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COASTAL MODELING – A RETROSPECTIVE

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ABSTRACT

This paper presents a retrospective look at Coastal Modeling, the central topic of the Coastlab Conferences. Its aim is to provide a context for coastal modeling. The paper begins with basic information about coastal models. It continues with a discussion of the development of coastal knowledge, reaching the conclusion that coastal engineering is in a stage of 'old age', in which the most pressing problems have been solved and much time is spent on sophisticated theoretical developments to further validate the existing coastal engineering paradigm. The next section of the paper focuses on how we should progress into the future. The final section returns to physical modeling and discusses what a powerful research tool it is and how it is an excellent visual tool for teaching and generating understanding of coastal processes.

KEWORDS: Coastal models, Numerical Models, Physical Models.

1 INTRODUCTION

The purpose of this paper is to develop a basic understanding about what coastal engineering is; in particular what coastal modeling is in 2016, how coastal engineering and coastal modeling have progressed in time, and how we can proceed into the future. Kamphuis (2000) forms a good background paper.

2 BASICS OF COASTAL MODELING

Coastal Models are essentially a trial-and-error (T&E) tool. Coastal problems are complex and our theoretical and practical knowledge is usually insufficient, Kamphuis (2012). So the normal procedure to solve a problem or to make a design consists of the following steps:

a. Build or purchase the best possible model (T&E)
b. Insert the best available data
c. Run the model and adjust it (T&E) to give the best possible representation of the data (called calibration)
d. Verify the model against any additional data, such as post-construction data (T&E)
e. Then finally, test possible solutions or design changes for the prototype, by introducing them into the calibrated, verified model to see how they perform (T&E).

Coastal models are primarily physical or numerical models. The important attributes of physical models are:

a. Physical models behave in a manner that is similar to the prototype
b. Physical models provide a direct visual impression of the processes
c. As a result, physical models are often the most useful tool available to the researcher/engineer
d. The model results should always be regarded as qualitative
e. According to a) and b) above, physical models *add* to the understanding of the problem
f. Because of modeling restrictions, such as model scaling and scale effect, model boundaries and laboratory effect, model distortion, etc. (Kamphuis 1972, 1974), the interpretation of the qualitative model results into quantitative conclusions is difficult and requires thorough knowledge of the physics, and of the impacts of the modeling restrictions.
g. Physical models of large geographical areas or long time durations are prohibitively expensive, when compared with numerical models. Therefore physical models are now generally used to simulate details of complex processes.

The important attributes of numerical models are:

a. Numerical models do *not* add to the understanding of the problem; they simply reflect the input by the creators of the numerical model.
b. Since this input knowledge is generally much greater than the user's knowledge, it will *appear* to the user that the numerical model adds knowledge.
c. Numerical models can produce completely incorrect results – there is no innate similarity between the physics of the prototype and the computer code.
d. Numerical models *are* capable of simulating large areas and long durations.
e. Numerical model results are at best qualitative.
f. Interpretation of the qualitative numerical model results, normally shown by attractive, user-friendly graphics, requires a thorough understanding of the coastal processes, equations, coefficients, numerical methods, pitfalls such as instability, numerical diffusion and dispersion, smoothing, etc
g. Meaningful interpretation of the qualitative model results can, therefore, only be accomplished by an informed and careful user who understands the items in f) - not by amateurs who simply put some boundary conditions into a model, record the attractive pictorial results, simply trust the pictures and think they now understand what is going on.
h. Interpretation of the qualitative numerical model results is often so poor that an oft-heard major research conclusion is something like: 'The model results are a reasonable representation of the prototype'. This is nonsense. How can the user justify this kind of conclusion? The time, work and the expense put into the model study deserve better conclusions than this, and surely the model was run for a definite research or engineering purpose. How does this conclusion bring the problem closer to resolution?
i. A second Common Conclusion: 'To improve these results we must use a more powerful, more sophisticated model.' This is often incorrect. This is either wishful thinking or an excuse for poor workmanship.

