Combined Waves and Currents Over Gravel Mounds

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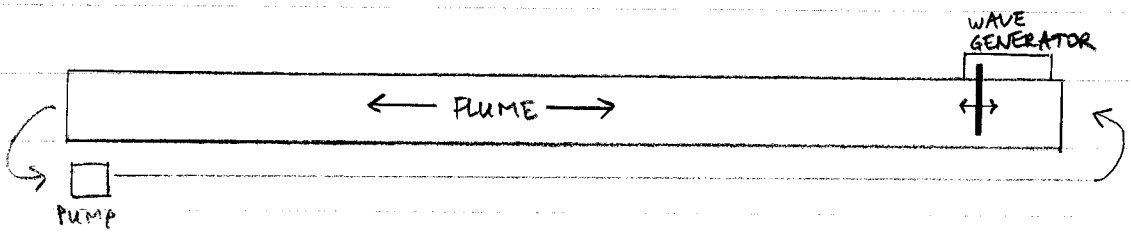
Preliminaries

Test Setup, Norwegian Hydraulics Lab
~25 meter wave flume
60 cm wide, 60 cm deep
Pump for current circulation
Automatic wave machine w/ active wave absorption



18/4/07
19/4/07 Learn Operational Basics

Computers:
Windows 2000 Machine for wave control, others
Windows 98 Machine for acoustic velocity sensor

Pump: 2 "ON" switches, brown knob controls prop speed

Wave Machine: "ON" on panel, green "ON" on remote
Control through software setting H, T, d.
See operations manual.

Test Plan w/ Prof. Tørum - see theor. notebook
- Map current vel. over flume cross-section and correlate prop. speed to current velocity.

- Prof Arntsen recommends wave reflection check
- Prof. Tørum recommends Test Matrix with groups for constant wave steepness

$s_{m0} = \frac{2\pi H_s}{g T_z^2}$

Test #	s_{m0}	H_s (cm)	T_z (s)	$\bar{u}$ (m/s)
1	0.06	7	0.85	0
2	0.06	10	1.0	0
3	0.06	13	1.2	0
4	0.04	7	1.1	0
5	0.04	10	1.3	0
6	0.04	13	1.5	0
7	0.04	13	1.5	0.1
8	0.04	13	1.5	0.3
9	0.04	13	1.5	0.5

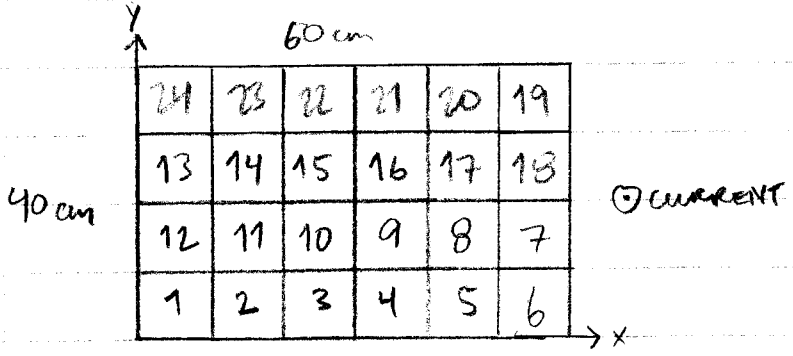
~3000 waves

Take intermediate steepness

20/4/07 - 21/4/07 Begin Velocity Measurements

Lower flume to 40 cm depth

Divide cross-section into 10 cm squares:



Recorded square 1 for 12 minutes

To extract velocity data:

Run... GETVEL(space)<input file>(space)<output file>

Data showed that any 5-minute average within data was within ± 0.5% overall average. Use 5 minutes for each test.

Note: Each velocity record is at center of grid square.

ie. Grid 2 measured at coordinate (15cm, 5cm).

