Ships: Loads, stability and erosion

Chapter 9

ct4310 Bed, bank and shoreline protection

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June 3, 2012

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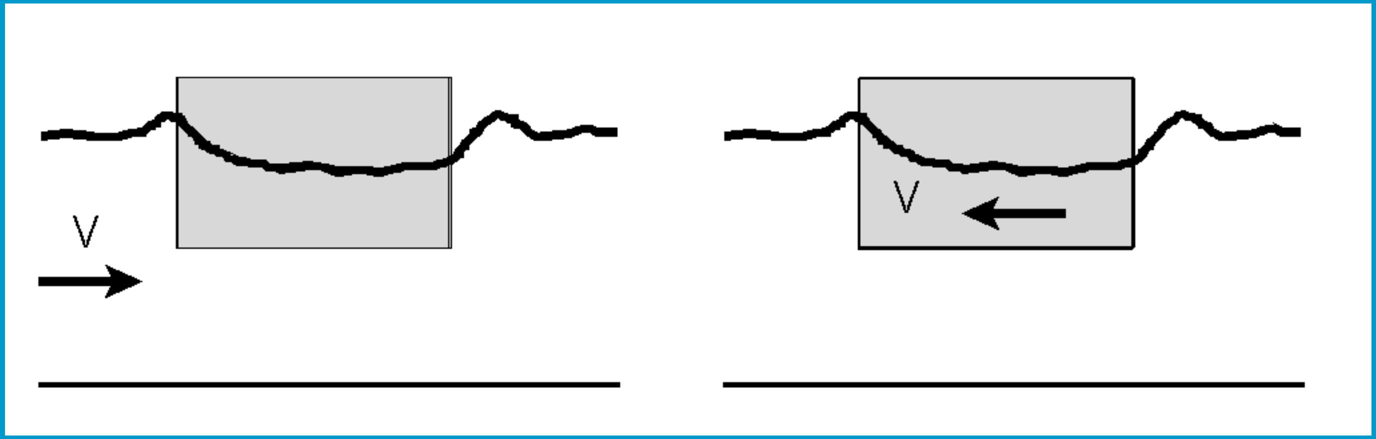
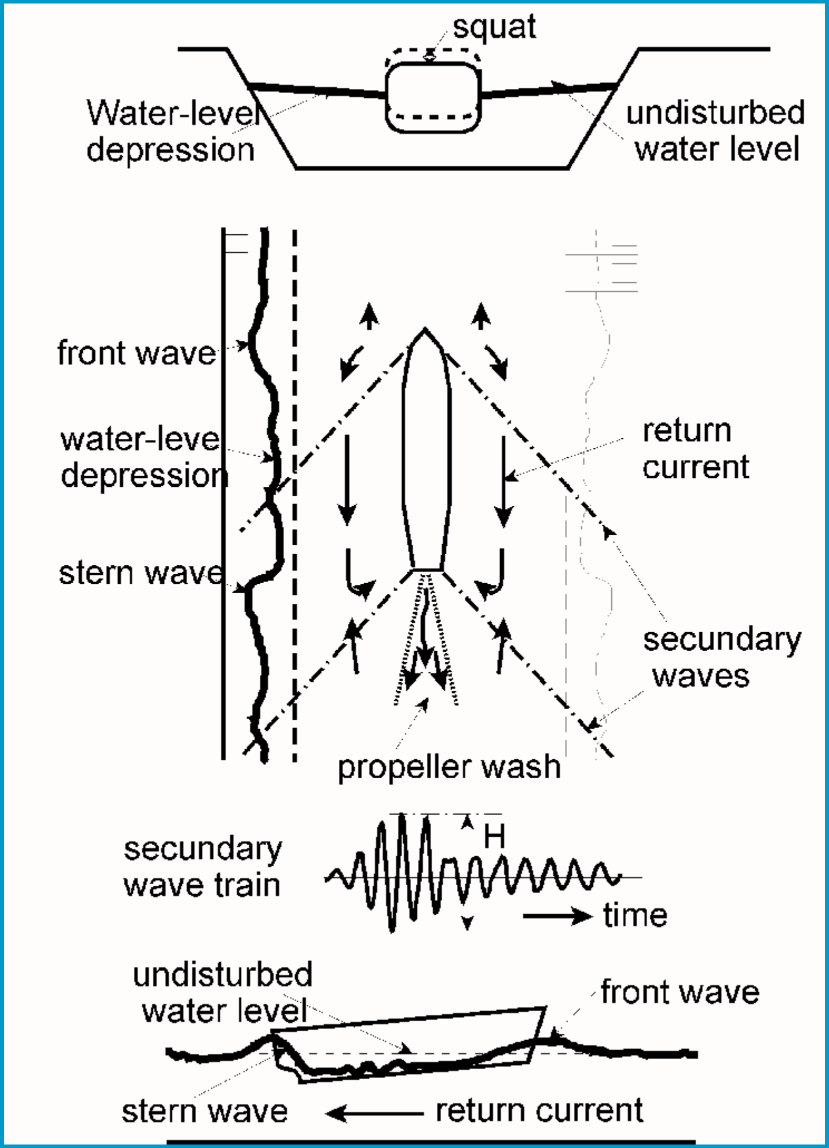
Introduction

