A curved flume bed-load experiment.

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part of:
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Faculty of Civil Engineering
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SUMMARY

In this report the results of a bed-load experiment in a curved flume are presented. The experiments have been carried out in the Laboratory of Fluid Mechanics (L.F.M.) at the Delft University of Technology. The main object of the experiments is to develop and to test data-acquisition procedures for future suspended-load experiments. At the same time data were acquired which apply to the case of bed-load only. In this report the experimental data are presented. The bed-topography in the bend shows an harmonic oscillation of the lateral bed-slope. The reported results apply to the stationary bed topography under steady flow conditions.
LIST OF FIGURES

1. Layout, Laboratory of Fluid Mechanics curved flume
2. Sieve curve of bed material
3. Velocity measurements 15 mm below water level
4. Contour lines of the relative water depth a/a₀
5. Water depth in cross-direction
6. Longitudinal profile of the water depth

LIST OF SYMBOLS

\( a \) water depth
\( a₀ \) mean water depth of cross-section \( l \)
\( W \) width of the flume
\( C \) Chézy coefficient; \( C = \bar{u}/\sqrt{a₀i} \)
\( D_{s₀} \) median grain size
\( Fr \) Froude number
\( i \) water surface slope
\( L_c \) arc length of the bend
\( Q \) discharge
\( R_c \) radius of curvature of axis of flume
\( \bar{u} \) depth averaged mean flow velocity
\( \theta \) Shields number; \( \theta = a₀i/(\Delta D_{s₀}) \)
\( \Delta \) relative density of the sediment; \( \Delta = 1.65 \)
1. **Introduction**

A mathematical river bend model has been developed, Olesen 1987, in which the type of sediment transport was limited to bed-load only. The project at hand is directed towards the extension of this model by including suspended-load also. To this purpose laboratory experiments are necessary. To develop and to test data-acquisition procedures, which will be used in future suspended-load experiments, a bed-load experiment has been performed. The results of this experiment can be used to verify the existing model.

This research is a part of the project: 'River bend morphology with suspended sediment', project no. DCT55.0842. The project is supported by the Netherlands Technology Foundation (STW).
2. **Model features**

The layout of the L.F.M. curved flume is shown in figure 1. Water is pumped from an underground basin to an elevated head tank and led to the model. The water discharge is controlled by a valve in the supply circuit and is measured using an orifice plate. After passing the weir at the end of the flume, by which the water level is adjusted, the water pours into a settling reservoir. After passing this reservoir the water flows back into the underground basin.

The dimensions of the flume are:

- **inflow section length**: 11.00 m
- **outflow section length**: 6.70 m
- **arc length of the bend**: \( \text{L}_c = 12.88 \text{ m} \)
- **radius of the bend**: \( \text{R}_c = 4.10 \text{ m} \)
- **width of the flume**: \( \text{W} = 0.50 \text{ m} \)
- **depth of the flume**: \( \text{H} = 0.30 \text{ m} \)

The bottom of the flume is made of glass and the side walls are made of perspex.

The flume is filled up with sand. The height of the sand bed at the entrance of the flume is about 0.1 m, at the exit the bed height is about 0.06 m. The sieve curve of the sand is given in figure 2. The sand is supplied to the model 2 m downstream of the entrance of the flume. The supply is effected by a constant discharge of dry sand from small holes in the bottom of a container. The sand discharge is measured every day.

The sand settled down in the settling reservoir is gathered every day and weighted under water. The results are converted to equivalent weights of dry sand. The amounts of sand supplied and gathered from the settling reservoir are compared.