For pump set at 5.0:

Grid	$\bar{u}$ (cm/s)	Grid	$\bar{u}$ (cm/s)
1	5.63, 4.85	15	5.41
2	5.31	16	5.92
3	5.21	17	5.98
4	5.22	18	5.75
5	4.92*, 5.23	19	5.44
6	5.06	20	5.40
7	5.97	21	5.25
8	6.05	22	6.19, 5.53
9	4.69, 4.52	23	5.27
10	6.00	24	5.02
11	5.88		
12	5.41		
13	5.72		
14	5.85		

* Effect of side of flume seems significant. Test repeated in same place but with ADV facing towards centerline.

2/4/07 Grain Size Distribution Test

Bowl + Sample: 1588.1 g

Bowl:

Sample:

Sieve Trays:

mm	No	Mass	Mass+Soil	Soil
6.30	1/4	528.8	531.4	
4.75	4	537.9	555.9	
4.00	5	464.1	503.7	
3.35	6	505.3	602.3	
2.80	7	491.0	644.8	see GSD.xls
2.36	8	494.2	702.1	
1.70	12	429.0	814.2	
1.18	16	446.7	663.3	
0.600	30	411.7	588.5	
0.300	50	381.4	489.0	
0.150	100	351.4	386.2	
0.075	200	348.0	358.3	
0	Tray	359.6	359.9	

24/4/07 Begin Velocity Check at ~10cm/s

Raise water level to 50 cm.
New "grid" cross-section of 30 squares:

25	26	27	28	29	30
24	23	22	21	20	19
13	14	15	16	17	18
12	11	10	9	8	7
1	2	3	4	5	6

⊙ CURRENT

For pump set at 10.0:

Grid #	U (cm/s)	Grid #	U (cm/s)
+ 1	9.77	+ 16	12.19
+ 2	10.22	+ 17	12.04
+ 3	10.22	+ 18	11.80
+ 4	10.02	19	8.52
+ 5	9.40	20	10.02
+ 6	9.42	21	10.39
+ 7	11.21	22	10.38
+ 8	11.59	23	10.17
+ 9	11.65	24	9.69
+ 10	11.65	25	9.86
+ 11	11.05	26	9,99
+ 12	10.25	27	10.04
13	9.19	28	10.16
14	9.95	29	9.50
15	10.23	30	7.98, 8.06

+ Recorded after installation of grate at pump outlet

25/4/07 Gustav installed a grate where current enters flume to minimize turbulence at high flow rates. Note that it may affect velocities.

Finished 10 cm/s check with grate. Records noted.

26/4/07 30 cm/s check, pump set at 26.0:
Same cross-section as 10 cm/s, 50 cm water depth

Grid #	U (cm/s)	Grid #	U (cm/s)
1	25.69	16	30.36
2	22.20	17	24.55
3	27.57	18	29.46
4	26.34	19	28.49
5	24.06	20	27.67
6	24.38	21	29.55
7	28.53	22	29.30
8	23.88	23	23.12, 28.36
9	29.39	24	28.71
10	29.22	25	26.17
11	24.87	26	N/A *
12	26.70	27	27.61
13	28.30	28	28.37
14	26.06	29	23.97 *
15	29.53	30	26.62

$8 \leq Sur 1 \leq 12$

* Greatly affected by noise, [illegible]ded to not include

27/4/07 50 cm/s check, pump set at 42.5
Same cross-section as 10, 30-cms, 50 cm depth

Grid #	U (cm/s)	Grid #	U (cm/s)
1	44.11	16	57.23
2	45.40	17	49.05
3	46.67	18	41.50
4	45.43	19	49.62
5	34.72*	20	50.23
6	41.44	21	57.12
7	48.67	22	50.61
8	46.05	23	43.67
9	50.79	24	49.57
10	49.77	25	48.96
11	47.74	26	43.39*
12	45.41	27	48.80
13	48.99	28	48.42
14	47.53	29	41.96*
15	50.44	30	45.97

Snr ≈ 14-16

*Large error in same locations as 30 cm/s tests

Anders Storler - electronics / laser scanner

>6.3 mm Grain Size Distribution

Sample + Bowl: 1528.7 g Bowl: 78.4 g

mm	No.	Mass	Mass + Soil	Soil
4.75	4	538.0	1573.0	
4.00	5	464.2	809.6	
3.35	6	505.3	619.8	
2.80	7	491.1	500.8	
0	Bowl	328.7	334.1	

