6, 2014