The water surface slope in longitudinal direction is measured every day. After about 450 hours of flow, to establish equilibrium conditions, the measurements of the bed topography have been started. At that stage no significant changes of the water surface slope and differences between in and outflow of sand were measured. It is thus assumed that an equilibrium state has been reached.
The measurements of the bottom and water level are performed with an electronic indicator (PROVO). This device is traversed in cross-sectional direction. In each cross-section 9 equidistant measuring points are used. The carriage in which the PROVO is mounted is also traversed in longitudinal direction. In longitudinal direction 49 cross-sections are situated, they are indicated in figure 4. The distance between these cross-sections at the flume axis is 0.32 m. The profile indicator is continuously moved in cross-sectional direction, this is achieved by specially developed electronic hardware. The position of the profile indicator is measured electronically. The carriage is moved by hand in longitudinal direction.

In one measuring session the water level and the bottom topography of the 49 cross-sections were measured. The data were digitized and stored at a local data-acquisition system which uses a HP 1000 mini computer. Next, the data are processed by a central main frame IBM computer of the Delft University.
3. Results

From a theoretical point of view the choice of model parameters was influenced by the following arguments:
The sediment transport rate in the whole channel should be sufficient to prevent locations with no transport at all. Such locations are not modelled in the morphological model, and therefore should be avoided. A large width/depth ratio is desired to correspond with the validity of the flow model and realistic prototype conditions.

From a practical point of view the flow conditions are controlled by; the volume flux of water, the mass flux of sediment and the height of the weir at the downstream end of the flume. Also a minimal water depth of 0.02 m at the inner side of the bend is desired in order to be able to use the PROVO at these locations.

By careful adjustment of controls an equilibrium state has been reached.

3.1 Relevant experimental parameters

The flow conditions of the equilibrium state are a compromise between the theoretical and practical considerations. The condition of sufficient transport was judged by eye. The width/depth ratio was chosen such that the PROVO could be used at nearly all locations in the flume. Only at the location of the point-bar the PROVO could not be used.

The relevant parameters of the experiment are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0$</td>
<td>[m]</td>
<td>0.07</td>
</tr>
<tr>
<td>$Q$</td>
<td>[$m^3/s$]</td>
<td>0.0115</td>
</tr>
<tr>
<td>$W$</td>
<td>[m]</td>
<td>0.5</td>
</tr>
<tr>
<td>$\bar{u}$</td>
<td>[m/s]</td>
<td>0.32</td>
</tr>
<tr>
<td>$i$</td>
<td>[-]</td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>$D_{50}$</td>
<td>[mm]</td>
<td>0.780</td>
</tr>
<tr>
<td>$W/a_0$</td>
<td>[-]</td>
<td>7.14</td>
</tr>
<tr>
<td>$a_0/R_c$</td>
<td>[-]</td>
<td>0.018</td>
</tr>
<tr>
<td>$C$</td>
<td>[$m^{0.5}/s$]</td>
<td>39</td>
</tr>
</tbody>
</table>
Although no locations with absence of sediment transport were seen, it should be realized that the overall Shields number is close to initiation of motion of the sediment. The critical value is $\theta_{\text{crit}} = 0.047$.

### 3.2 Flow velocities

Also a few velocity measurements are carried out to check the magnitude of the flow velocities. The measurements are taken 15 mm below water level at the beginning of the bend where the bed topography is almost smooth.

The relative flow velocity $u/u_{\text{inflow}}$ is shown in figure 3.

### 3.3 Bed topography

The bed topography has been obtained by ensemble averaging of 18 independent measuring sessions. Each session consists of 49 cross-sectional traverses. Within a cross-section 9 measuring points are used. By ensemble averaging the stationary part of the bend is determined. The bed topography is shown in the figures 4 - 6.

Figure 4 shows the ensemble averaged contour line map of the relative water depth. (normalized with the mean water depth of cross-section 1) The contour lines are drawn at intervals of $\Delta a/a_0 = 0.2$.

The figures 5A-L show the ensemble mean relative water depths of each cross-section. At each measuring point the $\sigma$ interval is also indicated. These intervals are based on 18 data points.

Figure 6 shows three longitudinal profiles of the relative water depth, one left and one right of the axis at a distance of 0.3W from the side walls and one along the axis of the flume.

