MODEL INVESTIGATIONS INTO THE INFLUENCE OF CONSTRUCTIONAL ELEMENTS ON SEDIMENT TRANSPORT

W. Bechteler, H.-J. Vollmers, S. Wieprecht
Institut für Wasserwesen
Universität der Bundeswehr München

1. Introduction

1.1 General Remarks

Most natural rivers are in a sensitive state of hydraulic-sedimentological balance, which is defined by mutual influences of water and solids. Lowland rivers show in general a "continuous" transport behaviour throughout the year. Depending on the discharge, more or less material is being transported.

In the case of alpine rivers the transport behaviour is characterized by different factors of influence. As the bed material consists of rather coarse grain diameters bed load transport will only start at higher bed shear velocities. In order to set the bed material into motion high discharges are necessary, i.e. only flood events are actual transport events. Up to 80 or 90 % of the total annual transport volume may be transported in the course of a single flood wave.

1.2 Problem Description

Recently the attempt has been made to renaturalize the last section of the Weissach River before it flows into Lake Tegernsee. This part had been previously regulated in a schematic monotonous way. During the last flood period an agglomeration of sediment has occurred, which may provoke an overtopping of the dams. In a hydraulic model with movable bed (scale 1:20) the existing conditions and possible improvements were studied in order to prevent agglomerations. Furthermore fundamental investigations were made about the influence of obstructions on sediment transport and water levels.

2. Similarity Considerations

2.1 General Remarks

Up to the present day physical models (in the meantime extended to mathematical ones) are part of the hydraulic engineer's standard tools in answering practical questions. Hydraulic models with movable bed belong to the highest category of difficulties and can only be successfully operated in laboratories with excellent equipment and big experience. One of the problems is the conversion of model test results into natural values and vice versa. The creation of similarity between nature and model is time-consuming and physically not exactly feasible. Finally it has to be pointed out that the major part of the present knowledge about sediment transport comes from investigations performed on simplified physical models.

2.2 Model Similarity

The movable bed physical model of the Weissach River was built at a geometric scale of 1 : 20 in the hydromechanics laboratory of the Federal Armed Forces University Munich at Neubiberg. All geometric and hydraulic values were calculated according to FROUDE's similarity law, which means that processes dominated by gravitation and inertia are represented similarly in nature and model.

The choice of the model sand was guided by the idea to keep the part of the suspended material as low as possible, because the geometrical reduction would have contradicted natural conditions. Therefore an almost uniform sand was selected, the mean diameter

($d_m \approx d_{65} \approx 0.85$ mm) of which corresponds well with the geometric reduction of the d_m-value of the natural bed material ($d_m = 14.3$ mm).

