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CHANGES OF SEDIMENT DISTRIBUTION IN A CHANNEL BIFURCATION – 3D MODELLING

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Plan

- Introduction
- Calibration of the model
- Flow results - bifurcation 90°, 45° and 135°
- Analysis of sediment distribution and influence of diverting angle
- Conclusions

Introduction

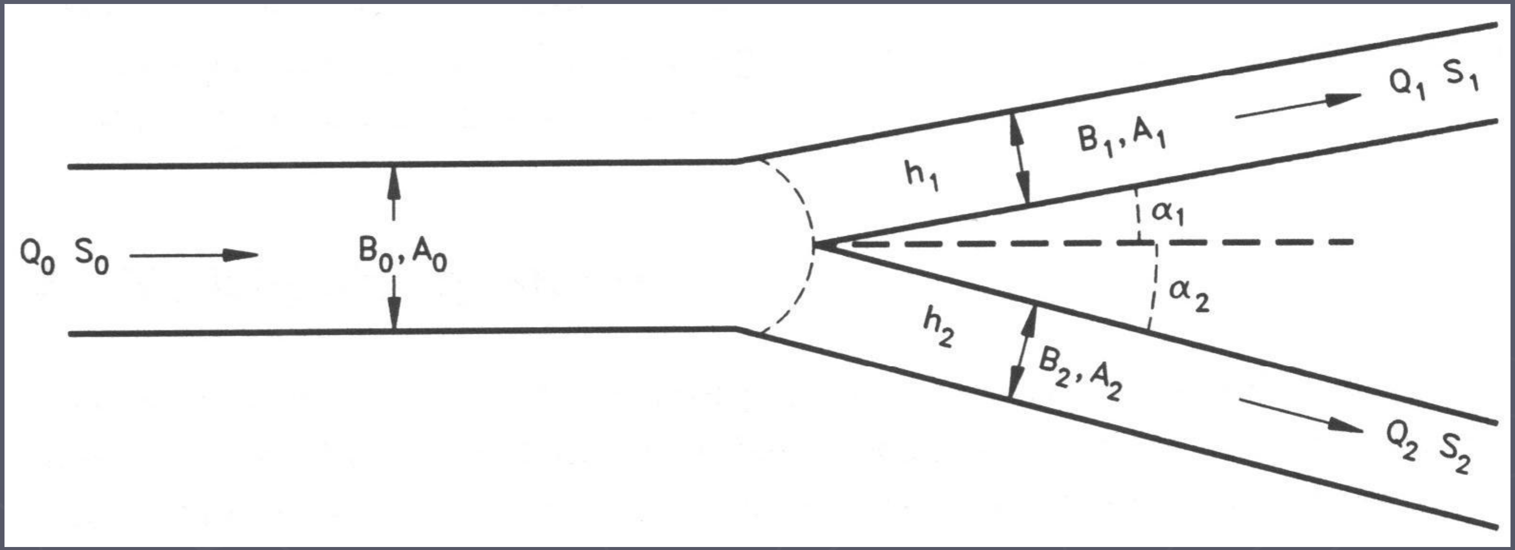
This study is about sediment distribution problems in channel bifurcations.

The purpose of this research is to get a better understanding of the physical processes of sediment distributions in channel bifurcations, deal with sediment management and optimize of river structures, for instance, inlet structures, sluices or fish laders.

Secondly, the models need to be tested in the field to understand bed forming process.

Mathematical models are the simplification of real objects.
In real cases the model is a compromise between cost of designing process of the model, collecting sufficient amount of parameters which characterize the object and accurance of results. Uselly the most important criterion is the purpose of simulations.

Introduction



There are many factors involved in how suspended and bed-load sediment are distributed over the branches of a bifurcation:

- discharge Q_0 and its distribution Q_1 and Q_2,
- geometry of the bifurcation: cross-sections A, depths h, widths B, angles α_1 and α_2, slope of the embankments,
- conditions in the approaching channel: straight channel/bend flow, turbulence intensity (caused by bed roughness / structures)
- sediment characteristics,
- sediment management measures: sills, guide vanes.

Introduction

In river morphology models, the bifurcation problem is usually approached by defining nodal-point relations in which the sediment distribution is a function of the discharge distribution.

Some of the nodal-point relations used in 1D morphological computations:

$$\frac{S_1}{S_2} = \frac{Q_1}{Q_2} \qquad (1)$$

S_1, S_2= sediment inflow into branch 1 and branch 2 (m^3s^{-1}), Q_1, Q_2 = discharge in branches 1 and 2 (m^3s^{-1})

It assumes proportionality between the sediment transport and the discharge in the bifurcation.

Introduction

$$\frac{S_1}{S_2} = \alpha \frac{Q_1}{Q_2} + \beta \qquad (2)$$

user-defined values for α and β.

The exponential nodal-point relation [Wang 1993]

$$\frac{S_1}{S_2} = \left(\frac{Q_1}{Q_2}\right)^m \left(\frac{B_1}{B_2}\right)^n \qquad (3)$$

with theoretically n = 1 – m

Introduction

Mathematical model - Governing Equations

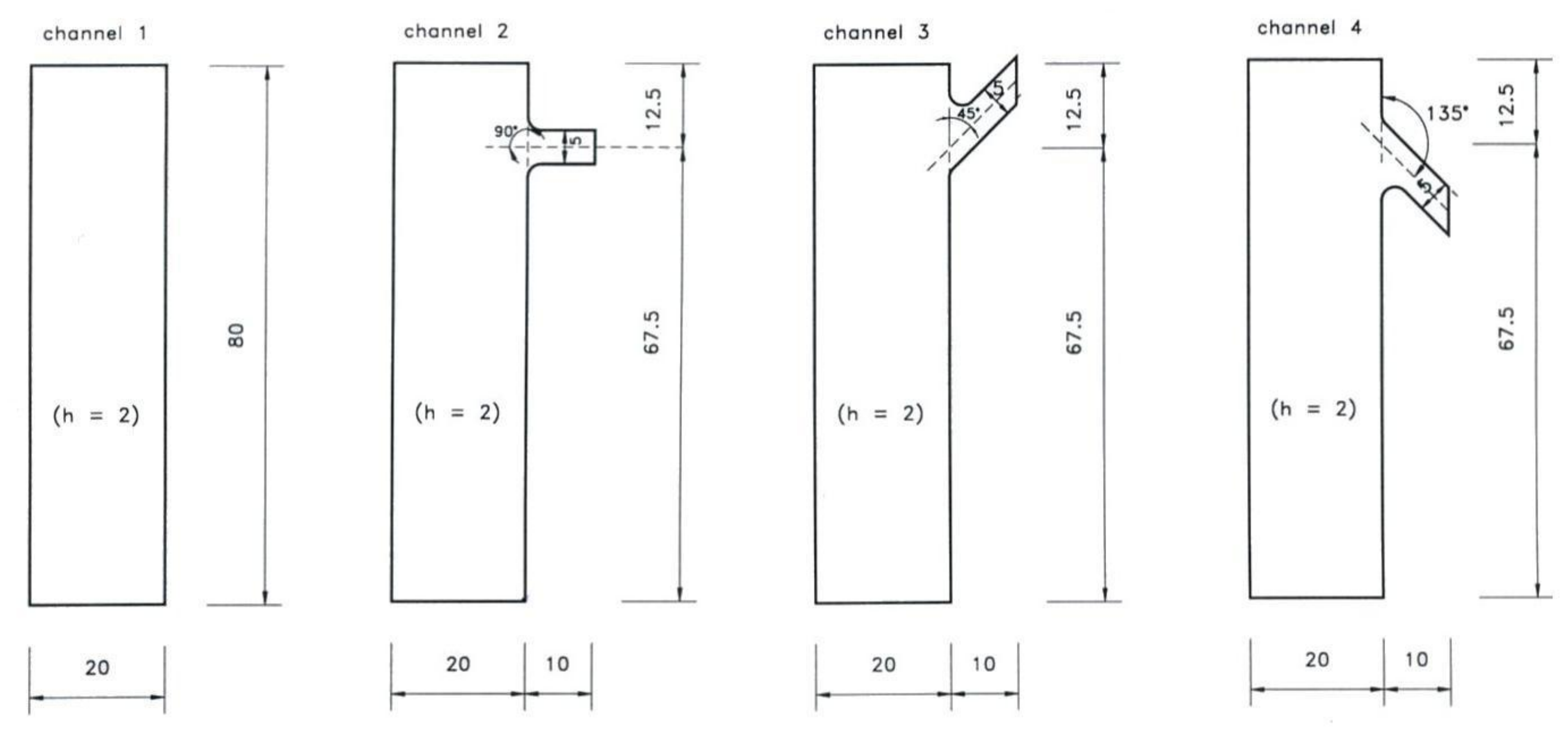
A mathematical model investigation was carried out using the 3D-modelling system FLUENT.