- In inland waterways ships may cause waves
  - primary wave
  - secondary waves
  - propeller wash

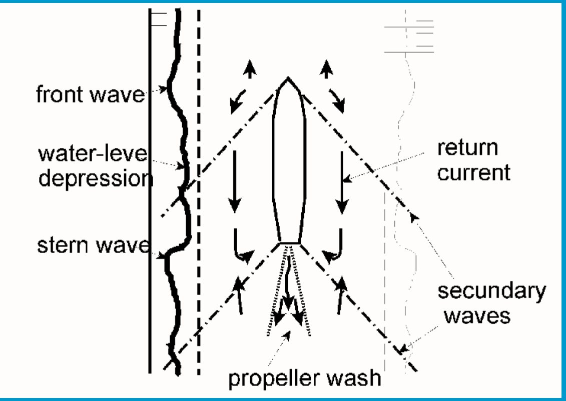
flow around fixed object & moving object in stagnant water



Phenomena around a moving ship in a waterway



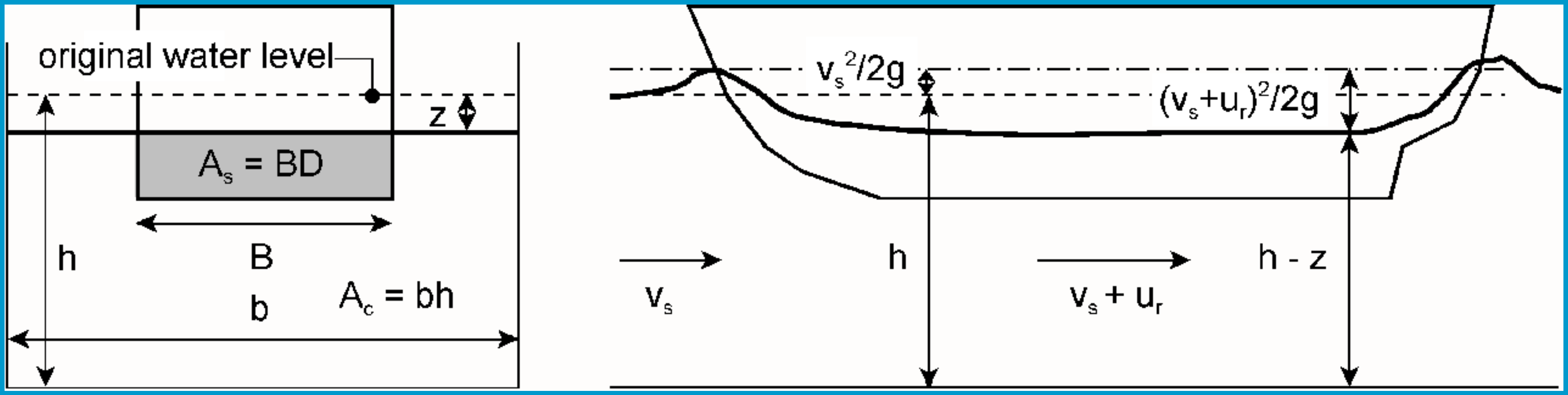
Return current and primary wave



Ship in Elbe river, courtesy prof. Erik Pasche, TU Hamburg

propeller wash

Definition in 1-d approach



$$c = \frac{gT}{2\pi}\tanh\frac{2\pi h}{L}$$

$$L = cT$$