3. Model Set-up

3.1 Model Description

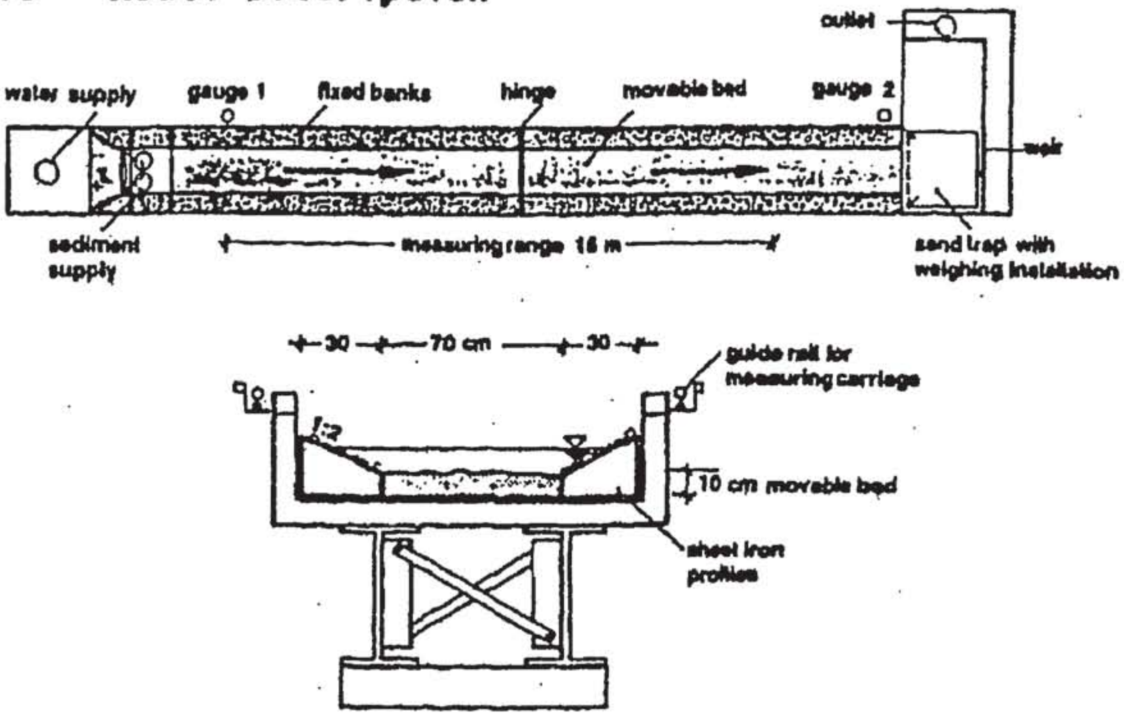

Fig. 1: Schematic cross-section and plan view of the model

The model consists of two equally long sections that are connected by a hinge. It is supported by two I-shaped steel girders, the elevation of which can be adjusted to any slope desired for different investigations. The simplified trapezoidal cross-section of the river has been placed into the frame of a rectangular cross-section. The lateral embankments are made of sheet iron. Roughness is simulated by coarse sands glued onto the surface. A bed material ground layer of 10 cm thickness prevents the ground plate from being washed free in erosion ranges. Two circular metal rods, one on each side of the flume, serve as rails for the measuring carriage. Fig. 1

shows a model cross-section and a plan view of the model.

3.2 Operating and Measuring Installations

The water supply for the model comes out of an elevated reservoir. Discharge regulation is controlled by an inductive flowmeter. Both are connected to the computer. At the model outlet the water pours down into a basement reservoir where it is pumped back into the elevated supply reservoir. The water level at the model outlet is controlled by a nearby gauge and may be adjusted by an overflow plate. A second gauge is installed at the beginning of the measuring range, about 5 m away from the inflow and the sand supply. Measuring instruments are so-called vibrating water level followers (Delft) with an accuracy of ±0.5 to 1 mm.

For the assessment of river bottom changes longitudinal profiles were registered both before and after a test. Registration was performed using a Delft profile follower with a vertical adjustment velocity of up to 50 cm/s and an accuracy of ±1 to 1.5 mm.

The input comes as a sand-water-mixture out of a plexiglass tube with a vertical slot, which is opened at a constant predefined speed and thus provides a constant inflow of material per unit of time. The collection device (sand trap) at the model outlet is a balance pan suspended from a pressure/strain transducer. At certain variable time intervals signals are transmitted to the computer.

4. Model Tests and Results

4.1 Tests without Constructional Elements

Tests without constructional elements served as the basis of comparison with the others that were to be performed later on and to contain different variations. At the beginning tests with constant discharges provided a transport-discharge relation. They have been executed for three different slopes (S_I = 0.002, S_{II} = 0.004 and S_{III} = 0.006). In order to allow systematic comparisons regarding the sediment transport, the transport rates obtained in the calibration tests were used as input rates for the tests with constructional elements.

4.2 Tests with Constructional Elements

4.2.1 Test Programme and Performance

The test programme comprised investigations of ten series of different arrangements of constructional elements, each of which was to be tested for three discharges (Q = 10 l/s, 20 l/s, 40 l/s), three slopes (S = 0.002, 0.004, 0.006) and one characteristic grain diameter (d_{ch} = 0.85 mm). Fig. 2 presents all variations of arrangements of constructional elements schematically in plan view and cross-sectional elevation (series I through X).

As actual construction works use boulders of about 1 m side length, all constructional elements were modelled using stones of 5 to 6 cm diameter, which corresponds to the 1 : 20 scale. Boulders and groynes are put directly upon the movable bed, whereas levelled and elevated ground sills are placed on the fixed solid ground plate, which lies 10 cm lower. Thus it can be checked whether some of the elements change their positions owing to erosion and scouring.

The execution of a test is similar with and without arranging constructional elements. Bed profiles were registered before the test after levelling the flume bed and after test execution. Comparing both regis-

