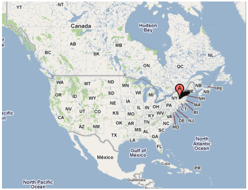
# Computer simulations and physical modelling of erosion

C.S. Stuetzle, J. Gross, Z. Chen, B. Cutler, **W.R. Franklin**, K. Perez & T. Zimmie

Rensselaer Polytechnic Institute
Troy, NY, USA




ICPMG, 29 June 2010

# A Collaborative project

National Science Foundation, Cyber Enabled Discovery and Innovation program CMMI-0835762.

- Civil Engineering:
  T Zimmie.
- Computer Graphics:
  B Cutler.
- Computational Geometry:
  WR Franklin.
- students:
  CS Stuetzle, J Gross, Z Chen, K Perez.


*Goal:* Journal papers in $\geq$ 2 disciplines.

# Problem and goals

Validation of Erosion Models for Levee Overtopping

Levee overtopped for several hours during Katrini

Dramatic gouging/scooping

- new representation for volumetric terrain, a.k.a. *soil*,
- better modeling of local erosion in terrain and earthen structures such as levees,
- experimental validation in the RPI geotechnical centrifuge,
- predictive reverse simulation of earthen levee erosion,
- visualization of non-homogeneous terrain erosion,
- out-of-core parallel simulation on large terrain datasets,
- collaboration in Brazil.

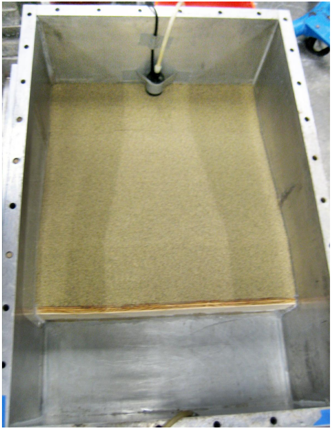
# Prior art: Civil engineering

- Erosion models
- Ecosystem models: IBIS, PALMS
- Soil loss: Hanson, Wang
- Erodibility: jet index, Monte Carlo, Hole/Soil erosion tests. Briaud.
- Usually well validated by field or lab tests.
- only *mass* erosion

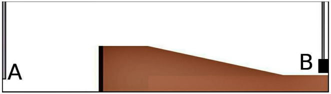
# Prior art: Computer graphics

- Physically-based erosion simulation w sediment transport: smoothed particle hydrodynamics (SPH). Navier-Stokes on voxel grid.
- Terrain development: layered height field, fractal terrain, erosion simulation
- realistic (or at least pretty), detailed, pictures
- but little validation

# Soil erosion test



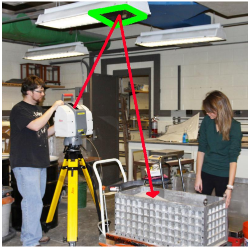
Model levee




Side view

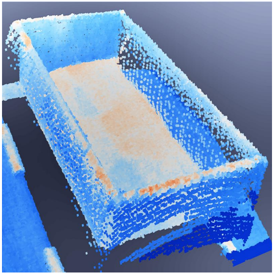
Rills

# Data collection



Scanner setup

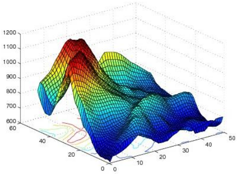
Closeup of tank



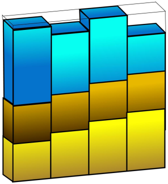
Dense grid of
scanner points

# Data structures

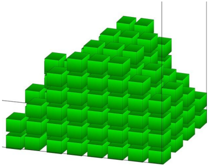
*Previous:*




Height field

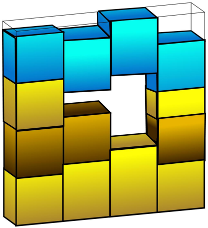


Layered height field

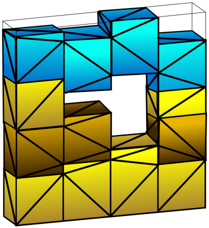


Voxel grid

*Us:*



Segmented height field



Segmented height field with tetrahedral mesh

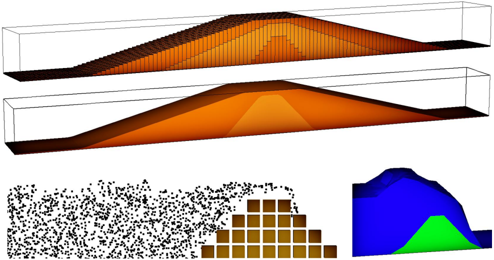
# To date

- model with homogeneous lifts of sand
- 1-g tests
- laser scanning
- data structure design and implementation
- importation of scan results into data structure
- initial visualization
- initial SPH model and simulations
- visit to Brazil

# Future

- multiple layers of soil.
- sand-clay mixtures, silts, layered materials.
- complete SPH model.
- geotechnical centrifuge.
- automated change detection.
- More info:

`http://www.cs.rpi.edu/research/groups/graphics/erosion/`



Preliminary simulation

Transcript of my ICPMG Zurich talk 29 June 2010 for the paper:

Computer simulations and physical modelling of erosion

C.S. Stuetzle, J. Gross, Z. Chen, B. Cutler, W.R. Franklin, K. Perez & T. Zimmie

-- 1

Good morning. RPI has various overlapping teams using our geotechnical centrifuge. I am part of one such project.

