Dam-break waves on a movable bed:  
A test case exploring different bed materials and an initial bed discontinuity.

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ABSTRACT

In view of going further than the previous “flat bed” test case explored within the framework of the EC-funded IMPACT project, we present a novel set of idealised dam-break experiments investigating a different set of initial conditions and bed materials. Whereas the previous tests considered a flat movable bed extending on both sides of the gate, the present set of initial conditions feature an initial discontinuity in the bed levels across the dam, with initially higher bed levels on the upstream side. The discontinuity is believed to affect significantly the behaviour of the flood wave. Two types of bed materials were investigated, with the objective of exploring the role of sediment density and grain size on the development of the wave and the intensity of geomorphic action. These tests were chosen within a larger database of experiments, with the purpose to serve as a basis for comparison among a range of numerical models developed by the respective IMPACT partners. As opposed to the first series, the tests were performed in a new flume specially designed for dam-break experiments, equipped with a thin gate rapidly pulled down by a pneumatic jack, with total opening times in the range of 0.1 second over the full available depth of 0.5 metre. We describe the set-up and test conditions in details, as well as the measured parameters obtained with fast digital cameras through the continuous glass side-wall. We outline the results that will be made available to the benchmark participants after the blind test phase, and we set up the common shape of expected outputs from the various modellers for inter-model comparison.

1 INTRODUCTION

The present note describes a series of idealised dam-break experiments carried out at the Civil Engineering laboratory of the Université catholique de Louvain. The tests constitute a second set of experimental data shared within the framework of the IMPACT project. Whereas the first series of tests were performed on a flat bed of artificial PVC particles (Spinewine & Zech, 2002), theses tests investigate the influence of differing initial conditions and bed materials. The bed levels show an initial discontinuity across the gate section, the upstream bed level being higher than its downstream counterpart. Two series of tests were carried out with different bed materials, namely sand and PVC pellets, differing both in grain sizes and density. For each series, several tests were performed with the cameras placed at differing viewing windows across the flume, so that the images pertaining to different runs may then be reassembled into large flow mosaics over a length of 4 metres.

As for the “flat bed” test case, the tests will again serve as a benchmark for validation and inter-comparison of the numerical models used by the research teams involved in the IMPACT project. Any external modeller willing to take part in the modelling exercise is welcomed to participate by contacting the authors to receive further guidelines.
The test case is described with more details in the next section. The two following sections describe the measurements that were performed, and highlight the guidelines of the benchmark including the expected results from the participants.

2 DESCRIPTION OF THE TEST CASE

Tests were performed in a new flume designed at the Civil Engineering Department (Fig. 1). The flume is 6 m long, 0.25 m wide and 0.7 m high, and was specifically designed for idealised dam-break experiments on movable beds. Breaking of the dam is simulated by the rapid downward movement of a gate at the middle of the flume, entrained by a pneumatic jack. Opening time in the order of 0.1 to 0.2 s is achieved over the full nominal height of 50 cm. The flume provides a series of substantial improvements compared with the previous flume used for the “flat bed” test case experiments, listed hereafter:

- It is equipped with a thin vertical gate simulating the idealised dam. As opposed to the “flat bed” test case experiments performed with an upward moving gate, the direction of movement was chosen here to provide better initial conditions, by avoiding the initial mobilisation of water and grains induced by friction along the rising gate, and the piping effect underneath the gate inducing strong vertical effects during its gradual opening. The downwards moving gate necessitated special care to insure watertightness at the bottom of the flume, while reducing at the maximum the friction that slows down the gate movement. The pneumatic jack inflated at a controlled pressure of 7 bars provides a much faster and reproducible movement, and shock absorbers avoid a rebound of the gate against the flume bottom.
- The gate was made thinner (6 mm) and lighter, by using a layered aluminium structure. This reduces the void volume left over inside the bed when the gate is removed.
- The available depth is 50 cm, while the previous tests were performed with 10 cm of water over a 6 cm bed layer.
- The upstream and downstream reaches extend both over a distance of 3 metres, hence the behaviour of the wave in the far field may be investigated, and among others the slow-down action of friction losses at the wave front.
- Continuous observation of the wave is possible through the 4-metre long glass wall, from 1 m upstream of the gate to the downstream end of the flume, with no vertical upright perturbing the view.
- By operating the flume in the inverse direction, the side walls along a reach of 2 metres may be displaced laterally to simulate a sudden channel enlargement, 1 metre downstream of the gate.