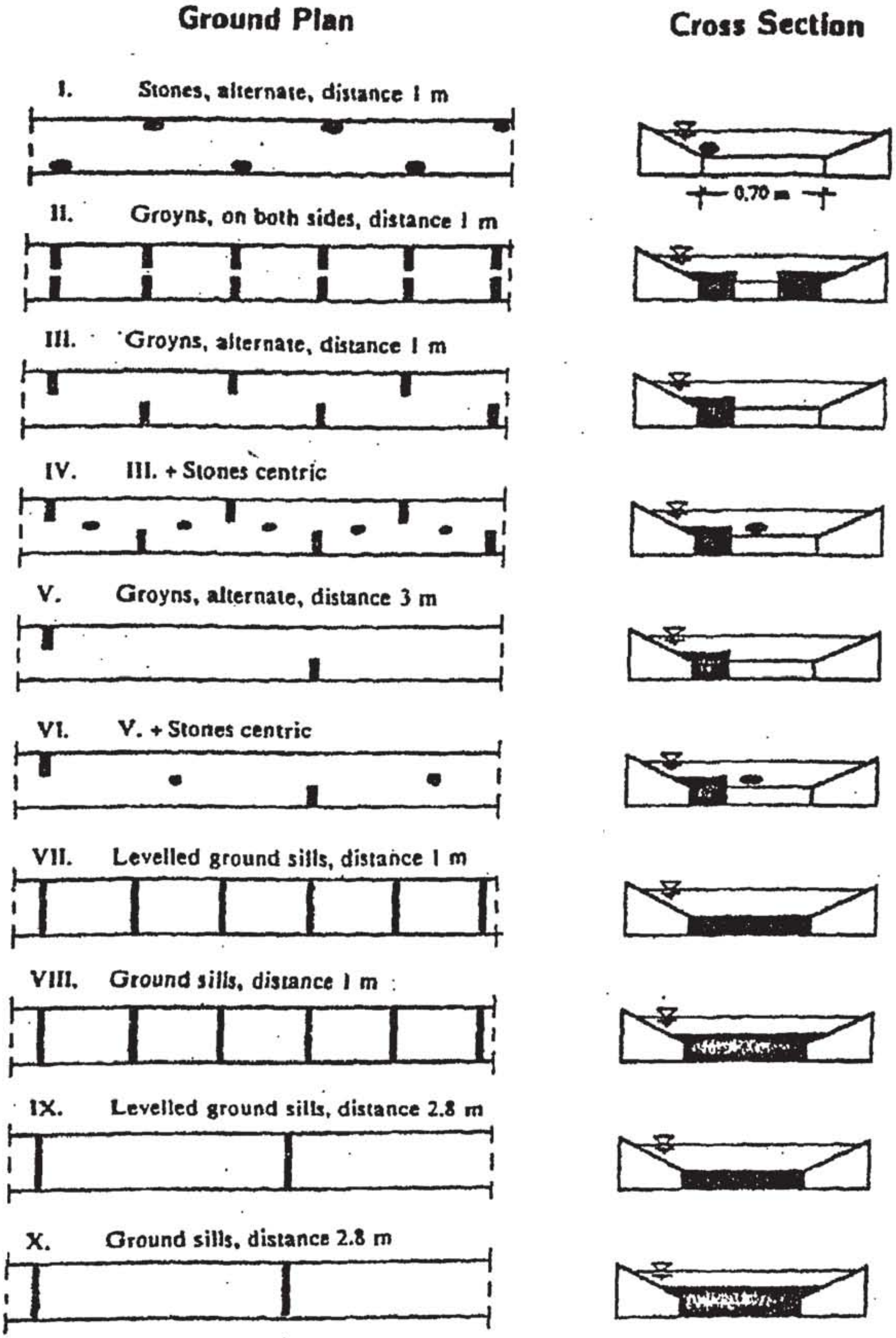

Fig. 2: Plan view and cross-section of different constructional measures (schematic)

trations allows the assessment of bottom changes. Their differences show where erosion or sedimentation, occurred in the 16 m measuring range. Every minute the discharge, the two water level gauges and the sediment transport are recorded and printed in a data sheet.

4.2.2 Test Evaluation

The comparison of test series results was made possible by introducing a number characterizing the degree of obstruction caused by the constructional elements. As these elements have different distances the degree of obstruction was calculated to be the ratio of "obstructed volume" to "unobstructed volume". Reference length is one metre.

Thus levelled ground sills have an obstructional degree of 0 %, as their crests are at an even level with the bottom elevation, and therefore do not obstruct the cross-sectional area at all.

In all performed tests you can find the same systematic tendency. Water levels increase with an increasing degree of obstruction. Fig. 3 show the results from test with a slope $S_{II} = 0.004$. Measurement points in the diagram are connected by a polygonal line. The second degree fitting curves demonstrate the systematic tendency of the measurements. They are not meant to serve as calibration curves for the relation between degree of obstruction and water depth.

Flow depths served to compute velocities and FROUDE numbers as well as MANNING-STRICKLER coefficients. For increasing degrees of obstruction there is a constant decrease of roughness coefficients, velocities, and FROUDE numbers. This tendency can be recognized for more or less all values calculated.