At the bend entrance the bed is relatively smooth, downstream of traverse 15, approximately, the bed consists of elongated undulations ($\approx 1$ a 1.5 m length, $\approx 0.05$ m height at crest.) moving downstream, which resemble the alternating bar type but are only present in the outer part of the bend.
Figures 5 and 6 show that at the bend entrance the bed is nearly horizontal. The bed topography displays a pronounced harmonic oscillation of the lateral bed-slope. In the 180° bend one point-bar at traverse 12 and three pools at traverses 12, 26 and 39 are present, see figure 4.

4.0 Conclusions

Ensemble mean water depths of a curved flume bed-load experiment have been determined. Also some velocity data have been obtained. The experiment is characterized by a Shields number near initiation of sediment motion. Consequently the bed at the entrance of the bend is relatively smooth. In the bend large bed forms develop which resemble the alternating bar type. By ensemble averaging the stationary part of the bed topography is determined. The topography displays a harmonic oscillation of the transverse bed-slope. The numerical computation of the experiment by the bed-load model of Olesen is beyond the scope of this report and will be reported separately.

References

Olesen, K.W. 1987
Bed topography in shallow river bends
also as: Communications on Hydraulics and Geotechnical Engineering 87-1, Dept. Civil Engrg., Delft Univ.


**Appendix A: Ensemble averaged water depths.**

In this appendix the ensemble averaged relative water depths of the 18 measurements are tabulated.

Discharge \(0.0115 \text{ m}^3/\text{s}\)  
Sediment transport 2.3 kg/h dry sand.

from relative mean water depth \(a/a_0\) \(a_0 = 0.07 \text{ m}\)  
inner side of bend CS01 CS02 CS03 CS04 CS05 CS06 CS07  
0.05 0.90 0.88 0.91 0.91 0.91 0.90 0.81  
0.10 0.97 0.92 0.96 0.97 0.97 0.97 0.90  
0.15 1.01 0.95 0.98 1.00 1.01 1.01 0.97  
0.20 0.99 0.94 0.98 0.97 1.00 0.99 0.98  
0.25 1.02 0.97 1.02 1.00 1.01 1.01 0.98  
0.30 1.03 1.00 1.03 1.01 1.02 1.02 1.02  
0.35 1.01 0.97 1.00 0.99 1.00 1.00 1.00  
0.40 1.02 0.99 1.02 1.01 1.02 1.03 1.08  
0.45 1.03 0.99 1.00 1.00 1.01 1.02 1.02  

from relative mean water depth \(a/a_0\) \(a_0 = 0.07 \text{ m}\)  
inner side of bend CS08 CS09 CS10 CS11 CS12 CS13 CS14  
0.05 0.70 0.58 0.49 .29* .29* .29* .60  
0.10 0.78 0.68 0.58 .29* .29* .29* .78  
0.15 0.88 0.79 0.67 .29* .29* .29* .81  
0.20 0.93 0.90 0.80 .64 .54 .57 .80  
0.25 0.93 0.94 0.89 .75 .70 .89 .95  
0.30 1.00 1.02 .96 .88 1.08 1.27 1.24  
0.35 1.05 1.11 1.13 1.26 1.57 1.64 1.55  
0.40 1.17 1.29 1.50 1.77 1.98 1.95 1.80  
0.45 1.31 1.58 1.89 2.10 2.23 2.14 1.95
Discharge: 0.0115 m³/s  Sediment transport: 2.3 kg/h dry sand.

<table>
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<td>0.78</td>
<td>0.77</td>
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<td>0.20</td>
<td>0.94</td>
<td>0.84</td>
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<tr>
<td></td>
<td>0.25</td>
<td>1.01</td>
<td>0.93</td>
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<tr>
<td></td>
<td>0.30</td>
<td>1.13</td>
<td>1.03</td>
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<tr>
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<td>1.34</td>
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<td>0.45</td>
<td>1.69</td>
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<table>
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<td>0.35</td>
<td>1.20</td>
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<td>1.39</td>
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<td>0.45</td>
<td>1.55</td>
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Discharge 0.0115 m³/s  Sediment transport 2.3 kg/h dry sand.

