PHYSICAL MODELLING OF COMPLEX HYDRAULIC STRUCTURES TO ENSURE YOU SLEEP WELL AT NIGHT!

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Physical models have been used for many decades to understand and refine our understanding of water's behaviour through and over structures. Early physical models have provided the basis for hydraulic assumptions and numerical modelling methods, equations and rates. In many (and perhaps most) situations, application of these numerical methods are the most time and cost effective means of hydraulic design. However hydraulic engineers must be aware of the limitations of any applied method and when further, detailed investigations may be required.

This presentation is targeted to hydraulic engineers and presents various hydraulic structure physical models that have been built, tested and refined in recent years at the University of New South Wales, Water Research Laboratory (WRL). The paper does not concentrate on the specific results of each study, but rather flow behaviour that has been found that may not have been readily predicted with other methods. These models include: pump intakes, drop structures, stormwater structures and complex overland flow.

The time and cost to design, build and test physical models is often seen as a deterrent to commissioning them. However, this paper provides information on the typical costs and duration to undertake various models, while considering the confidence provided both to the engineer and the water infrastructure owner. Opinions are presented (supported by findings from various models) which may provide guidance on when a hydraulic engineers may need to commission a physical model.

1 INTRODUCTION

Good hydraulic design should make preliminary use of desktop methods and calculations to estimate what flow conditions may occur and to provide an order-of-magnitude quantification of these conditions. If required, the design may then continue to numerical modelling to provide better quantification of the conditions and to refine the design. However, an equally critical part of good hydraulic design is to consider adverse flow conditions and how these conditions may come about. A few examples include: dam overtopping due to spillway efficiency; air being entrained at an intake and damaging the pump; localised rapid flows on a floodplain resulting in unsafe pedestrian conditions; and inefficient flow distribution in a storm water system resulting in greater headloss and surface flooding.

The challenge for a hydraulic engineer is understanding the fundamentals that desktop and numerical methods are based upon and how representative are the parameter values from previous studies. In many cases hydraulic design can be made without site specific advanced numerical modelling or physical modelling. Unfortunately, the decision of whether proceed to physical modelling is often based on costs and timelines without a true assessment of the project uncertainties or their implications.

This paper provides examples of studies undertaken at UNSW Water Research Laboratory to demonstrate that physical models can be built and tested much faster and cheaper than most engineers expect. It also shows that the majority of physical models undertaken result in optimized design that give overall project cost savings, improved hydraulic performance and reduced risk of adverse performance.

With a greater reliance on software packages in the hydraulic design process, it is imperative that hydraulic engineers seek advice from experts about when hydraulic physical models are required. It is equally imperative that those experts providing hydraulic modelling services provide un-biased advice on when physical models are not required.

2 SPILLWAYS

It is imperative to understand the hydraulic behaviour of a spillway to ensure that unintentional overtopping does not cause catastrophic failure of the dam wall. It is equally imperative that the energy of discharging water is dissipated in a controlled manner to avoid damage to the spillway and downstream waterways. Physical models of dams and spillways to optimize head versus discharge and downstream energy dissipation have been used for a great many years and provided they are undertaken at an appropriate scale can accurately predict prototype behaviour.

The Suma Park Dam spillway modelling (Figure 1) undertaken at WRL (Wyllie and Miller, 2009) is a good example of when physical modelling is required as the flow is too three dimensional and turbulent to be reliably predicted by other means. At a scale of 1:60 the model was used to confirm the overflow depths and to refine the shape and widths of the spillway apron and the heights of the deflector walls. Refinement was based on water level, velocity and high speed pressure measurements. Total cost for this model was approximately $90,000 with half on construction, setup and testing of the initial design. The second half of the budget was spent testing a further four different configurations to refine the design. The initial model was built and tested within three months but the refinement tests took less than two weeks each. The physical model provided a fast, cost effective and reliable means of assessing each potential refinement.

Figure 1 - Suma Park Spillway

In 2005, rock spillways were being considered (but were never built) for the large river to lake weirs in the Penrith Lakes Development in western Sydney. These had the advantage of alleviating groundwater pore pressures within the embankments, but relied on a less common approach than a concrete spillway. Physical modelling (Peirson and Pells, 2005) was undertaken to assess the rock sizes required for stability in highly aerated flows. This is an example of a case with complex bed form combined with highly aerated supercritical flow which very little data was available. Hydraulic design could either rely on theoretical methods and apply a high factor of safety or undertake a relatively expensive research program (approximately $150,000) taking more than eight months. However, the findings of the study provided a range of stable bank slopes and rock sizes, which would have saved more than the modelling costs many tens of times over. Further, the physical modelling gave confidence in the hydraulics of the final design that could not have been achieved by any other means.

With spillways being large, expensive, critical infrastructure, physical modelling provides a greater confidence in the hydraulic performance. If the hydraulic engineer is using a common spillway design and is confident about the performance or testing of similar structures, physical modelling may not be required. However, if there are uncertainties on aeration, energy dissipation or complex three dimensional flow patterns, the modest costs and timeframes for modelling should not be a deterrent.

3 PUMP INTAKES, DEARATION CHAMBERS AND DROP STRUCTURES

Hydraulic structures which have combined air and water are very difficult to investigate with numerical models. There are many design guides available for sizing pump intakes, dearation chambers and drop structures which a hydraulic engineer can make an initial design. WRL's experience is that physical models of these structures allow for either cost saving in construction or avoid hydraulic conditions that would require expensive retrofitting.