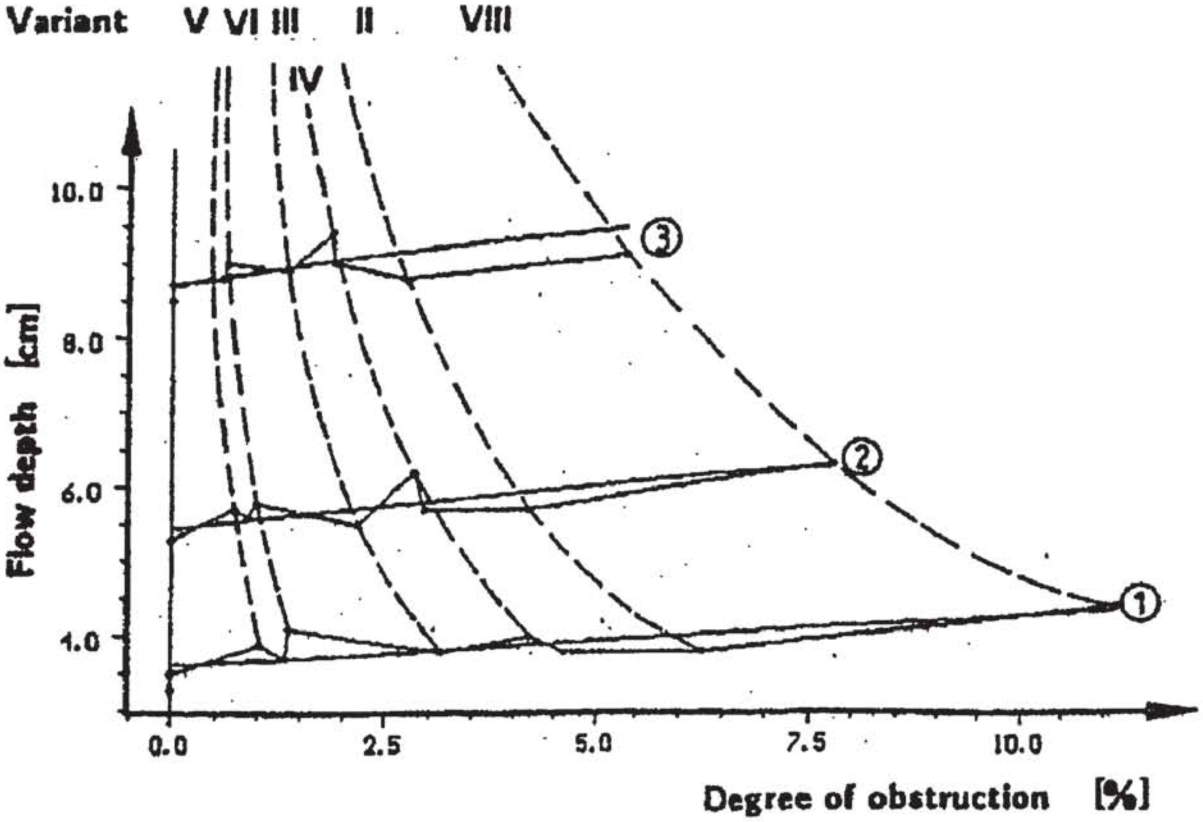

Fig. 3: Changes of flow depths versus degree of obstruction and corresponding fitting curves for slope $S_{II} = 0.004$ and discharges Q = 10 l/s (1), Q = 20 l/s (2) and Q = 40 l/s (3)

Contrary to tests with fixed bottom and constant roughness, k_{St}-values do not increase but rather decrease with rising discharge and water level. Flume roughness grows for greater discharges due to bed form shaping. As flow depths are altogether rather low, i.e. between 3 and 11 cm, bed forms have a great influence on roughness. This influence was reduced by increasing water depths.

Changes of transport behaviour are strongly dependent on slope. A slope of 0.002 does not show any transport changes. For Q = 10 l/s and 20 l/s no transport at all takes place, as is the case without constructional elements. For Q = 40 l/s transport corresponds, within measuring tolerances, to an input rate of 7.5 g/s.

In Fig. 4 the transport behaviour is shown in relation to the degree of obstruction for the tests with a slope of 0.004. For all three discharges the transport oscillated, within measuring tolerances, around the supply values. The exception from the rule is given by series VIII, the one with the greatest obstructional degree. All tests show transport values clearly below the ones found at the beginning in the initial test series.