<table>
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<th>inner side of bend</th>
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<th>( a/a_0 )</th>
<th>( a_0 = 0.07 ) m.</th>
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<td>1.33</td>
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<td>0.40</td>
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<td>1.36</td>
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<td>1.70</td>
<td>1.46</td>
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<tr>
<th>inner side of bend</th>
<th>relative mean water depth</th>
<th>( a/a_0 )</th>
<th>( a_0 = 0.07 ) m.</th>
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<td>0.57</td>
<td>0.53</td>
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<td>0.59</td>
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<td>0.15</td>
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<td>0.95</td>
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<td>1.06</td>
<td>1.10</td>
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<td>1.46</td>
<td>1.62</td>
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Discharge: 0.015 m³/s  Sediment transport: 2.3 kg/h dry sand.

<table>
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<th>$a_0 = 0.07$ m</th>
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<td>.78</td>
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<td>1.01</td>
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<td>CS48</td>
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FIG. 1

LAYOUT, LFM CURVED FLUME

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SIEVE CURVE OF BED MATERIAL

FIG. 2

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MODEL OF RIVER BEND  
BED LOAD TRANSPORT
VELOCITY MEASUREMENTS 15 mm. below waterlevel

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FIG. 3
CONTOUR LINES OF RELATIVE WATER DEPTH A/A₀
AT INTERVALS OF A/A₀ = 0.2
WATER DEPTH AT BEND ENTRANCE A₀ = 0.07 M

FLOW

MODEL OF RIVER BEND, BED-LOAD EXPERIMENT
ENSEMBLE MEAN OF 18 LONGITUDINAL TRAVERSERS

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FIG. 4
WATER DEPTH IN CROSS-DIRECTION

W = 0.5 M \quad AO = 0.07 M

± σ of 18 measurements

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FIG. 5A
CROSS-SECTION 5

CROSS-SECTION 6

CROSS-SECTION 7

CROSS-SECTION 8

W = 0.5 M  \( \Delta = 0.07 M \)

WATER DEPTH IN CROSS-DIRECTION

\( \pm \sigma \) of 18 measurements

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FIG. 5B
CROSS-SECTION 9

CROSS-SECTION 10

CROSS-SECTION 11

CROSS-SECTION 12

W = 0.5 M  \( R_0 = 0.07 M \)

\[ \pm \sigma \text{ of 18 measurements} \]

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5C
CROSS-SECTION 13

CROSS-SECTION 14

CROSS-SECTION 15

CROSS-SECTION 16

W = 0.5 M   AQ = 0.07 M

± s of 18 measurements

WATER DEPTH IN CROSS-DIRECTION

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W = 0.5 M  
AO = 0.07 M

\[ \pm \sigma \text{ of 18 measurements} \]

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5E
W = 0.5 M \quad A_0 = 0.07 M

\pm \sigma \text{ of 18 measurements}

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5 F
CROSS-SECTION 25
CROSS-SECTION 26

CROSS-SECTION 27
CROSS-SECTION 28

W = 0.5 M    AO = 0.07 M

± s of 18 measurements

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5G
WATER DEPTH IN CROSS-DIRECTION

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CROSS-SECTION 37

CROSS-SECTION 38

CROSS-SECTION 39

CROSS-SECTION 40

W = 0.5 M  AO = 0.07 M

± 6 of 18 measurements

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5J
W = 0.5 M    AO = 0.07 M

WATER DEPTH IN CROSS-DIRECTION

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FIG. 5K
W = 0.5 M  AO = 0.07M

WATER DEPTH IN CROSS-DIRECTION

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FIG 5 L
LONGITUDINAL PROFILE OF THE WATER DEPTH

W = 0.5 M  \( a_0 = 0.07 \) M

FIG. 6

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