The model simulate a range of physical phenomena by solving conservation equations for mass, momentum and energy, using a control volume based finite volume method.

It solves the Navier-Stokes equations as momentum conservations and describes turbulence using several turbulence models.

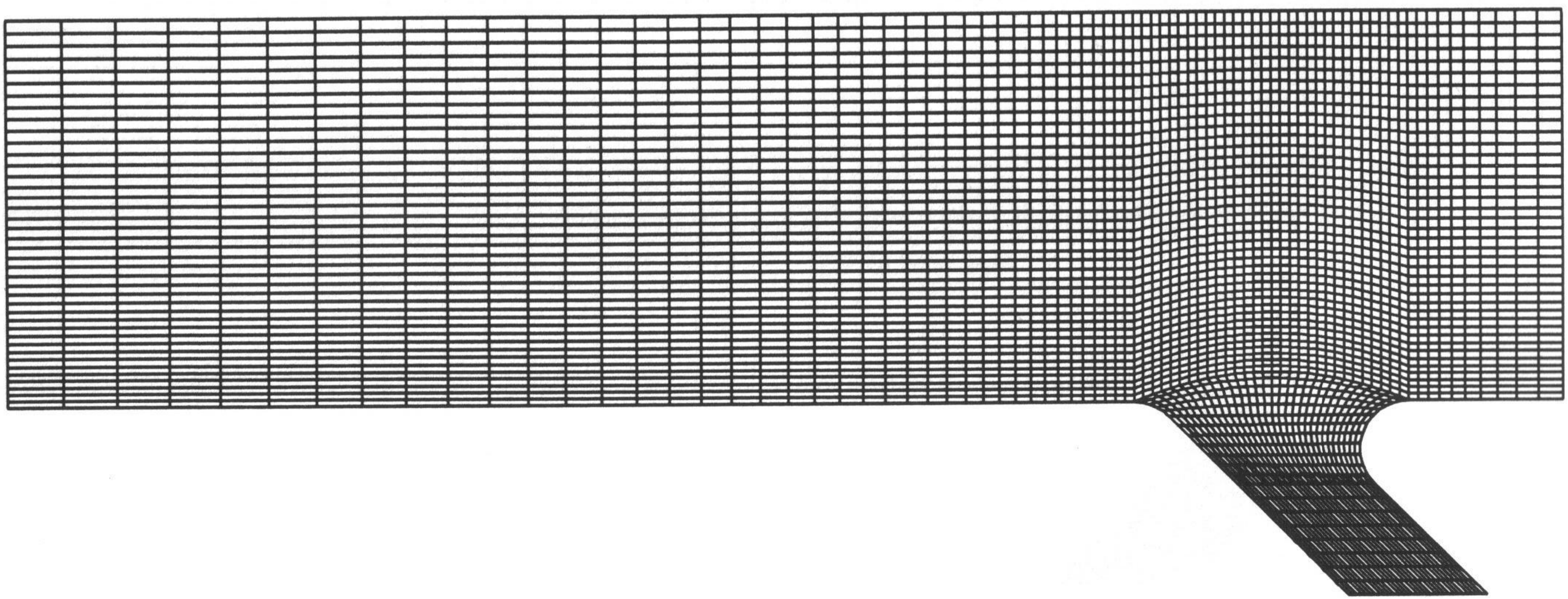
The model computes trajectories of particles in the flow. The trajectory of a particle is determined by its diameter, its Reynolds-dependent drag coefficient CD, and the external forces caused by the flow and gravity. The fluctuating component of this force is related to the turbulence intensity. In this way, several identical particle releases can yield different trajectories.

Channel geometries



channel 1 - without bifurcation,
channel 2 - with bifurcation of 90°, channel 3 - 45° channel 4 - 135°

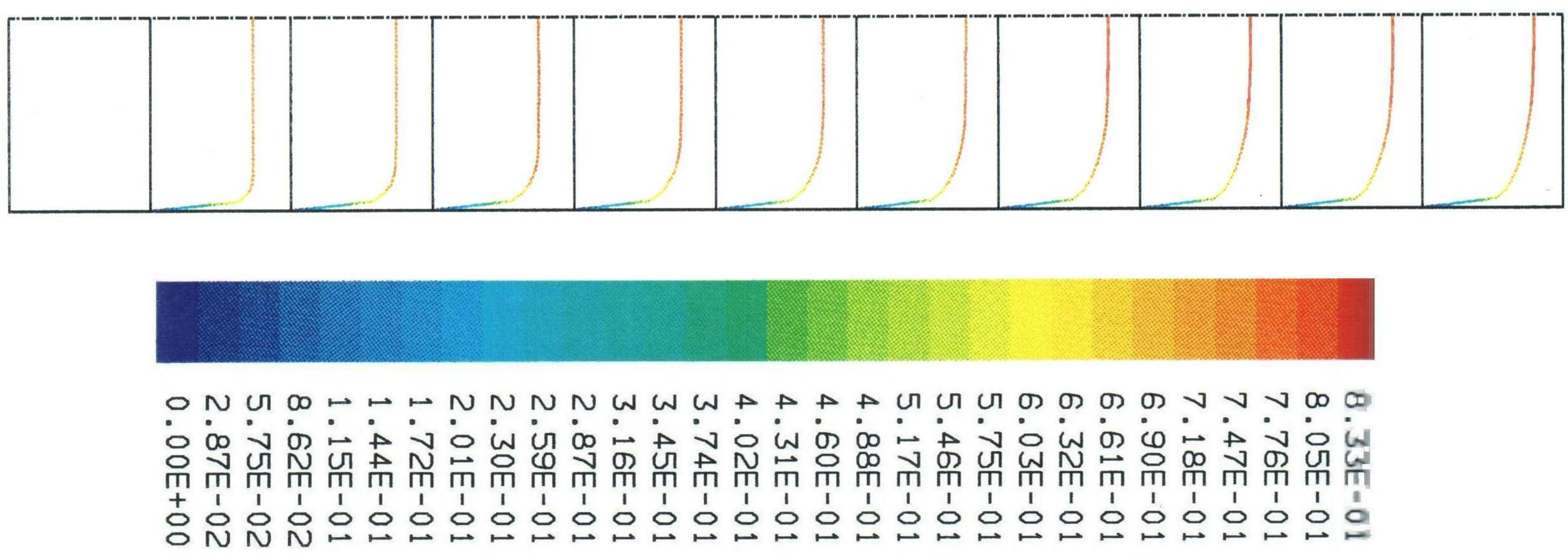
Grid



The largest variations in the fluid flow, sediment transport and turbulence occur in the region of the bifurcation and in the boundary layer so grid (86 428 cells) refinement is applied in these regions.