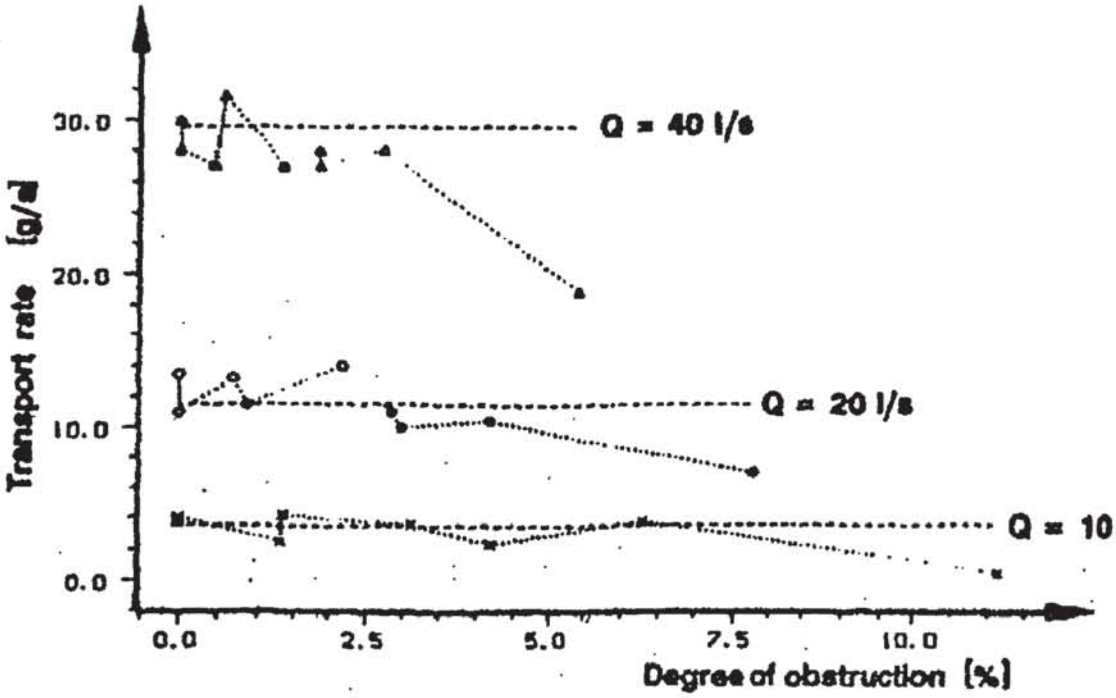

Fig. 4: Transport rates versus degree of obstruction for slope $S_{II} = 0.004$

A slope of 0.006 does not show any difference in transport rate for all three discharges. With a measuring tolerance of 10 % you can measure the input-rates of 10, 21 and 60 g/s in the sediment trap at the model outlet for Q = 10 l/s, 20 l/s and 40 l/s.

5. Conclusion

Calculation procedures already exist to deal with overgrown cross- sections (DVWK, Merkblatt 220). The influence of constructional elements, however, still cannot be described exactly. First investigations on changes of transport capacity have been performed (DVWK, Mitt. 25).

In all test series the same systematic development could be observed. With an increase in the degree of obstruction the water depths also increased, and velocities, FROUDE numbers and roughness coefficients decreased. The results of the investigations on the transport capacity differ considerably. For the slope of 0.002 it is hardly possible to make any satisfying statement owing to the late start of transport at discharges of $Q > 20$ l/s. In the case of $S_{II} = 0.004$ the influence of constructional elements was visible for high degrees of obstruction only. For the tests with $S_{III} = 0.006$ no change of transport rate is seen in comparison to those without constructional elements.

The limitation to one characteristic grain size so far makes a global assessment of constructional measures for natural rehabilitation difficult. Therefore additional investigations with two more grain sizes are actually executed.

6. REFERENCE

BECHTELER W. VOGEL G. VOLLMERS H.-J.	Model Investigations on the Sediment Transport of a Lower Alpine River Proceedings, International Workshop on Fluvial Hydraulics of Mountain Regions, Trento, Italy, 1989
	Hydraulische Berechnungen von Fließgewässern DVWK-Merkblatt 220/1991, Verlag Paul Parey, 1991
	Hydraulic Modelling DVWK-Bulletin No. 7, Editor H. Kobus, Verlag Paul Parey, 1980
DVWK (author MERTENS)	Hydraulisch-sedimentologische Berechnungen naturnah gestalteter Fließgewässer, Mitteilungen Nr. 25, 1994
VOLLMERS, H.-J.	Sediment Transport Equations and Annual Total Load, 5th Int. Symp. on River Sedimentation, Karlsruhe, 1992
ZANKE U.	Grundlagen der Sedimentbewegung Springer-Verlag, Berlin Heidelberg, 1982