![Figure 1. Flume for idealised dam-break experiments. Left: upstream 3D view. Right: downstream photograph](image)

Two series of tests were performed with different bed material. The initial conditions for the two series of tests were identical, as summarised in Figure 2. The initial bed profile feature horizontal reaches upstream
and downstream, with an initial discontinuity at the gate section, so that the upstream level is initially $h_{s,0} = 10$ cm higher than the downstream level. In the upstream reservoir, an additional layer of 25 cm of pure water at rest is provided, so that the total head upstream is $h_0 = 35$ cm. This configuration provides a rough analogue to real reservoirs partially filled with sediments. Additionally, the discontinuity is believed to affect significantly the structure of the propagating wave and erosion pattern, a challenging aspect for the validation of predictive models. The upstream reach is ended by a wall while the downstream reach is closed partially by a weir whose crest level corresponds to the downstream sediment level, in such a way that the downstream water table is initially at the same level as the sediments, which are thus saturated in the initial conditions. Above this downstream weir the outlet is free.

![Figure 2. Initial conditions for the test case with a positive bed discontinuity across the gate.](image)

The two types of particles used as bed material were uniform coarse sand on the one hand, and light PVC pellets on the other hand. The materials further differed in density, grain size and shape. Estimated characteristic properties are summarised in Table 1. Roughness factor was obtained for the coarse sand in uniform flow experiments, leading to a Manning coefficient of $n = 0.0165$ s/m$^{1/3}$. The roughness coefficient for the PVC pellets has to be derived from the grain diameter and shape.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Symbol</th>
<th>Dimensions</th>
<th>Sand</th>
<th>PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific density</td>
<td>$\gamma_s$</td>
<td>[kN/m$^3$]</td>
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<td>15.5</td>
</tr>
<tr>
<td>Grain size</td>
<td>$d_{50}$</td>
<td>[mm]</td>
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<td>3.6</td>
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<td>Grain shape</td>
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<td>–</td>
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<td>Cylindrical</td>
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<tr>
<td>Porosity</td>
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<td>%</td>
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<td>42</td>
</tr>
<tr>
<td>Friction angle</td>
<td>$\phi'$</td>
<td>[°]</td>
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<td>38</td>
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<tr>
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<td>$c'$</td>
<td>[N/m$^2$]</td>
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<td>0</td>
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<tr>
<td>Permeability</td>
<td>$k_s$</td>
<td>[m/s]</td>
<td>0.0154</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

Table 1. Material properties.

### 3 DESCRIPTION OF THE MEASUREMENTS

Tests were conducted by first profiling the bed on the two sides of the gate. For the sand tests, the bed was compacted in a number of steps towards the Proctor optimum. Analysis of in-situ samples confirmed that the degree of compaction attained the value mentioned in Table 1. Tests carried out with uncompacted sand have shown to induce large bed instabilities in the form of antidunes, which were not the purpose of the study.
After profiling the bed, the upstream reservoir is filled to the desired level slowly enough, so as to reduce the amount of residual air pockets entrapped in the pores.

The gate is then released to initiate the dam-break wave. The pneumatic jack is equipped with a tie-rod cylinder, allowing to pressurise the upper chamber at the nominal pressure (7 bars) while the rod is still fixed. The release of the rod then occurs at the full pressure, providing maximal acceleration instantaneously. Figure 3 shows images corresponding to the release of the gate, where one may clearly see the nearly vertical wall of water left over when the gate is removed.

![Figure 3. Close-ups of initial stages during gate opening. Left: initial condition; middle: nearly unperturbed water body after gate removal; right: wave formation at a later instant.](image)

Instrumentation of the tests mainly involve digital imaging through the transparent side-wall, from one metre upstream of the flume to the downstream end. To guarantee a sufficient degree of detail with the limited resolution of the camera(s), the maximal viewing window covers 80 cm. Identical tests are hence repeated in successive steps by translating the camera(s) by multiples of 75 cm. The remaining 5 cm overlap between bordering frames are used to verify the reproducibility of the tests.

Images are acquired at a frequency of 200 Hz. Resolution of single images was $512 \times 256$ pixels for the sand tests (using two synchronised Dalsa CAD1 CCD cameras) and $1024 \times 512$ pixels for the PVC tests (using a single Dalsa 1M150 CMOS camera). Four halogen spots of 1000 W were required to provide sufficient front lighting and minimise the exposure time to avoid blurry images. A common reference frame for time was obtained by placing a pulsed flash light in the field of the image. The flash is triggered by a contact reed along the cylinder of the pneumatic jack.

The relevant flow interfaces are positioned by a semi-manual procedure on the images corresponding to multiples of 0.25 s. Interfaces between air and water on one hand, and between water and moving grains on the other hand, are located without ambiguity (Fig. 4).

![Figure 4. Detection of flow interfaces. Left: upper and intermediate boundaries are easily identified on individual images; Right: position of the bed interface enhanced by subtracting two successive images.](image)
The interface between moving and immobile grains, on the contrary, is more subtle and subject to interpretation. The moving region is first highlighted on a differentiated image created by subtracting the given image with the previous image. The static bed appears black while the moving layer of grains appears brighter on the image (Fig. 4). Identification of the interface is then obtained using the same semi-manual procedure as for the other two interfaces.