Calibration of the model

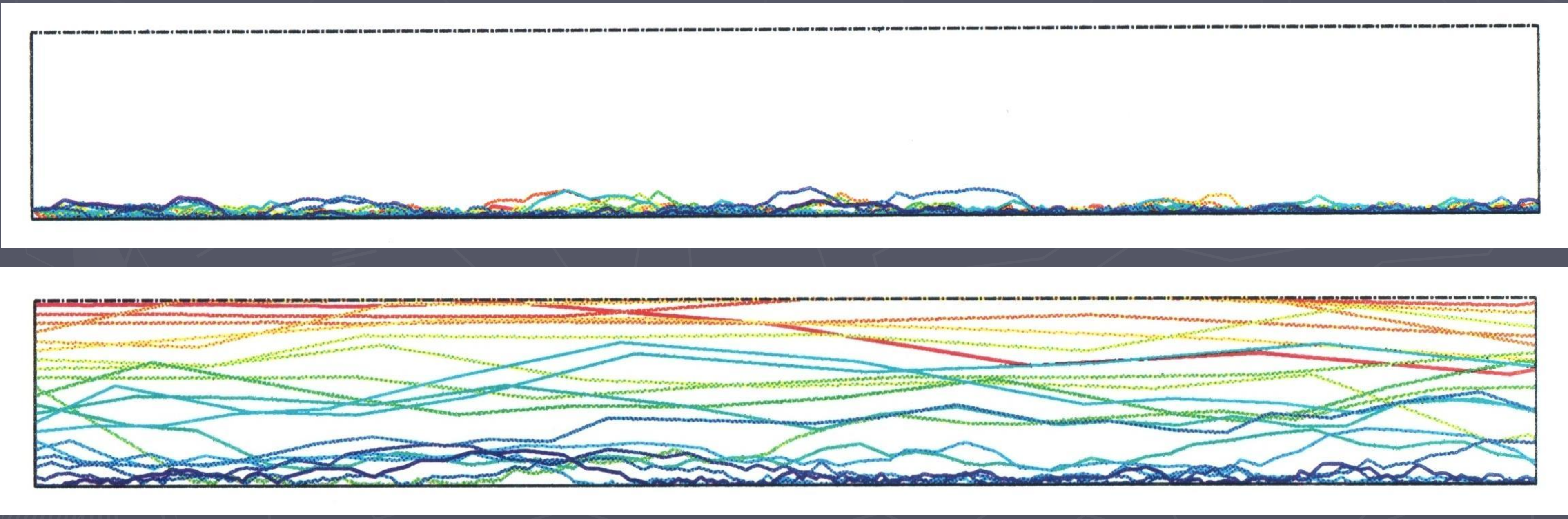
The channel without bifurcation is established as a basic geometry to investigate the fluid flow and the movement of sediment particles. It allows to check the inlet conditions and the development of the profiles of the flow velocity, the turbulent kinetic energy, the eddy dissipation and the particle concentration.



Channel 1 – velocity profiles

In preliminary computations using channel 1 various particle tracking experiments were carried out (particle diameters: 0.01, 0.05, 0.1, 0.15 and 0.2 mm). Two diameters are chosen that characterize bed load and suspended sediment respectively D_1 = 0.15 mm (w_1 = 20.2 mms^{-1}), D_2 = 0.01 mm (w_2 = 0.09 mms^{-1}).

The suspension parameter $Z=w/\kappa u_*$:
z_1 = 2.0 (bed load and suspended sediment in near bed region), z2 = 0.009 (suspended sediment).
The Shields parameter is defined $\theta=\tau w/(\rho s-\rho)gD$: θ_1 = 0.41, θ_2 = 5.98.



Side view of the particle trajectories for channel without bifurcation, a) as bedload transport, b) as suspended transport

Flow results

Runs

For the channels with a bifurcation two discharge ratios are chosen with the following discharges and flow velocities in the branches:

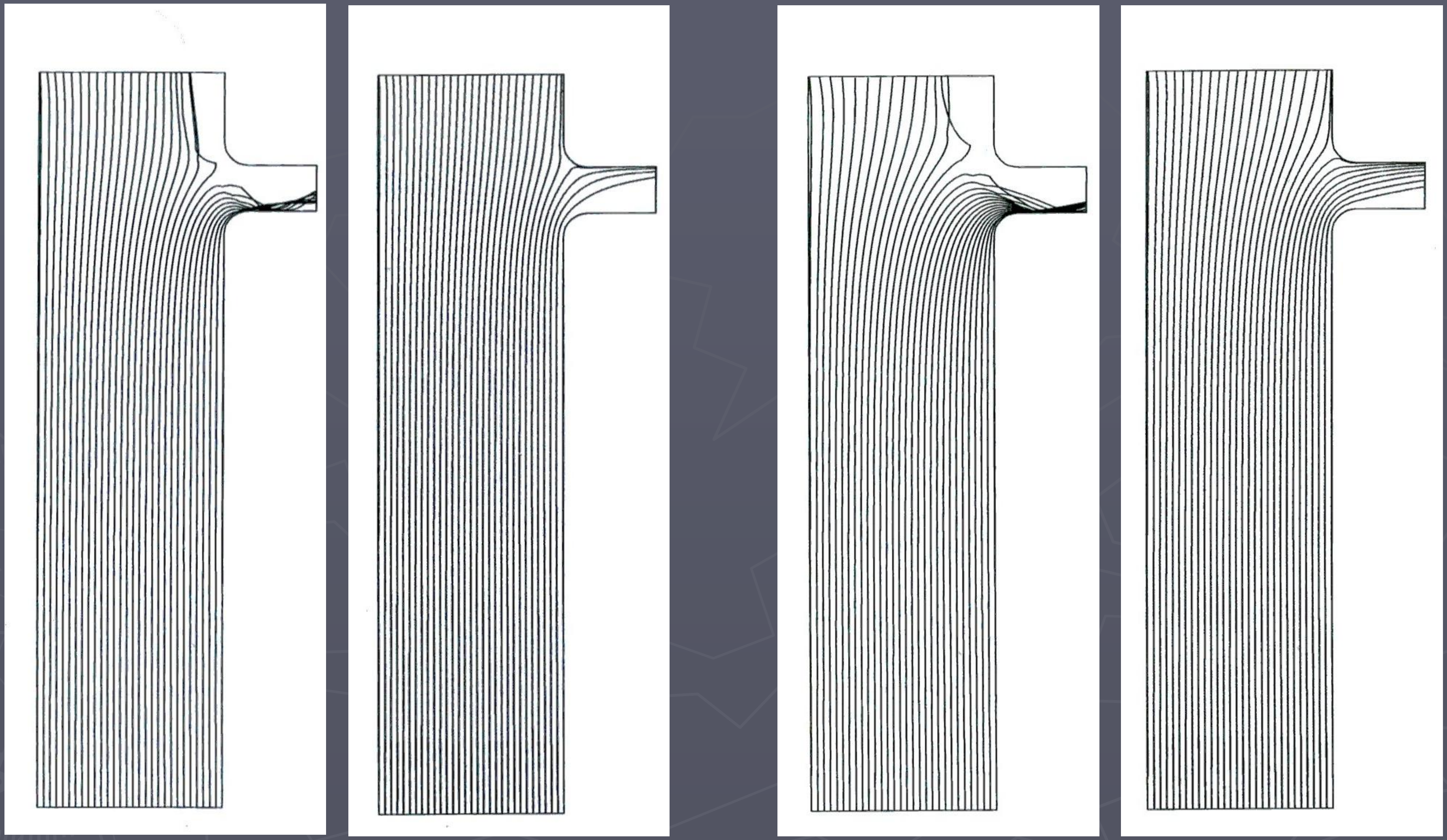
$Q = 30\ m^3s^{-1}$ $Q_1 = 5\ m^3s^{-1}$ => $u_1 = 0.500\ ms^{-1}$ (branch)
$Q_2 = 25\ m^3s^{-1}$ => $u_2 = 0.625\ ms^{-1}$ (main)
$Q = 30\ m^3s^{-1}$ $Q_1 = 10\ m^3s^{-1}$ => $u_1 = 1.000\ ms^{-1}$ (branch)
$Q_2 = 20\ m^3s^{-1}$ => $u_2 = 0.500\ ms^{-1}$ (main)

Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)

Bifurcation 45° - run 3a/b ($Q_1/Q_2 = 0.2$), run 3c/d ($Q_1/Q_2 = 0.5$)