30/4/07 Using GSD.xls, developed a plan to simulate Torum 1965
2/5/07 sand and scaled version of Conoco-Phillips:
→ 40% original sand, 40% larger gravel (<4.75 mm), and
20% filtered sand (<4 mm, > [illegible])

GSD Mixture:

Sample + Bowl: 1457.1 Bowl: 77.3 g
: 1298.5

mm	No.	Mass	Mass + Soil	
4.75	4	537.7	537.7	
4.00	5	464.1	628.7	759.2
3.35	6	505.3	775.9	854.2
2.80	7	490.9	620.8	627.0
2.36	8	495.6/494.2	682.4	653.6
1.70	12	429.0	797.2	650.2
1.18	16	446.7	598.0	496.5
0.60	30	412.0	477.9	420.3
0.30	50	381.6	404.7	382.7
0	Bowl	328.6		

3/5/07 Anders came and set up laser scanner
Gustav built track supports across flume.

Controlled by BASIC programs
- one for movement
- one for data collection

Near success, but transformer melted at end of day

4/5/07 Wait until Monday for new transformer
Built mounds in flume
Stone density test:

Stone + cup: 353.0 g
Cup: 3.6 g
Stone + cup + water: 436.5 g
Cup + water (full): 212.1 g

Stone density: 2.80 g/mL

8/5/07 Laser Collection:

- FILNAVN

  TEST1.TXT

- PRESS ENTER, SCANNING BEGINS
- MOVE BEAM FOR BACK-SCAN

Note naming scheme:

TEST 1A2 – 25
(a: Test number. A before, b after
b: Mound number. 2=2:1, 3=3:1
c: Profile number. 5=5,15; 25=25,35; 45=45,

Wave Gauge Calibration:

Length gauge 3: 26.5 cm
0: 35 cm
-5: adjust to 2.5 V
+5: -2.60 V

Length gauge 2: 35.5 cm
0: 35 cm
-5: adjust to 2.5 V
+5: -2.43 V

Length gauge 1: 35 cm
0: 25 cm
-5: adjust to 2.5 V
+5: -2.48 V

10/5/07 Begin first test - Test 1

~3000 irregular waves

$H_s = 0.07$ m, $T_z = 0.85$ sec, $\bar{u} = 0$ m/s

Approx. wave gauge locations:

Wave generator:	0.0 m
Gauge 1:	6.65 m
Gauge 2:	12.94 m
Gauge 3:	16.71 m
Begin beach:	22.26 m
Peak beach:	23.81 m

Beach raised so peak is approx. 2 cm above water level

Estimate reflection coefficient

- Sent series of regular waves for 30 sec, recorded for 2 minutes
- Amplitude 0.034 m measured, T = 1.2 sec
- After waves stopped, waves measured with amplitude 0.007 m, T = 1.2 sec. Assumed to be reflections
- $0.007 / 0.034 = \frac{A_r}{A_w} =$ **2.0% reflection coeff.**

JONSWAP Parameters

- To fit Torum's parameters $T_z = 1.46$ s, $T_p = 1.96$ sec
  $\gamma \equiv 1.4$
- $H_s = 0.07$ m, $T_p = 1.4$ s, $\gamma = 1.4$, $d = 0.5$ m

Record Orbital Velocities at both mounds
5 minutes record
- Test1_2 and Test1_3
Wave gauge data saved in folder Test1

Drain water from tank, measure with laser

No change in shape, but some smaller grains shifted to edges

Mounds not rebuilt, so laser measurements are same
TEST1B... = TEST2A...

