Scanning for Hydraulic Modelling

A novel approach to obtaining validation data

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Scanning for Hydraulic Modelling

Hydraulic modelling - support the design of hydraulic flow interventions (e.g. rivers, reservoirs, flood management infrastructure).

Often - there is a need to understand the shape and location of water surface (alongside the velocity and related flow phenomena).

Examples
- river management features (weirs, spillways, etc)
- design of flow behaviour in recreational white-water courses (e.g. Teesside/ Olympic Lee Valley courses).

Numerical modelling (& CFD)
=> detailed medium/large-scale simulations becoming feasible.

BUT we need experimental data to validate models.
Tees Barrage International White Water Centre

£4.6 million re-development

Lee Valley (Olympic) White Water Centre - £30 million development

www.bbc.co.uk
Scanning for Hydraulic Modelling

Terrestrial Laser Scanning (TLS)

=> convenient and accurate mapping of ‘modelling domain’ of interest
(river/valley bed or channel)

TLS not typically used to measure the surface of water
(no return from the water)

However-
The broken water surface of white-water offers some interesting/useful results.

**AIM**

Investigate use of TLS to measure position of standing waves and other flow features
(as that found on white-water course etc),
1:10 Froude Scale hydraulic models

\[ Fr = \frac{v}{\sqrt{gd}} \]
Motivation for modelling

Research Question

Can numerical modelling (CFD) accurately predict the free-surface location and other flow features for complex flows such as those found in white-water courses and other industrial flows?

Potential for cost savings and more responsive design approaches
River Hydrodynamics

- **Main features**
  - White water
  - Standing waves
  - Holes/stoppers
  - Eddies

- **Hydraulic jump**
  - Supercritical -> subcritical
  - No flow transferred upstream
  - Undular, weak, stable, breaking
CFD Pilot study
– based on Teesside white-water course

CFD (Computational Fluid Dynamics)
3D Numerical grid required – (over which equations solved)
2-phase flow – VOF method implemented

Boundary conditions
• 6 m³/s - inlet flow rate
• Weir at outlet
Free Surface of water coloured by streamwise velocity

Pilot CFD modelling study

e.g. Channel with 1m high weir at outlet

High mesh refinement required to avoid diffuse free-surface (million+ cells)
Varying Weir Height

Contours of volume fraction on centre plane for varying weir heights

0.5m

1.0m

1.25m

Water Volume Fraction

Velocity vectors on the breaking wave
Varying Weir Height

Comparison of free surface coloured by streamwise velocity for different weir heights

Velocity vectors plotted on free-surface show recirculation zones.
Wave Modelling

Channel containing two 1m wide blocks one block high added to channel with 1.0m high weir.

The effect on the free surface height when placing a row of single blocks in the channel.
Motivation for Experiments

Very challenging to reliably validate models - water depths vary across the flow and not typically accessible to take point measurements.

Looking for alternative - data collection approach
Experimental study - Validation data
White-water channel Teesside
Experimental study - Validation data
White-water channel Teesside
Validation data: White-water channel Teesside - setup

Terrestrial Laser Scanning (TOPCON GLS1500):
- course bed and physical features
- white-water surface (attempt to retrieve water free surface information)

Acoustic Doppler Current Profiler (velocity profile)
- Channel flow Velocities measured within channel at inlet

Course boundary conditions:
Inlet - Flow rate fully specified \((1\text{ m}^3/\text{s} - 10\text{ m}^3/\text{s})\)
Outlet - Downstream weir height controlled \((0.25\text{ m} \text{ increments})\)
Insert Blocks added into the channel \((0.25 \times 0.5 \times 1.0 \text{ m})\)
Flow rate: 6 m$^3$/s

Pilot study CFD prediction (weir height = 0.5m)
Qualitative check of standing wave shape
Qualitative check of standing wave shape

Flow rate: 6 m³/s
Flow rate: 2.3 m³/s

Higher flow rate results in ‘steeper’ angle in both CFD and experiments.
Measured stationary wave location

Flow rate: 8.3 m$^3$/s (weir 0.25m)

Flow rate: 6.2 m$^3$/s (weir 0.25m)

Flow rate: 3.1 m$^3$/s (weir 0.25m)

Flow rate: 3.1 m$^3$/s (weir 0.5m)

Data above – points close to centre line
Full geometry CFD model
(VOF – Georeconstruct method)
(4 million + cells required)

Flow rate: 2.3m³/s
Flow rate: 2.3 m³/s
Phase 2 Experiments - ‘Insert Blocks’
Boundary conditions:
Inlet - Flow rate specified (2.2 & 5.5 m$^3$s$^{-1}$)
Outlet - Downstream weir height controlled (0.5m)
‘Insert Blocks’ added at specific locations in the channel
Flow rate: 5.5 m³/s

Flow rate: 2.3 m³/s

Setup-3
Comparison with TLS data
Challenges - Transient flow fluctuations
Impact of changing outlet weir height (0.5 vs 0.25m)

Impact of changing inlet flow rate (2.3 vs 5.5\text{m}^3\text{s}^{-1})
Mesh independent predictions (for transient flows)

2.4 million cells

4.6 million cells

pink – 2.4M cells
orange – 4.6M cells
Summary of findings

- We have been able to use TLS to:
  - obtain accurate data of our modelling domain geometry
  - help validate hydraulic (CFD) models

- TLS provides a valuable source of high quality data for validating hydraulic models
  - where there is white-water and steady-flow conditions

- CFD is a viable tool for predicting complex flow where position of free surface of interest
Other applications areas...

Design of artificial surfacing waves (SPH)

Profile moved through a large man-made ‘lake’ to produce ‘surfable’ waves
Design of artificial surfacing waves (SPH)

Profile moved through a large man-made ‘lake’ to produce waves
Other applications areas...

Industrial flows

e.g. Design of irregular earth embankment spillways

-understand impact of ‘overtopping’ flow and related phenomena

-CFD/SPH suitable for complex geometries where location and depth of water, velocities, high stress areas are of interest
Other applications areas...

- understand impact of ‘overtopping’ flow and related phenomena

- CFD/SPH suitable for complex geometries where location and depth of water, velocities, high stress areas are of interest
Other applications areas...
Thank you

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Positions of Blocks

Weir at A (setup 1)

Blocks at D – setup 2 (left), setup 3 (right)
Validation data: 3D Free-surface heights

9 point clouds for different experiments

Position of hydraulic jump for $4\text{m}^3\text{s}^{-1}$ when increasing downstream weir height by 0.25m

Water surface for $4\text{m}^3\text{s}^{-1}$ and $8\text{m}^3\text{s}^{-1}$