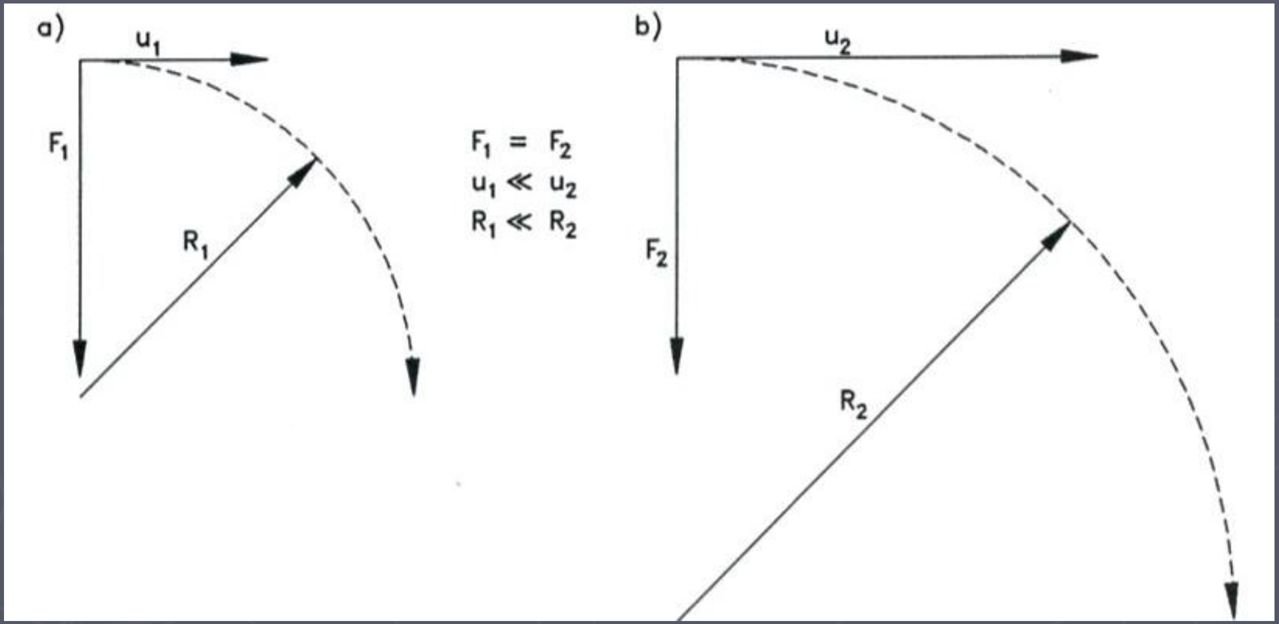
Bifurcation 135° - run 4a/b ($Q_1/Q_2 = 0.2$), run 4c/d ($Q_1/Q_2 = 0.5$)

Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)



Flow conditions at height z=0.01 m and z=1.93 m: a) streaklines for discharge $Q_1/Q_2 = 0.2$, b) streaklines for $Q_1/Q_2 = 0.5$

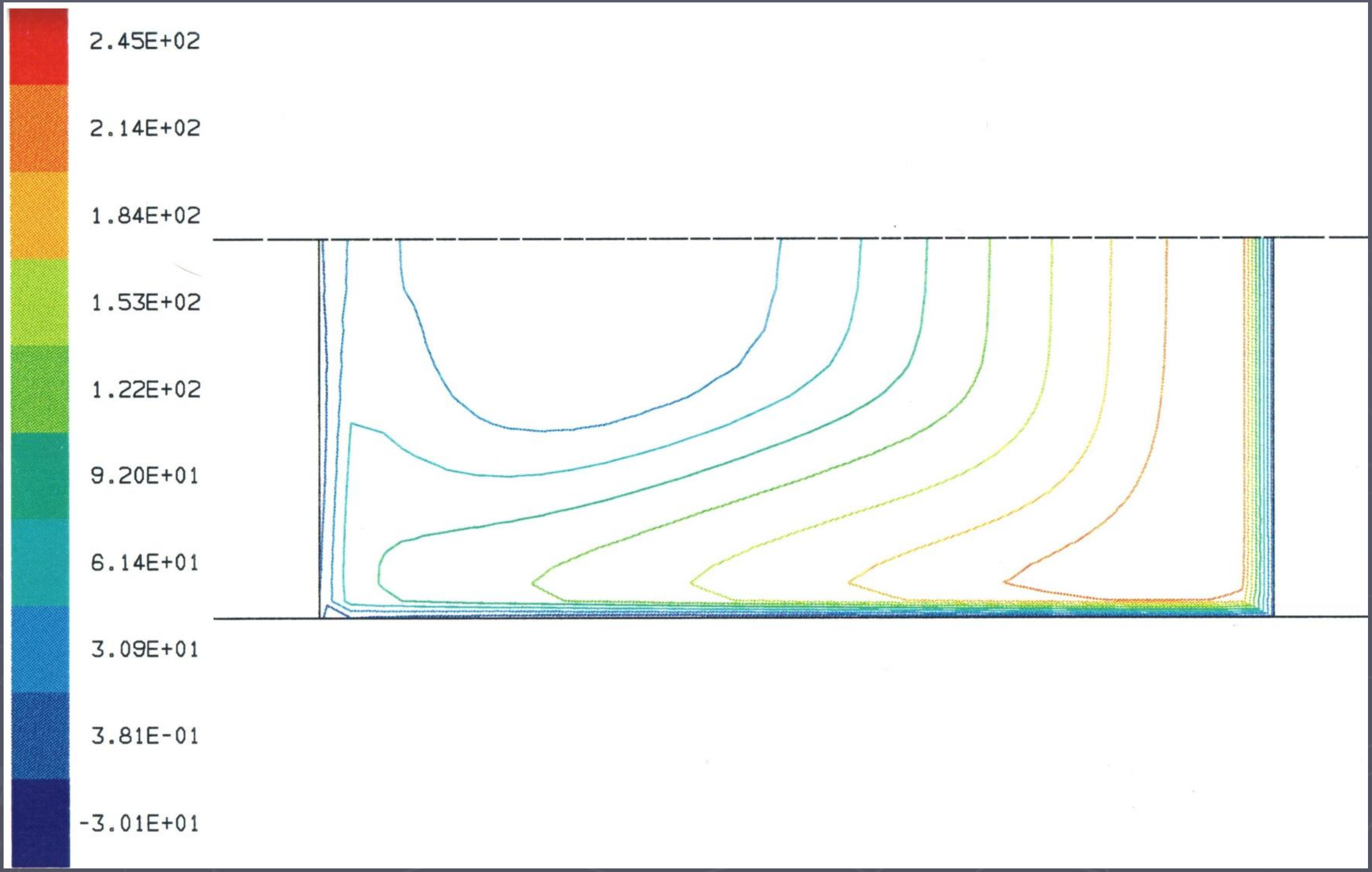
Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)



Resultant trajectories of fluid particles under centripetal force, a) at the bottom, b) at the surface