Finally, this first section on the basics of modeling focuses on model validation. Without proper validation, the model results can be very badly in error and the model cannot to be trusted. A proper validation process consists of:

a. Benchmarking – reproduction by the model of standard analytical solutions
b. Calibration – reproduction by the model of measured field data
c. Verification – reproduction by the calibrated model of additional data, such as data obtained during construction, and post-construction data.

These validation steps are very costly. For physical models, the cost of validation can be half of the total modeling cost; for numerical models the cost of proper validation can easily be several times the actual modeling cost. Because of these costs, proper validation is often not done and simple comparison of model results with the prototype data is often used. Unfortunately, this essentially amounts to a subjective turning of knobs on a model to produce reasonable results.

On the other hand, comparison is often the only practical validation check possible; usually because there is insufficient funding for the model study. Yet, Comparison is never a justifiable alternative to proper Calibration and Verification.

3 LEARNING CURVES

The next topic of this paper is about learning curves and development of knowledge; see also Kamphuis (2010a, 2011). The basic learning curve is shown in Figure 1. It is seen that at the beginning, learning or development of knowledge is rapid. But, in time, the rate of development decreases until it becomes very small, or even zero. Kuhn (1977) labelled three stages of the learning curve: Infancy, Maturity and Old Age. These are shown in Figure 2 along with Kuhn's basic descriptions of the three stages of learning.

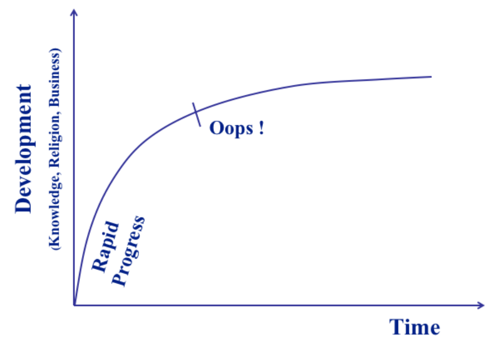

Figure 1. Development or learning curve

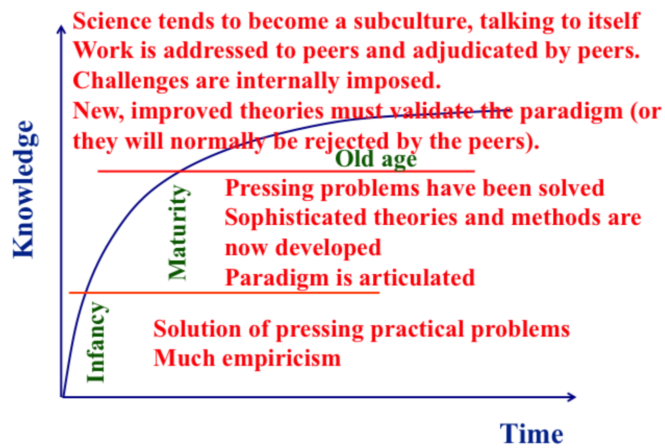

Figure 2. Stages of the learning curve, after Kuhn (1977)

A concept, closely related to the learning curve is Paradigm Shift, illustrated in Figure 3. It is a sharp, radical break with the original learning curve as a result of radically new philosophical, theoretical or technological development.

The paradigm shift is not just any improvement – it is a *radical* shift that shakes the existing paradigm. Examples of paradigm shift are Einstein's theory of relativity in physics, and the development (historically) of completely new technologies in photography, progressing from photographic plates to film to colour film to digital photography.