Particle tracking algorithms were also used to track the PVC pellets and obtain velocity fields and grain trajectories within the transport layer. The techniques could not be used successfully for the sand tests as the grains were substantially smaller and the camera resolution only $512 \times 256$ pixels.

For a subset of both series of tests however, neutrally-buoyant seeding particles were dispersed in the upstream water reservoir, as slightly visible on Figure 3. We used pliolite particles with diameters ranging from 1 to 2 mm. Tracking of those tracers with the same PTV algorithms as for the bed particles yielded full velocity fields in the pure water layer, allowing to investigate the vertical movements induced during the first stages of the dam-break wave, as well as the shape of the velocity profiles over the whole depth of the wave.

Finally, we measured the total amount of bed material transported by the dam-break wave and collected at the outlet of the flume. The sample was dried before being precisely weighted.

4 BENCHMARK DESCRIPTION

Based on the experiments described above, we propose the following model testing exercise to the participating modellers. The objective is to simulate the laboratory experiment for the two distinct bed materials. In particular, special attention will be paid to the speed of propagation of the wave, to the evolution of water levels and maximum attained flood levels along the flume, to the bed evolution in terms of transport, erosion and deposition, and to the most prominent characteristics of the wave structure: height of the wave front, presence of shocks and/or constant states, etc.

We propose the following guidelines:

1) The IMPACT team members taking part in the benchmarking process receive the description of the test-case as part of their implication in the IMPACT project. In addition, any interested modeller willing to take part in the exercise is invited to contact the authors to receive data and guidelines.

2) Any additional information regarding the flume, bed material or modus operandi of the tests may be requested if necessary.

3) The participants are invited to submit selected model outputs to B. Spinewine, no later than the 15th of September 2004. The extent and format of requested outputs is listed hereafter. Any additional “free style” results are welcomed and will be incorporated in the benchmark results, but will not be used for objective model inter-comparison.

4) Starting September 15th, and once model outputs have been received, the experimental data corresponding to the two series of tests will be provided to the participants for refining of their models and validation.

5) A joint communication will be produced with every output and description of models. A debriefing session might be held at the last IMPACT meeting in Zaragoza (4-5 November 2004) commenting on the lessons gained from the benchmark.
5 EXPECTED MODEL OUTPUTS

Model outputs should be prepared in the form of dimensionless graphs, based on the available head in the upstream reservoir $h_0$ ($h_0 = 35$ cm) and on Froude similarity. This procedure furnishes dimensionless variables for space ($x/h_0$, $z/h_0$), time ($t/t_0$ with $t_0 = \sqrt{h_0/g} = 0.189$ s), and velocities ($\sqrt{g h_0}$).

The following series of graphs are expected for both the sand and PVC tests. Data will also be provided in the form of tab-delimited text files.

- Snapshots of the flow, with the position of the relevant flow interfaces (water, transport layer, bed), prepared as dimensionless graphs of $z/h_0$ as a function of $x/h_0$, at selected dimensionless times $t = t_0 \times [1 2 3 4 5 6 8 10 12 14]$.
- The same snapshots scaled along an auto-similar reference frame, as graphs of $z/h_0$ as a function of $x/\left[ t(g h_0)^{1/2} \right]$, at the same selected dimensionless times.
- Time evolution profiles of water, transport layer and bed levels $z_w/h_0$, $z_s/h_0$, $z_b/h_0$ (see Fig. 5 for definition of the various levels) at selected dimensionless locations $x = h_0 \times [-2 -1 0 1 2 3 4 6 8 ]$, prepared as graphs of $z/h_0$ as a function of $t/t_0$.

Figure 5. Schematic definition of the parameters

- Characteristic path of relevant points of the wave structure, with at the minimum the position of the wave front $x_f$ and the position of the negative wave into the reservoir $x_b$, prepared as graphs of $t/t_0$ as a function of $x/h_0$. 
• The envelope of the maximum water levels attained along the flume during the whole duration of the flood wave, prepared as a graph of $z_{w, \text{max}}/h_0$ as a function of $x/h_0$.

• The envelope of the minimum bed levels attained along the flume during the whole duration of the flood wave, prepared as a graph of $z_{b, \text{min}}/h_0$ as a function of $x/h_0$.

• The cumulative mass of solid material collected at the outlet of the flume (3 m downstream from the gate), as a function of time.

6 REFERENCE TO BE USED

Test case participants who wish to use the data in their own future work or scientific publications will be welcome to do so. It will only be requested that they acknowledge the source of the data by citing the present document:

Spinewine B. and Zech Y. (2003). Dam-break waves on a movable bed : A test case exploring different bed materials and an initial bed discontinuity. CD-ROM Proceedings of the 3rd IMPACT Workshop (EU-funded research project on Investigation of Extreme Flood Processes and Uncertainty), UCL Louvain-la-Neuve, Belgium, 5-7 November 2003

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REFERENCES