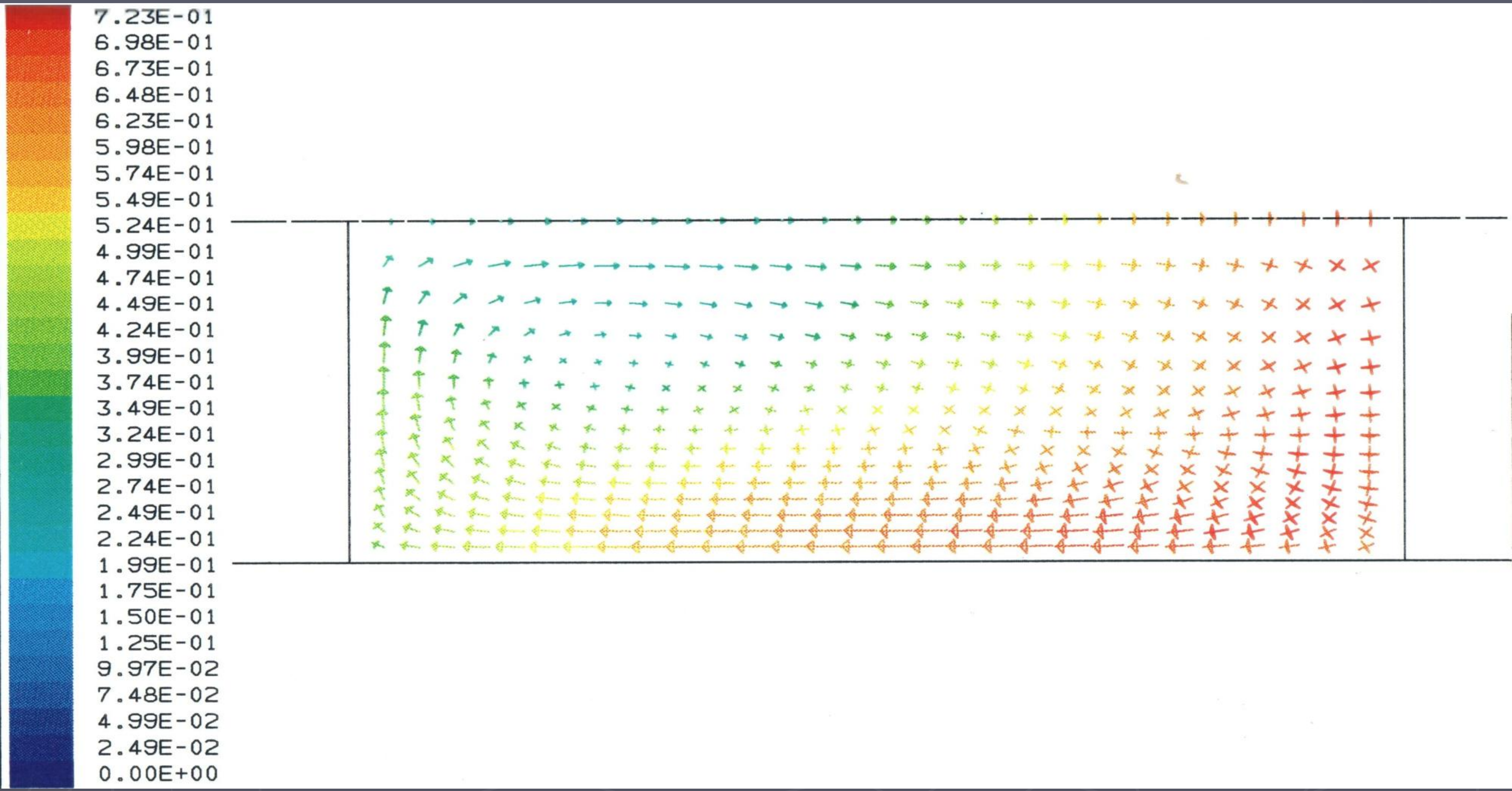
The fluid motion into the branch is different for both layers. At the bottom eight streaklines are banded into the branch whereas at the surface only four. This is caused by the difference in flow velocity between the bed region and the surface region. The driving force on the fluid motion into the branch, caused by the negative pressure gradient, bends the fluid particles at the bottom more easily into the branch because of their lower momentum.

Bifurcation 90° - run 2a/b (Q1/Q2 = 0.2) and 2c/d (Q1/Q2 = 0.5)



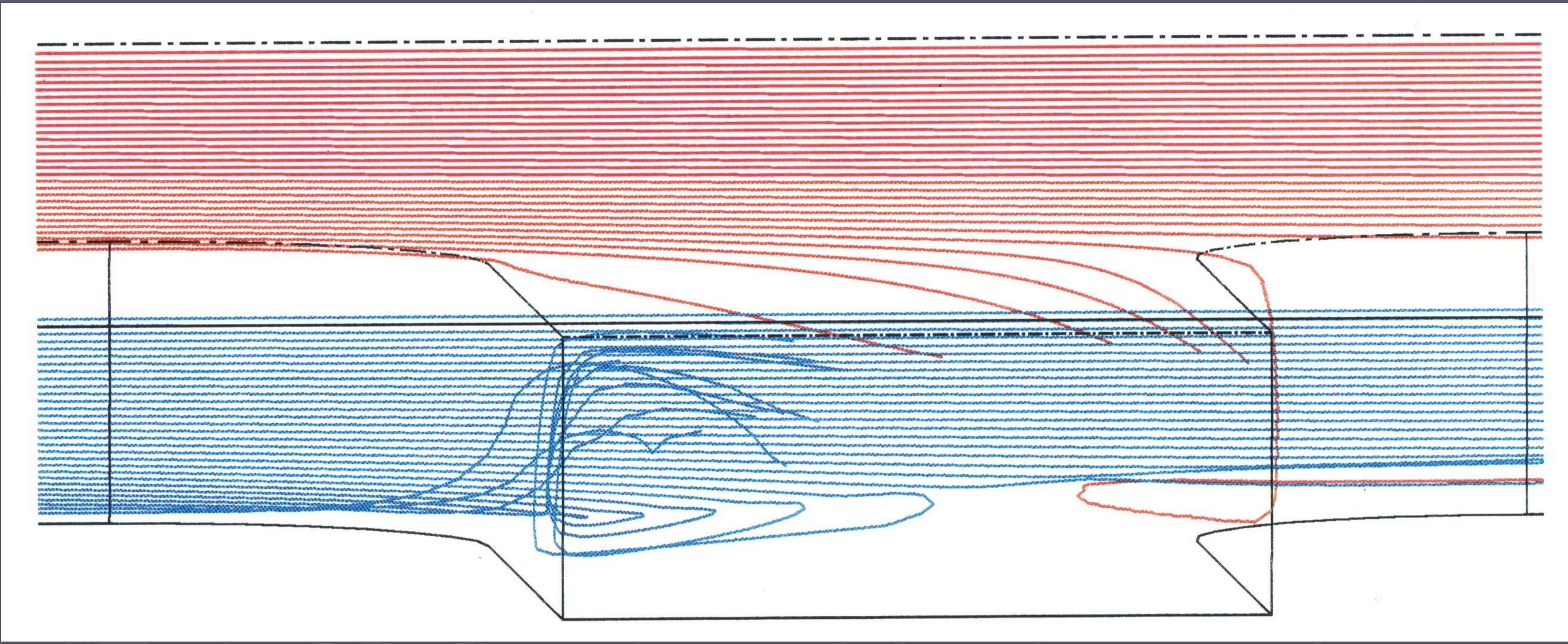
Relative total pressure [Pa] at downstream bundary of the branch – run 2a/b, Y-view

Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)



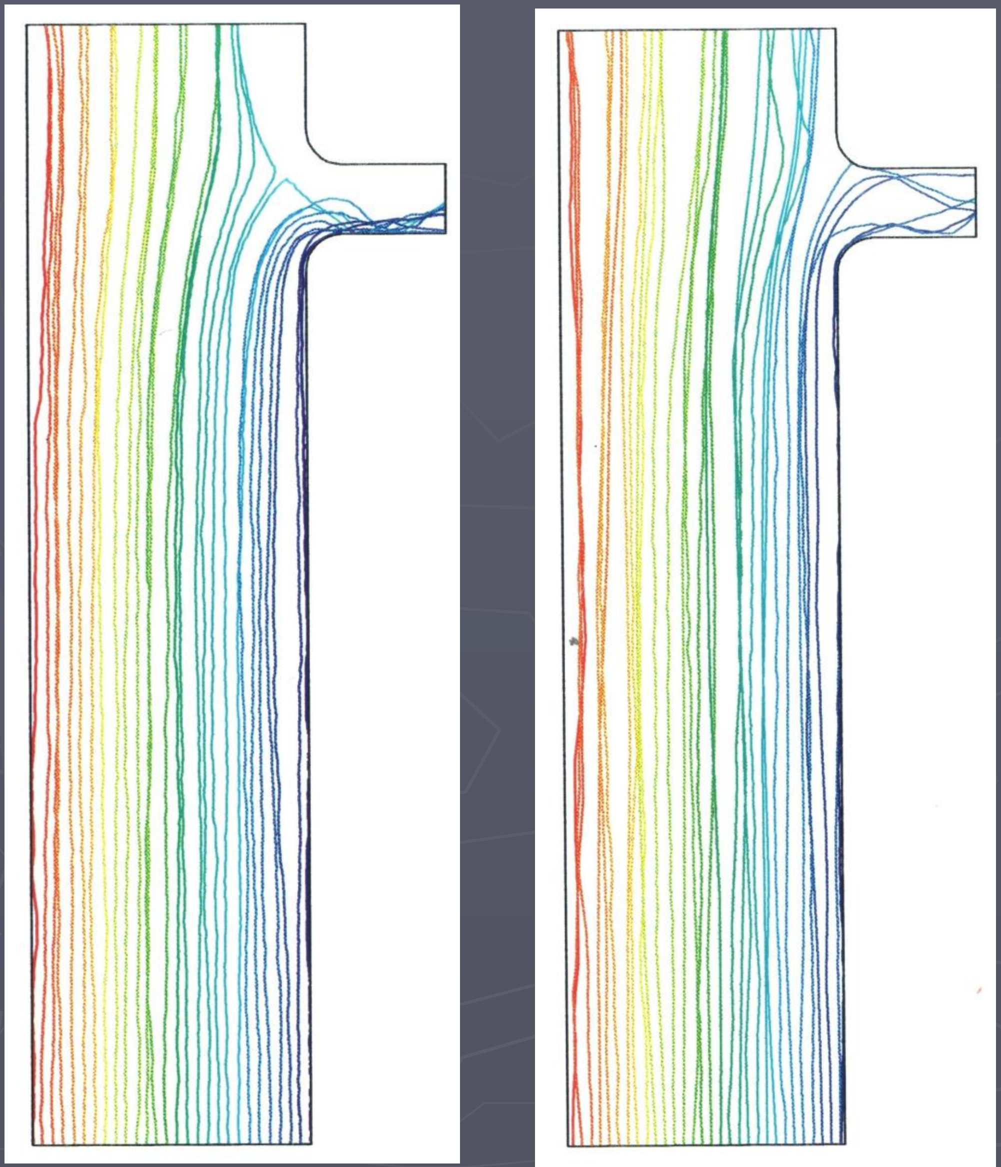
Velocity vectors at downstream boundary of the branch – run 2a/b, Y-view

Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)



Spiral motion – streaklines, run 2a/b, z=0,05 m and z=1,93 m, perspective view

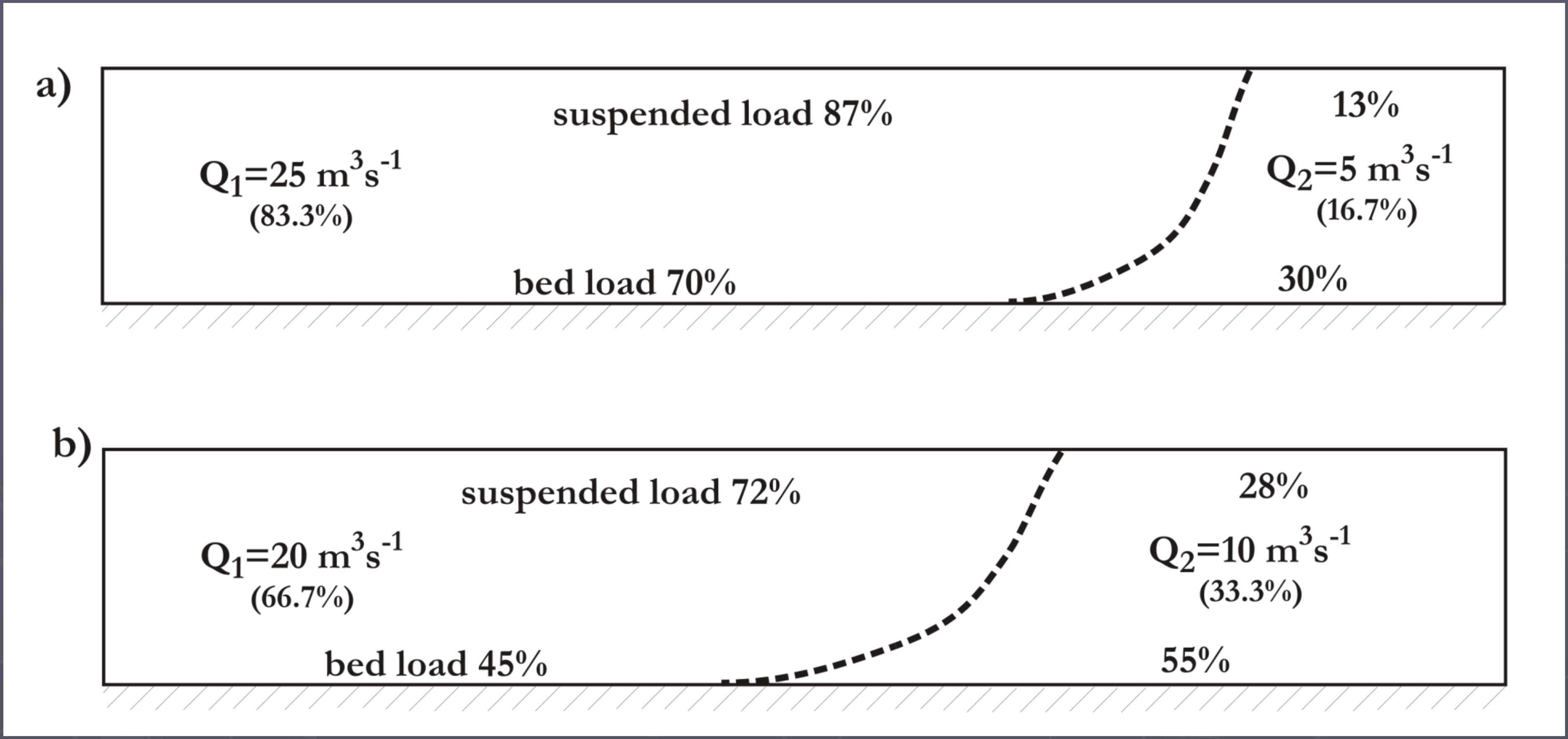
Bifurcation 90° - run 2a/b ($Q_1/Q_2 = 0.2$) and 2c/d ($Q_1/Q_2 = 0.5$)



Bed load trajectories which are, as expected, similar to the near-bed streaklines besides the turbulent deviations. The particle trajectories for suspended load show conformity to the streaklines.

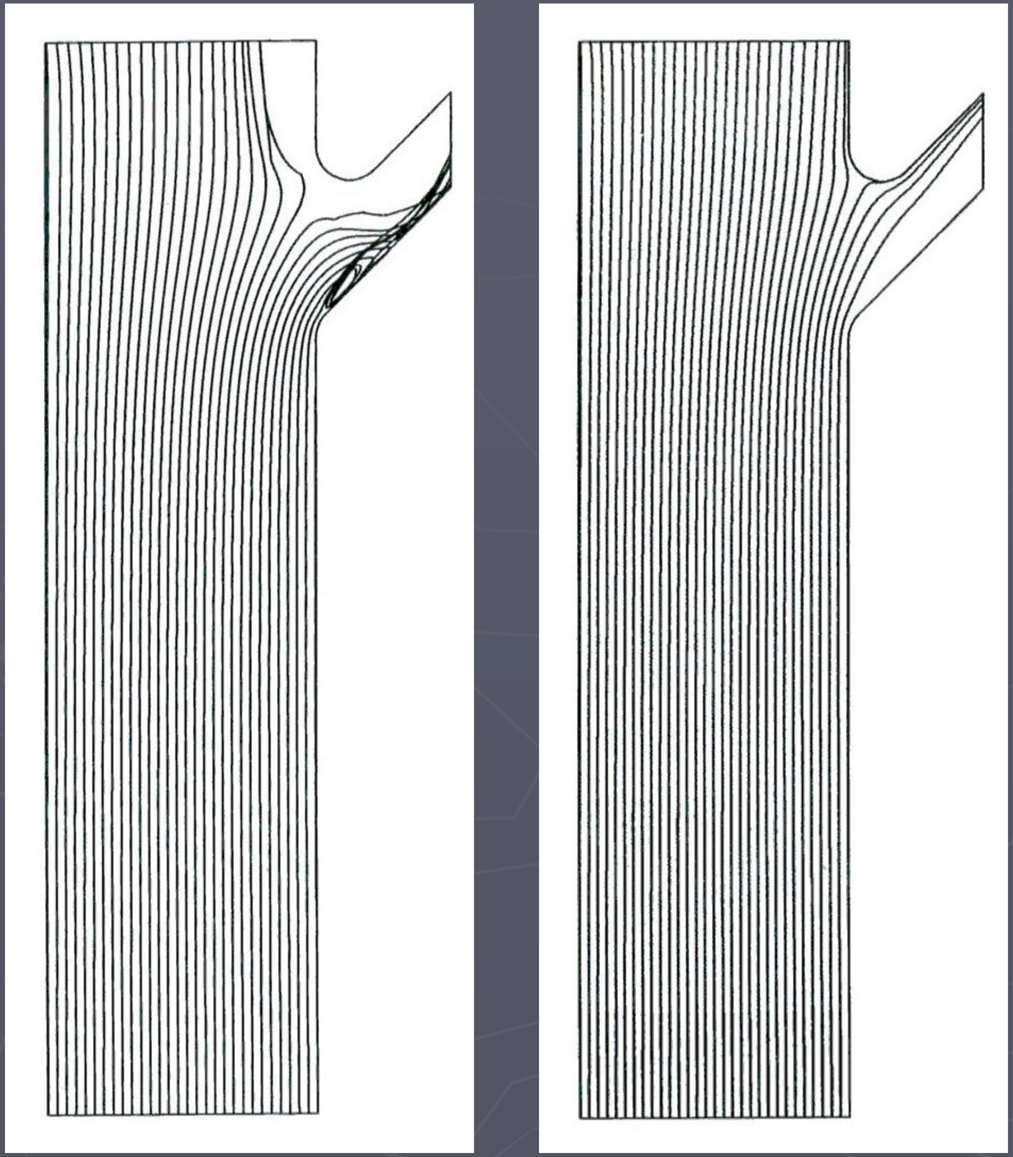
Particle trajectories for $Q_1/Q_2 = 0.2$ at height z=0.01 m and z=1.93 m