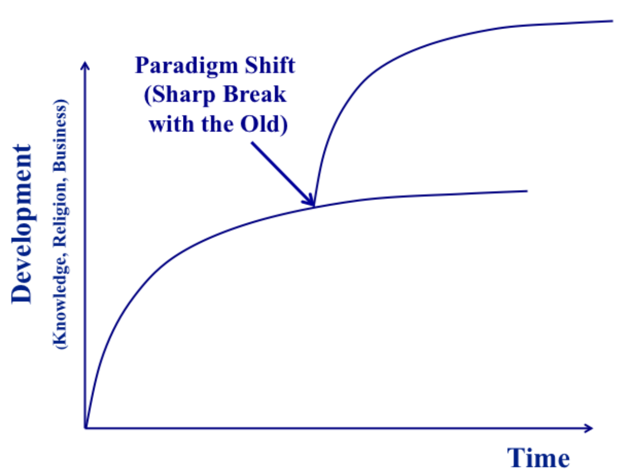

Figure 3. Definition of paradigm shift

Knowledge and development may decline in time, as technology reaches old age. This is particularly true after a Paradigm Shift.

Figure 4 shows example learning curves for coastal engineering. It is seen that the curve for physical model development begins early in the previous century and reaches its old age around 1960. In 1970 it became clear that it would be difficult to continue to expand knowledge on physical models without very large additional costs (much larger models, much smaller model scales, more intricate wave generation, etc.) As a result, knowledge and development of physical modelling has been slow, stagnant or declining since then. Part of the decline in physical modeling is certainly caused by the important advances in other technologies, particularly in numerical modeling, which resulted from the introduction of computers in the 1960's.

Figure 4 also shows the important advance in process knowledge and field data collection after the mid-century.

To advance after 1970, coastal engineering took full advantage of the available knowledge by maintaining good existing knowledge, but concentrating on the steepest learning curves for new developments.

Today, all the learning curves in Figure 4 are quite flat. This is the old age of coastal engineering. This means we cannot (must not) continue along the old paths.

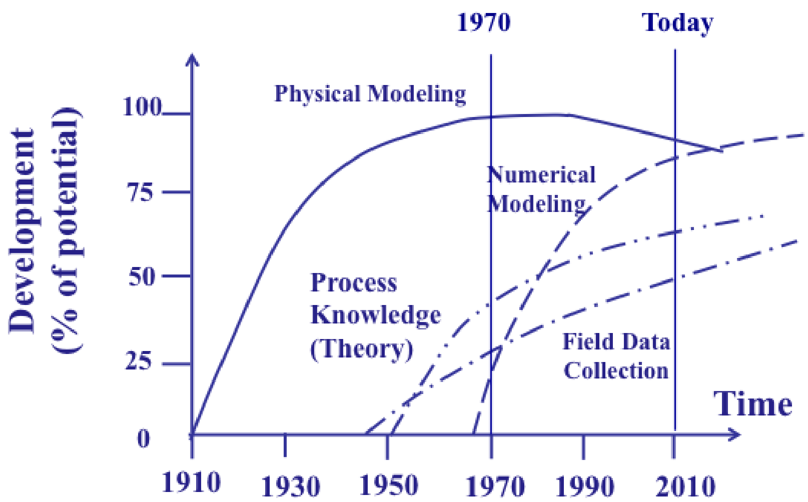

Figure 4. Coastal Learning Curves ?

It is possible to draw an alternate single learning curve for Coastal Engineering (Figure 5). This essentially equates the developments based on computer technology as a paradigm shift in Coastal Engineering.