WRL was commissioned to test the performance of a drop structure and dearation chamber for the Adelaide desalination plant outfall. The structure was a 40m deep, 1.5m diameter, vortex drop pipe into a large (8m diameter by 21m high) dearation chamber. Physical modelling required a scale of 1:6 to accurately predict the air entrainment in the vortex and the rising air bubbles in the dearation chamber. However at this scale, the physical model was more than 8 meters high (Figure 2) and needed to be build outside! The modelling cost approximately $250,000 but was built, tested and refined within six months as required for the construction schedule. While this may seem at face value to be a costly exercise, the physical model provided: refinement of the inlet to the vortex drop pipe, discovery that the air entrainment was almost twice what was originally predicted, addition of flow vanes to assist the dearation, addition of a flow hood near the offtake to restrict air bubbles and air core vortices, and identification of areas with unstable and destructive velocities that required further design.

Figure 2 - Adelaide Desalination Outfall Drop Structure

Pump intake hydraulic models also require similar scales, but are generally much cheaper to build and test. A model of a compact pumping well in Launceston (Miller, 2007) was built at a scale of 1:4 for less than $30,000 and completed within 10 weeks in an attempt to increase pumping capacity without increasing the overall size of the pit. In this instance, the physical model ensured that all hydraulic engineering options were considered before finally committing to an expensive pit resizing. A pump intake in Saudi Arabia was modeled at a scale of 1:12 for less than $40,000 in under 8 weeks to confirm the minimum water level to avoid swirls and vortices (Mallen-Lopez, L. and Miller, B.M., 2008).

4 STORMWATER INFRASTRUCTURE

Stormwater networks are commonly engineered using one dimensional (1D) hydraulic numerical models. While this is entirely appropriate, it is imperative to understand the assumptions of the 1D modelling. These models may not consider the influence of momentum in junction pits when estimating the distribution of outflows. Similarly, these models rely on estimates of hydraulic headloss through junctions and pits (k-factors) based on common designs and assumed flow regimes.

Several physical models of large and small stormwater infrastructure have been undertaken at WRL in the past few years. This “resurgence” of stormwater physical models seems due to hydraulic engineers realising how critical these structures can be to the overall performance of the drainage system. Physical modelling of a junction pit under a major shopping centre in Sydney (Guerry and Miller, 2013) (Phillips et al, 2015) was undertaken at a scale of 1:15 (Figure 3). This modelling included a base case and three alternative cases and was completed for approximately $70,000 in four months. The modelling was crucial in achieving the best balance of flows between the three outlet culverts and assessed internal baffling and realignment of inlet culverts. Further, the model provided data for the verification of headloss and other parameters within the associated 1D model.

The Green Square Trunk drain currently being constructed in Alexandria in Sydney required physical modelling of several junction and flow equalization pits. Three models were constructed (as yet unreported) with a range of costs between $50,000 and $70,000 with all three being completed within five months. These models provided confidence in the assumed head loss factors, the flow distributions and provided data-sets for validation of numerical CFD models.

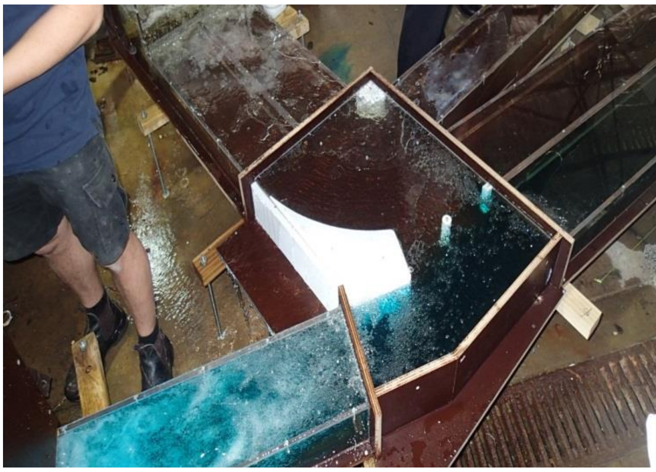

Figure 3 - Warringah Mall Junction B4

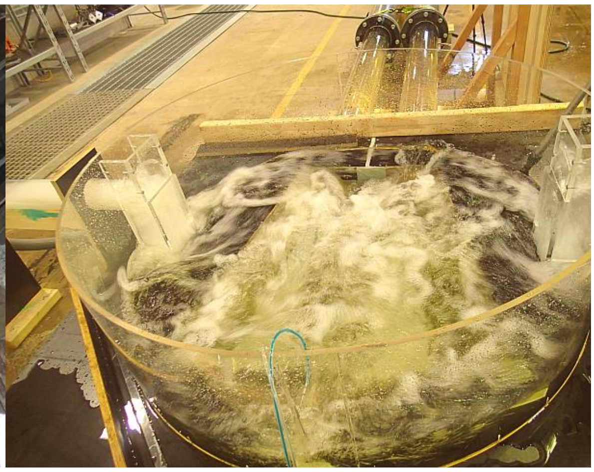

Figure 4 - Green Square Pit 14

5 CONCLUSION

Physical models of hydraulic structures are rarely done in less than two months, but also rarely take more than six months. The costs can be as low as tens of thousands but can also be hundreds of thousands, depending on the complexity. This paper has provided examples of timelines and costs so that hydraulic engineers may assess whether they have the time, budget and need to assess specific hydraulic issues. The assessment of whether to undertake physical modelling should be based on an uncertainty assessment and a consequences assessment. If numerical or desktop assessment methods include the appropriate physics and are based or have been shown to reproduce adequate observations, then physical model is most likely not required. However, if there is uncertainty in hydraulic processes, or if subtle changes in assumed parameter values result in the hydraulics no longer behaving, then it is recommended you discuss the problem with an expert in physical modelling. Do this early as physical models do take time, but don't dismiss these investigations because of the available design timeline. In the long run, you will sleep better!

6 REFERENCES

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