Bifurcation 90° - run 2a/b (Q_1/Q_2 = 0.2) and 2c/d (Q_1/Q_2 = 0.5)



Part of upstream cross-section that flows into the branch for cannel 2 for discharges a) Q_1/Q_2 =0.2, b) Q_1/Q_2 =0.5

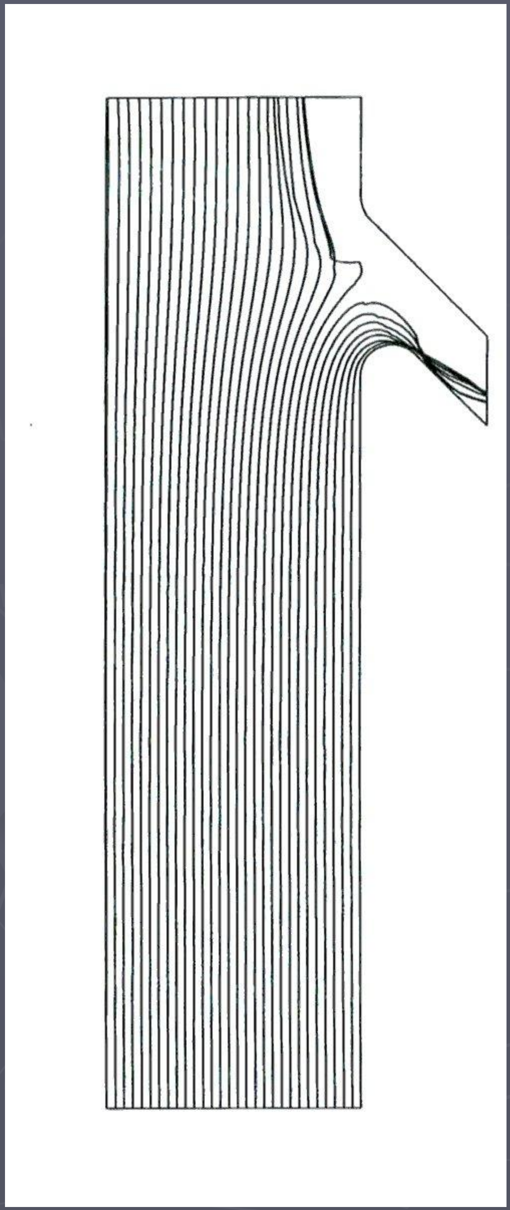
Bifurcation 45° - run 3a/b ($Q_1/Q_2 = 0.2$), run 3c/d ($Q_1/Q_2 = 0.5$)

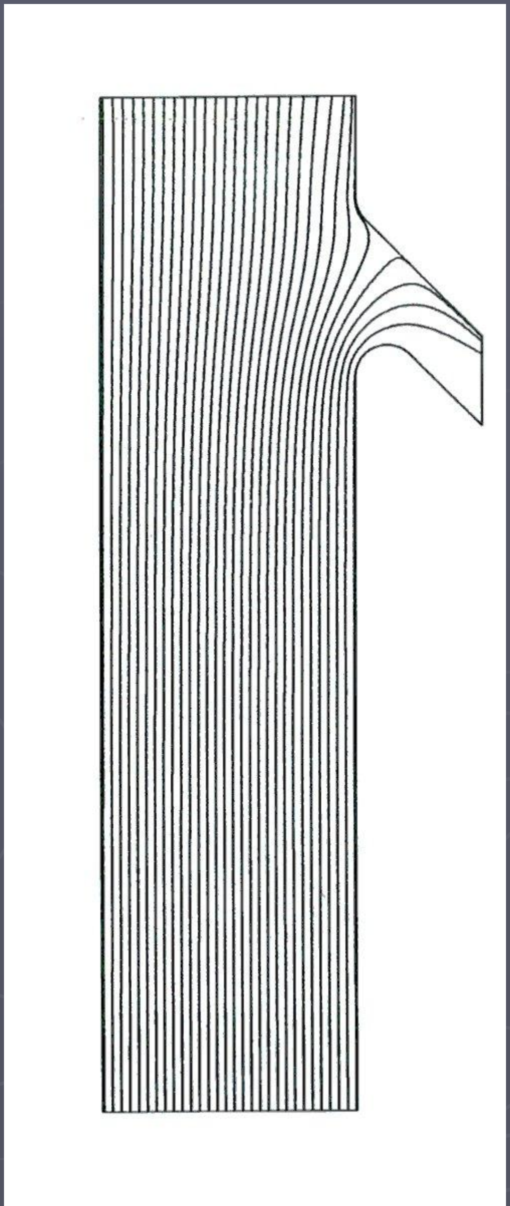


In the diverting branch a small recirculation zone appears, which has a local character and disperses a few centimetres above the bottom. An analysis of the shape of the streaklines on the bottom and near the water surface indicate a spiral motion of the fluid in the branch. With the higher velocity in the branch – discharge $Q_1/Q_2 = 0.5$, the vortex observed in the case $Q_1/Q_2 = 0.2$, seems to disappear.

Streaklines for channels 3 for discharge $Q_1/Q_2 = 0.2$

Bifurcation 135° - run 4a/b/c/d (Q_1/Q_2 = 0.2 and 0.5)





The streaklines indicate aspiral fluid motion for both discharge ratios.

Streaklines for channels 4 for discharge Q1/Q2 = 0.2

Analysis of sediment distribution

The sediment transport ratios S_1/S_2, based on the results of the particle tracking computations (run 2a up to 4d)

Channel Run	Angle of diverting branch (deg)	S_1/S_2			
		$Q_1/Q_2 = 0.2$		$Q_1/Q_2 = 0.5$	
		(a) D=0.15 mm	(b) D=0.01 mm	(c) D=0.15 mm	(d) D=0.01 mm
2	90	0.425	0.219	1.213	0.542
3	45	0.280	0.205	0.781	0.541
4	135	0.378	0.214	0.932	0.531

For the bed-load cases high α - values (α > 1), show the sediment ratio is more than proportionally related to the discharge ratio. The highest value appears for channel 2 (diverting angle 90°).