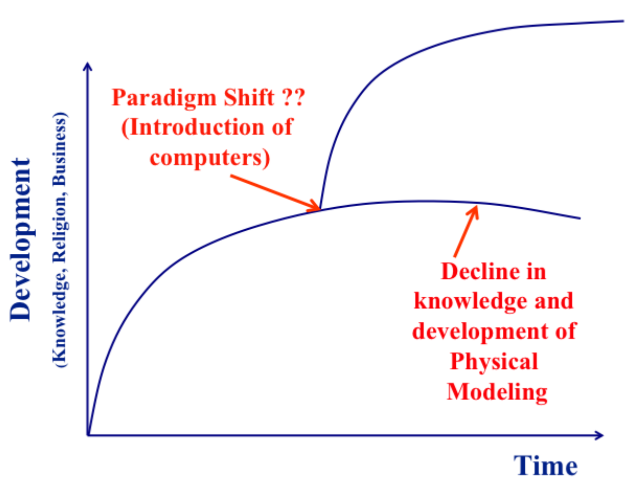

Figure 5. Another view of the Coastal Learning Curve

4 HOW DO WE PROCEED?

Without question, the Numerical Model has become the backbone tool of choice in Coastal Engineering research and design. It is cost-efficient; it needs only a desk and a computer. It is capable of simulating large areas and long durations. However, as discussed in Section 2, we must be very careful of facile, and/or incorrect solutions and conclusions with numerical models.

To advance in our discipline, we can certainly hope for and work toward a paradigm shift in the discipline, but what must be done in the absence of such a major event?

In that case, to advance at all (in order to be able to deal with the present and future design complexities, uncertainties, complex approvals processes, etc.) will require a concerted effort on all fronts – process knowledge (theory), physical modeling, numerical modeling and field measurement.

a. We must take advantage of the particular strengths of each element.
b. We must integrate science and engineering, re-integrate theory and practice (Kamphuis, 2011), and integrate all tools, people and facilities.
c. That means we must engage in (more) open, frank communication between the various 'silos of expertise' that have developed and generate (more) mutual appreciation, understanding and help between the various disciplines.

To be able to solve new, practical problems (such as dealing with climate impact):

a. We must seriously break down any barriers between various 'expert silos'.
b. In the end, we must achieve (re-achieve?) an integrated, generalist coastal engineering expertise, rather than continue to exist as a non-integrated mosaic of many varied, isolated, specialized science, engineering and governance disciplines.
c. To solve a complex practical problem, such as how to deal with regional water level rise, everyone's individual expertise is sorely needed, but everyone *must* be present around the same table, focusing together on comprehensive understanding and solutions.
d. The new problems are at the beginning of their learning curve and need innovative study and solutions now (see Figure 2 – Infancy). This is very exciting work; it requires innovative and out-of-the-box, original thought. These are challenging and unique opportunities and therefore, there should no problem finding committed, dedicated individuals to perform this work.
e. All this is very difficult for university-related colleagues, since their reputation and career advancement are normally based on specialization and number of publications (Kamphuis, 2010).
    - Working in a new field will (most likely) result in fewer papers.
    - The 'peers' may not approve of the topics and results, and thus research funding may be decreased.
    - The university may think this professor is no longer producing maximum output and this may result in fewer promotions, etc.
    - However, from my own fortunate experience, original research, and the development of novel thinking and solutions to emerging pressing problems are not only much more challenging, but also much more rewarding to both the students and the professor, than simply adding to the list of 'learned papers'.

Further discussion regarding integration of expertise, tools and people and integrated modeling may be found, for example, in Kamphuis (2010a).

5 BACK TO PHYSICAL MODELS

This final section returns to physical models to stress their unique usefulness and opportunities.

5.1 Anecdote

Figure 6 shows how an old coal harbour in the Kingston area was redeveloped into Portsmouth Olympic Harbour, the yacht harbour for the 1976 Olympics. The two wider breakwater sections are the original breakwater of the coal harbour. A breakwater extension was added to provide a narrower entrance channel, narrowly focused on the southeast, the shortest fetch (3.5 km). However, after this modification was finished, it was found that unexpected, unacceptably high waves existed along the west wall of the harbour and particularly also in the southwest pocket at the foot of the breakwater, where a busy launch ramp was located that needs to be (and was expected to be) one of the quietest areas in the harbour.

As I was thinking about this problem, a student came to me and said: 'Sir, I still do not have a project for my undergraduate thesis'. I suggested that he build a model of the harbour over the weekend and see what he could find. The student quite obviously thought that I was crazy. When I suggested that I would need the results shortly after the weekend, the student looked at me as if I was really crazy.