11/5/07 Test 2
~5000 irregular waves
H_s = 0.10 m, T_z = 1.0 s, $\bar{U}$ = 0 cm/s, T_p = 1.35 s, γ = 1.4

Calibrate wave gauges
1: 2.46 V at +5 cm
2: 2.63 V at +5 cm
3: 2.34V at +5 cm

Had to reduce amplification factor from 1.28 to 1.13 because JONSWAP spectrum wouldn't fit w/in machine capacity

Some minor stone movement on 3:1 and 2:1 mnds. large waves
Just back and forth

12/5/07 Laser measurements, stones not moved
Test 2B = Test 3A

14/5/07 Test 3

$H_s = 13$ cm, $T_z = 1.2$ sec, $\bar{u} = 0$ cm/s, $T_p = 1.61$ sec

Wave gauges
1: 2.48 V at +5 cm
2: 2.53 V at +5
3: 2.40 V at +5

- Would not accept amplification factor of more than 1
- Rocks moved slightly under bigger waves
Wave generator appeared to travel to back of machine, then stopped. Perhaps specified waves too severe.

Test 4

$H_s = 7$ cm, $T_z = 1.1$ sec, $\bar{u} = 0$ cm/s, $T_p = 1.48$ sec

Wave gauges remain same

Clearly no change in rocks, no movement during test

15/5/07 Test 5

$H_s = 10cm$, $T_z = 1.3s$, $T_p = 1.75s$, $\bar{U} = 0 cm/s$

Wave gauges
1: 2.42 V
2: 2.57 V
3: 2.41 V

No movement noted, camera record first 30 min

Test 6

$H_s = 13cm$, $T_z = 1.34$, $T_p = 1.75s$, $\bar{U} = 0 cm/s$

Wave gauges same, period lower from wave machine (i.e. T_p)

Some smaller rocks swept off 1:3 mound
Quite a bit of back & forth movement

No change, no laser measurement
Camera record until tape empty (about 1 hr)

Test 8

H_s: 13 cm, T_z: 1.34 s, T_p: 1.75 s, $\bar{u}$ = 30 cm/s

Current set to 21.5 on power supply per formula

$$V = \frac{\bar{u}+1.1}{1.13}$$

Wave gauges unchanged, period again limited

Some rocks swept down off of mound, then swept back up by eddies.

Wavelengths increased significantly

Some sand in the system piled up behind stones due to current. May affect Profile 55 on 1:3 mound.

Alf Tørum recommended that since there was no significant shift even under the most severe waves the machine can generate, we should try smaller grains, approx. 0.002 m Ø.

Piles measured by laser one last time

3/5/07 New gravel prepared. D_{50}: 1.9mm, well graded

Mounds installed, measured by laser.

Second test matrix:

Test #	S_{m0}	H_s (cm)	T_z (s)	$\bar{U}$ (m/s)
10	0.06	7	0.85	0
11	0.06	10	1.03	0
12	0.06	13	1.17	0
13	0.04	7	1.06	0
14	0.04	10	1.26	0
[illegible]	0.04	[illegible]	44	0
16	0.04	13	1.44	0.1
17	0.04	13	1.44	0.3
18	0.04	13	1.44	0.5

Test 10

H_s = 7 cm, T_z = 0.85 s, T_1 = 1.1 sec, γ = 2.2, $\bar{U}$ = 0 cm/s

Wave gauges:

1: 2.55 V

2: 2.53 V

3 not working properly. Discard data.

No change after 3000 cycles.

No laser measurement.

21/5/07 Test 11

H_s = 10 cm, T_z = 1.03 sec, T_p = 1.34 sec, $\bar{u}$ = 0 cm/s

Amplification factor limited to 1.21, AWACS off

Wave gauges:

1: 2.96 V

2: 2.62 V

3: 2.42 V

Some back-and-forth movement on top during large waves. No net change.

Test 12

H_s = 13 cm, T_z = 1.17 sec, T_p = 1.52 sec, $\bar{u}$ = 0 cm/s

Amplification factor limited to 7, AWACS off.

Wave gauges unchanged

Back-and-forth movement on tops under large waves. No permanent deformation.

Test 13

H_s = 7 cm, T_z = 1.06 sec, T_p =

Amp. factor set back to 1.28
Wave gauges unchanged

No shifting of sand noted

Test 14
$H_s = 10$ cm, $T_z = 1.26$ s, $T_p = 1.64$ s, $\bar{u} = 0$ cm/s

Amp. factor reduced to 1 automatically
Wave gauges unchanged.