Coefficients for nodal-point relations

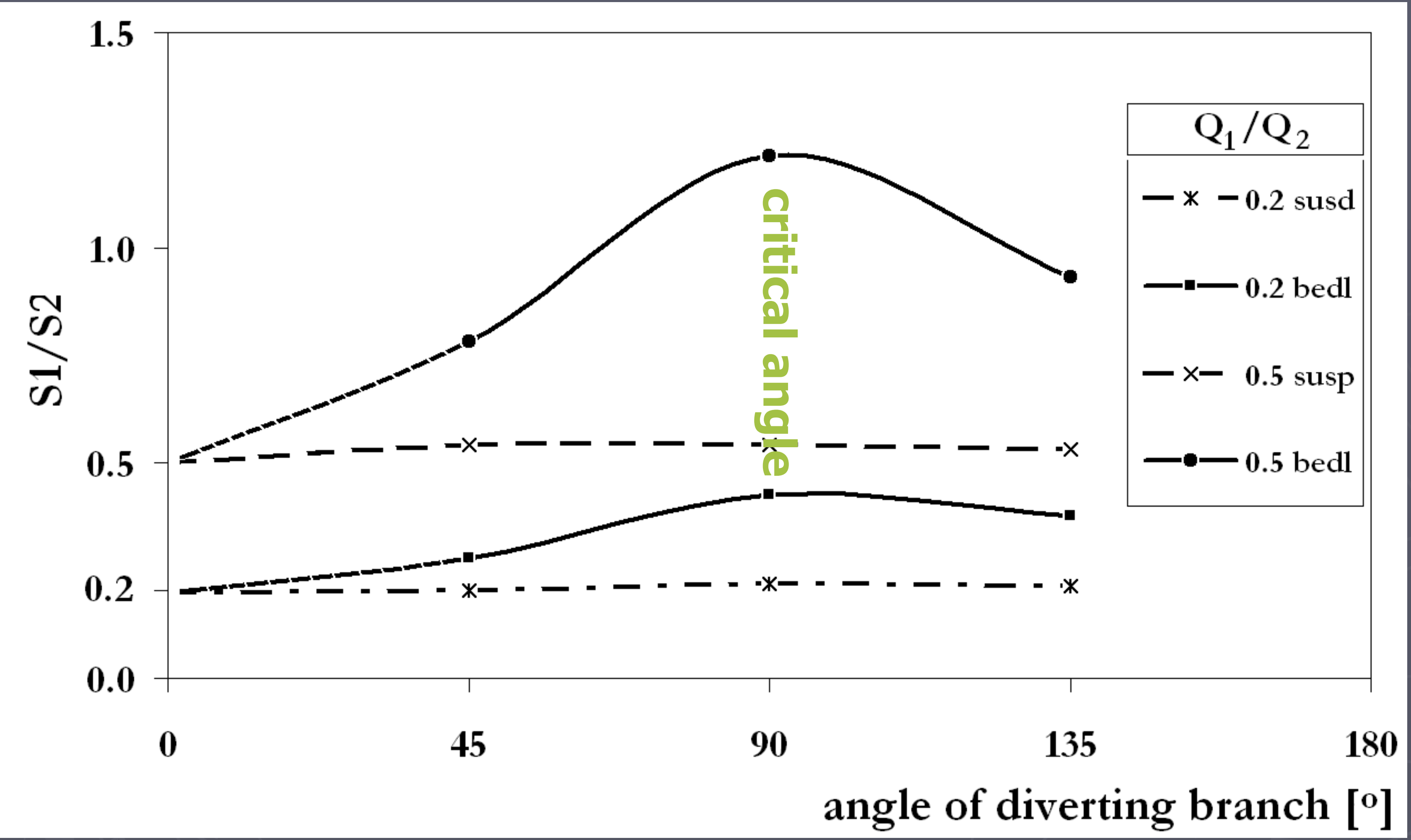
Particle D (mm)	Angle (°)	Channel	equation (2)		equation (3)	
			α	β	m	n
0.15 (bed load)	45 90 135	3 2 4	1.68 2.63 1.85	-0.06 -0.10 0.01	1.13 1.15 0.98	-0.39 -0.71 -0.44
0.01 (susp. load)	45 90 135	3 2 4	1.12 1.07 1.05	-0.02 0.00 0.00	1.05 0.99 0.99	-0.09 -0.05 -0.04

The m-values are slightly higher than unity for channel 2 and 3, indicating a weak non-linearity. For channel 4 the value m = 1 shows a fully linear dependence

The suspended sediment distribution is a practically proportional relation $S_1/S_2 = Q_1/Q_2$). The α-values indicates a nearly uniform sediment concentration profile. Together with the zero-values of β it approximates the proportional relation.

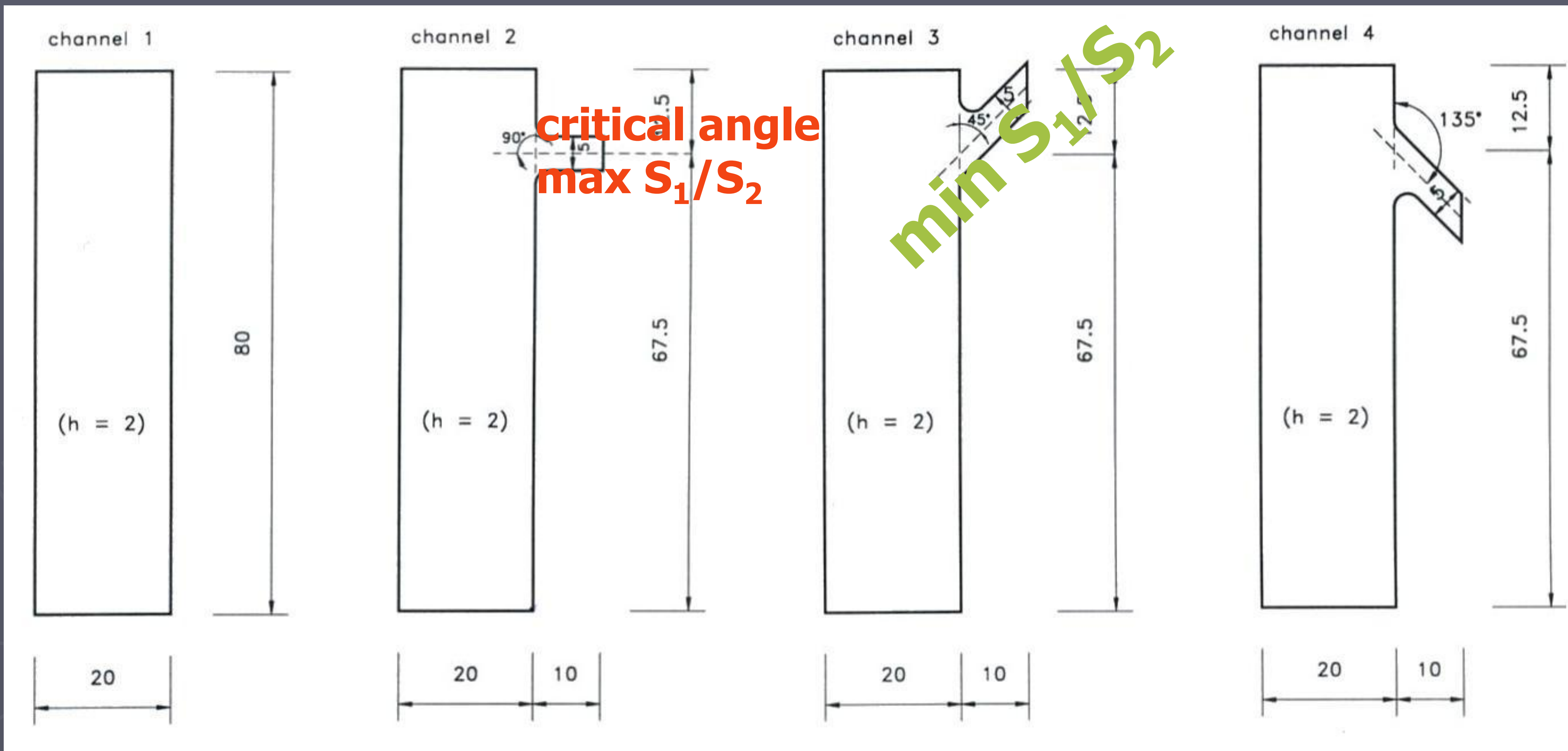
The negative n - values suggest a dependence on the widths of the branches

Influence of diverting angle



For bed-load problems a critical angle exists causing a maximum sediment load in the diverting branch. With an increasing angle the sediment load decreases again behind this point for both discharge ratios.

To sum up



channel 2 - with bifurcation of 90°, channel 3 - 45° channel 4 - 135°

Conclusions

- For suspended load a practically entire conformity of sediment transport with fluid motion is found, independent of geometrical conditions as the angle of the diverting branch.
- The distribution of bed load is dependent on the shape of the bifurcation. The amount of attracted sediment into the diverting branch is smallest for the channel with an diverting angle of 45°, and highest for the channel with an angle of 90°.

- The results of sediment distribution are considered to be satisfying because both nodal-points relations (2) and (3) are fit to the cases of this study. Nevertheless, for engineering purposes the nodal-point relation (3) is preferred for the following reasons:

- relation (3) shows the influence of the width ratio B1/B2,
- for strongly non-linear relations equation (3) will behave better than a linear approximation like (2).