He began to feel a little better, when I suggested he carefully and accurately build a small model on two sheets of plywood (i.e. 2.5 x 2,5 m). I provided him with some more instructions and with a wave generator that was normally used to generate small waves in a ripple tank. Note that there were no good numerical representations in 1973 of refraction-diffraction and harbour agitation and so a physical model was the only method that could be used to identify the causes of the harbour agitation.

When I arrived back at the laboratory on Monday, the student was beaming. He had literally discovered the answer with his rudimentary model. In Figure 6, at the place where the old and new breakwaters join is a strange-looking point with a dot on it. This was the base for the support structure for the future Olympic flame. When the student turned the model on, there was what looked like a piston wave generator located at the Olympic flame support structure, generating circular waves, in addition to the expected wave patterns. Clearly the incoming waves interacted severely with the odd-shaped structure, which caused massive diffraction of the waves, directing much wave energy toward the west and the launch ramp.

First, the 'model' clearly demonstrated that physical models have a direct visual impact and add to the understanding of the problem (Section 2, items b and e). In the end, the student had a successful undergraduate project and I had a better understanding of the wave processes. In fact, the results from this 'model' were so clear that we did not build a 'real' model but simply built two short breakwater stubs to direct the incoming wave action away from the angular base of the Olympic flame.

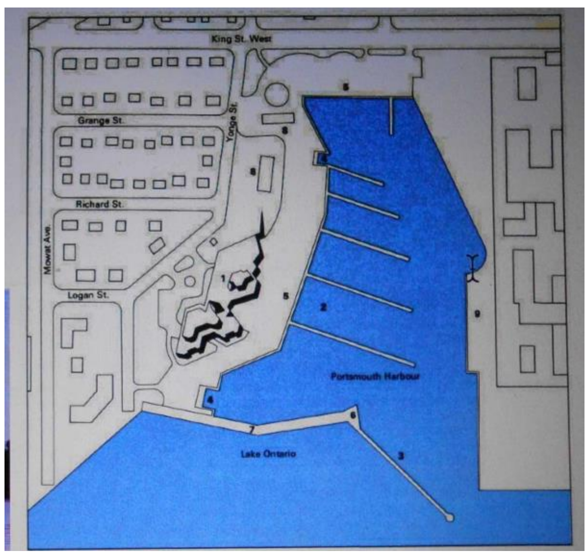

Figure 6. Portsmouth Olympic Harbour – Kingston

5.2 Example of the Use of Physical Models

A good indication that physical models are useful, when the complex processes are not clearly understood, is the long series (30 yrs.) of tests run at Queen's University on alongshore sediment transport and transport-related phenomena, such as groin fields, artificial nourishments, erosion of Sacrificial Islands, etc. At the beginning of these tests we (and everyone else) knew very little about the details of how beach processes took place. The Queen's tests provided valuable insight, first into the mechanics of how to design and operate such complex models and secondly into the process details of the complex phenomena. The tests brought out many conclusions that could not otherwise have been made. Straightforward, simple expressions were developed from the model studies, because contrary to field observations, the model input parameters such as waves, beach shape, sand grain size and distribution, etc. could be strictly controlled and continued indefinitely. As a result, the relationships derived from the models were much clearer than estimates based on the much more erratic field measurements. It was very encouraging that the expressions based on the model tests were also excellent representations of the few widely scattered field results available at that time (for example, Kamphuis, 1991).

So now that the basic sediment transport processes are better understood, the physical model results can be effectively introduced into numerical models, for example in numerical models to determine long term coastal change resulting from long-term climate cycles and climate change. Without the clear, basic input from these physical model studies, any numerical modelling of such a process would be forced to deduce direct cause/effect relationships between climate change or long-term climate cycles and coastal changes. Such directly derived cause/effect relationships will contain much greater uncertainties than when the basic sediment transport relationships derived from the model tests are understood and can be introduced into the formulation of the numerical model.