-- 2

Our work was motivated by the famous levee failures in New Orleans. It is funded by NSF as a very competitive interdisciplinary award intended to produce journal papers in at least two disciplines. We have people from Civil, CS, and Computer Engineering. I do computational cartography.

-- 3

Our niche is to study in detail how levees fail when water overtops them, flows down the back side, and forms ever larger gulleys.

The photos show a levee in New Orleans that was overtopped for several hours, suffered dramatic gouging, but survived.

Our various goals are as follows. They are in both civil engineering and Computer Science.

1st, we have designed and implemented a new representation for volumetric terrain, a.k.a. soil, which I'll describe in more detail later.

2nd, we are modeling more accurately local erosion in terrain and earthen structures such as levees. Rather than predicting only the quantity of soil removed, as a function of the soil type and water speed, we intend to model the type of gulleys and also use Navier-Stokes.

3rd, we intend to experimentally validate in the 200-g RPI geotechnical centrifuge.

4th, we are designing and implementing Hollywood-quality visualization of non-homogeneous terrain erosion.

5th, by scanning a failed levee, we intend to reverse simulate what happened.

6th, we will process large terrain datasets on supercomputers such as RPI's IBM Blue Gene.

7th, we have a collaboration with researchers in Brazil. Marcus Andrade from UF Vicosa visited RPI for a year, and I visited Brazil for a month last summer.

--- 4

There is considerable existing research in Civil Engineering on models of soil erosion. There are studies of soil erodability as a function of the soil type and water speed. There are also multilayer models of the biosphere. Considerable attention is paid to validating these models, either in the lab or in the field. However, it is the mostly the mass of the eroded soil that is modeled, not so much the details of how it happens.

--- 5

Computer Graphics has a different body of prior art. Here the emphasis is on realistic (or at least pretty) pictures of the details, as in the image shown here. There are various data structures to model terrain with several levels of different materials. Navier-Stokes is used to attempt to model the hydrodynamics. To assist in this, SPH (Smoothed Particle

Hydrodynamics) is used. This models the water with a small number of large virtual molecules. With more computer power, more and smaller molecules are used to increase the realism.

So, the computer graphics people produce photo-realistic images, as in the movie Perfect Storm. However they are not as concerned with accuracy or with validating in the real world.

We wish to combine these two disciplines.

--- 6

This shows our initial experimental setup. The model is about half a meter long. There is a half-levee with a wall. The levee itself is formed from multiple lifts of sand. Water is pumped in at point A and pumped out at point B. The photo on the right shows rills or small gulleys forming. While the precise details of rill formation are probably chaotic and not repeatable, we hope to discover some invariants of rill formation. They would remain valid across multiple experiments, but be more detailed than merely total quantity of soil removed.

--- 7

This shows more details of our experimental setup. The model levee is in the silver box in the left photo. The laser scanner is the white object on the yellow tripod. It was designed to scan the exterior of buildings, not small experimental setups. Neither the scanner nor the experiment can be tipped sideways, so we fixed a mirror, outlined in green, to the ceiling. The red line shows the laser path.

The middle photo shows a closeup of the experiment tank, with hand-drawn features in the sand.

The laser scanner's operating physical principle is the time of flight of the light beam. The right image is a typical point cloud produced by the scanner. The positional accuracy of the points is a few millimeters. Several scans can be combined to improve that (if the scans can be aligned).

Considerable work is required to transform that point cloud to a useful model of the soil. The points representing the sides of the tank must be removed and the remaining points registed to a standard coordinate system. Then the soil surface must be deduced by joining nearby points to form triangles. When the surface is uneven, that is harder than it sounds.

--- 8

We are proud of our new data structures. Previous representations have modeled only the surface of the soil, or at best, a fixed number of layers. The alternative to this was a voxel grid, which has limited vertical resolution.

We model the soil as an array of columns, and each column can have a different set of layers for different soil types, with each layer having smoothly varying parameters, such as moisture content. We can even model overhangs and voids in the soil. The most fundamental object in our representation is a tetrahedron. This allows us to model the slope of the soil surface accurately. That is required for the Navier-Stokes computations.

--- 9

We are incorporating new features into our experiments slowly and systematically, debugging our setup at each stage.

To date we have modeled a levee at 1-g, and laser-scanned it before and after erosion. Our data structure has been designed and implemented, with the scan results successfully being imported into it.  Preliminary visualizations are being produced.  We are computing initial simulations with the SPH model and Navier-Stokes.

I visited Marcus Andrade at UF Vicosa in Brazil last summer, and Marcus is visiting us again in 2 months.   Our collaboration with him is a starting as a related aspect, viz., terrain and hydrological modeling.

--- 10

However, a lot of work remains, listed here.  The images show a levee visualization and preliminary simulations using SPH of water overtopping the levee.

Check our public website for more information.

Thank you.