No motion noted

Test 15
$H_s = 13$ cm, $T_z = 1.44$ s, $T_p = 1.8$ s, $\bar{u} = 0$ cm/s

A.F. 1, Wave gauges unchanged

Significant movement of top stones under large waves, rounding seems to have occurred.

Tank drained, laser measurements taken

22/5/07 Test 16
$H_s = 13$ cm, $T_z = 1.44$ s, $T_p = 1.8$ s, $\bar{u} = 10$ cm/s ($V = 9.8$)

Mounds removed, laser measurements taken

Wave gauges	After current adjustment
1: 2.38	2.52
2: 2.59	2.30
3: 2.29 Discard	2.24

10 cm/s current started, all wave gauges dropped approx. 0.1 V. New calibration done.

A.F. set to 1.

Significant movement under large waves.

Drained and profile measurements performed.

23/5/07 Test 17

H_s = 13 cm, T_z = 1.44 s, T_p = 1.8 sec, $\bar{U}$ = 30 cm/s

V = 27.5. Wave gauges calibrated after speed attained.

1: 2.42
2: 2.60
3: 2.44

Est. averages. ±0.05 movement due to current

Significant movement of rocks noted immediately. Almost every wave sweeping away stones on 1:3. 1:2 has movement, but not so much swept away, perhaps due to undertow on lee side

Middle of channel more affected than sides

Current carried some sediment down the channel.

3:1 has significant damage.
2:1 has significant damage under location of Doppler velocimeter. Otherwise only rounding.

24/5/07 Water drained, laser measurements

Mounds effectively destroyed, rebuilt for next test

Test 18

Laser measurements on reconstructed mounds

25/5/07 V=45.2 Volts. As $\bar{u}$ increased, slight movement of stones at 30V (33 cm/s), then equilibrium reached. Increase to 40 cm/s, more stones move, no equilibrium

On increase to 50 cm/s, mounds rapidly destroyed. After 5 minutes, 1:3 mound exposed to pipe, 1:2 mound showed significant shifting

Waves not applied, laser measurements taken.

Mounds reconstructed

26/5/07 With test matrix complete, new test devised

Test 19

$H_s = 10$ cm, $T_z = 1.26$ s, $T_p = 1.59$ s, $\bar{u} = 30$ cm/s

Wave gauges

1: 2.47

2: 2.52

3: 4.17 Discard

Note that with 30 cm/s current apparently near the limit, most waves cause some slight movement of stones

Significant overall change of shape not apparent in either mound. Measured but not reshaped.

28/5/07 Test 20

$H_s = 11.5$ cm, $T_z = 1.35$ s, $T_p = 1.7$ s, $\bar{u} = 30$ cm/s

Wave gauges

1: 2.43

2: 2.62

3: 2.50

> Note that these fluctuate due to current.

Significant movement of stones in beginning

1:2 mound has back-and-forth movement on leeward slope, little on other 2 faces

Some change in shape noted.
1:2 mound appears to have added material to the top from the leeward face, indicating significant overtopping. Also, many stones have moved downstream.
1:3 mound seems relatively undamaged.

Tank drained, measurements taken.

29/5/07 Mounds reshaped, tank filled

Test 21
H_s: 13 cm, T_z: 1.44 s, T_p: 1.8 s $\bar{U}$: 20 cm/s
Maximum waves with slightly lower current than test 17, which caused significant damage.

Wave gauges
1: 2.50
2: 2.57
3: 2.42

Significant movement of stones, especially under larger waves. Rounding seen.

Drained, measurements taken, mounds not reshaped.

30/5/07 Test 22

H_s: 10 cm, T_z: 1.77, T_p: 2.30, $\bar{U}$: 30 cm/s

Wave gauges
1: 2.5m
2: 2.5m
3: 2.3m

Movement immediate, 1:2 mound has loss of stones again, rain tank

31/5/07 Laser measurements

End primary test phase, begin data analysis