Such a direct cause/effect derivation is actually what is done in the present climate change numerical models. By attempting to relate global temperature rise to greenhouse gas concentrations directly from field measurements of basic climate data and basic greenhouse gas concentration data, climate change predictions contain very large uncertainties. If it were possible to capture any details of the basic temperature/greenhouse gas relationships in isolation, such as for example in physical models, then the uncertainties in such numerical models would decrease substantially.

In coastal engineering we are fortunate to be able to do such basic physical experiments. This means we must continue to use physical models, even if this involves large expense. We need to start thinking seriously about sharing this expense (as is happening in some places now). Universities need to build or renovate their facilities or they need to team up with research institutes. Research institutions need to share facilities with each other and with universities.

5.3 The Physical Model as a Tool in Education

a. All educational formats benefit from extensive demonstration, Kamphuis (2012).

b. Hands-on lab experimentation and simulation experience are excellent demonstration tools.

c. Coastal concepts, both simple (e.g. orbital motion) and complex (e.g. beach stability) can be readily demonstrated visually and understood through simple physical modeling.

d. Physical laboratory demonstration/experimentation is excellent because it is:
   - Relatively easy to set up
   - Immediately visual
   - Tests are repeatable and can be controlled
   - Experiments generate interest, excitement and inspiration.

Figures 7 to 9 shows a class I taught in Porto, Portugal. The class included a laboratory session. In Figure 7 the professor still gets attention, but once the wave machine was started, the demonstration experiment took over the complete interest of the students, as in Figures 8 and 9.

Figure 7. Interesting, Exciting, inspirational (1)

Figure 8. Interesting, Exciting, inspirational (2)

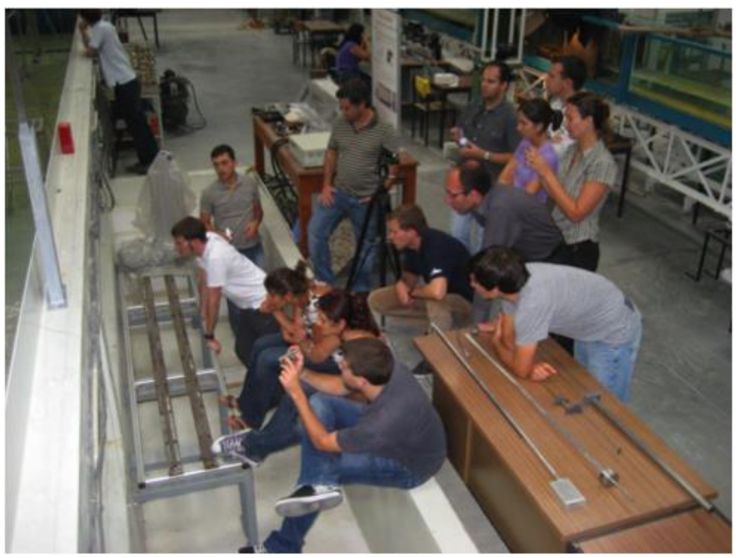

Figure 10. Interesting, Exciting, inspirational (3)

Since learning by trial and error, through models and simulation, meshes exactly with coastal design protocol, using models in class also teaches the students a basic step in coastal design.

Further, students who have been ‘coached’ through most of their life will welcome extensive hands on work, particularly experimentation in a laboratory to help them understand the basic principles as well as complex totally unfamiliar concepts. Lectures and textbooks provide the appropriate information, but hands-on experimentation generates intimate familiarity with and interest in the concepts.

Many universities now recognise that ‘educational experience’ (such as hands-on experience in coastal engineering) makes happy students and attracts excellent prospective students and professors; Coastal Engineering needs to lead and exploit this trend with physical modeling. Coastal engineers must similarly exploit a recent emphasis by universities on outcome-based learning. A graduate who has actually worked with water, rocks and sand is much better prepared for a career in Coastal Engineering than a graduate who knows waves only from textbooks and videos.

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