$$V_l = c = \sqrt{\frac{gL}{2\pi}\tanh\frac{2\pi h}{L}}$$

limit speed

Bernoulli: $$h+\frac{v_s^{\,2}}{2g}=h-z+\frac{\left(v_s+u_r\right)^2}{2g}$$

continuity: $$b\,h\,v_s=\left(b\,h-B\,D-b\,z\right)\left(v_s+u_r\right)=Q$$

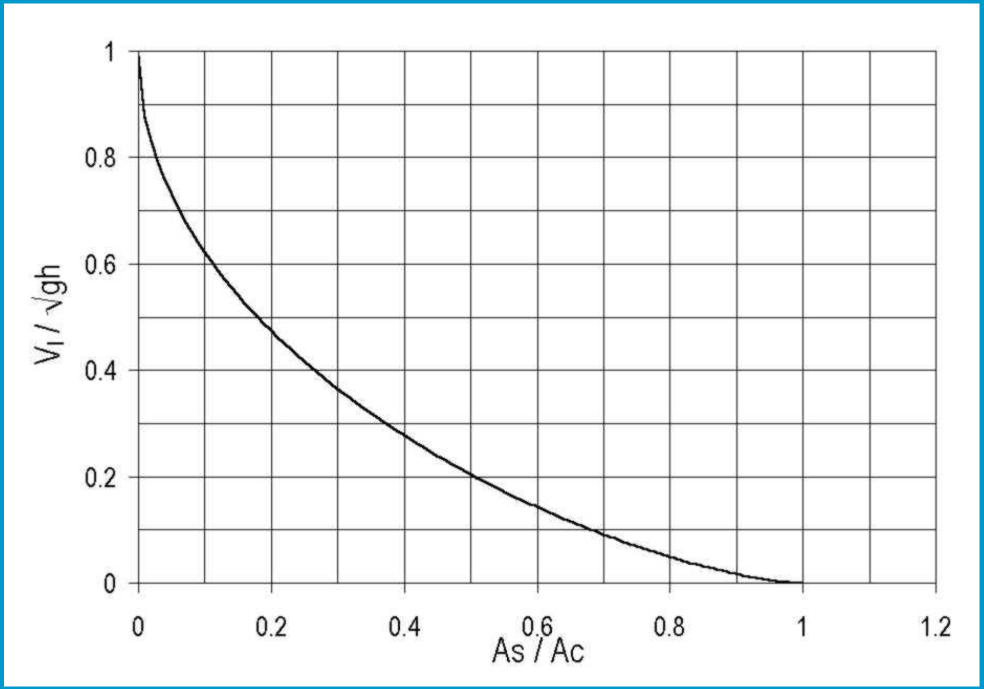
Maximum speed is reached when return flow becomes critical, i.e. when derivative of return flow to waterlevel becomes zero

$$\frac{dQ}{dz}=\frac{d\left(v_s+u\right)\left(Ac-As-bz\right)}{dz}=0$$

Combine this with Bernoulli:

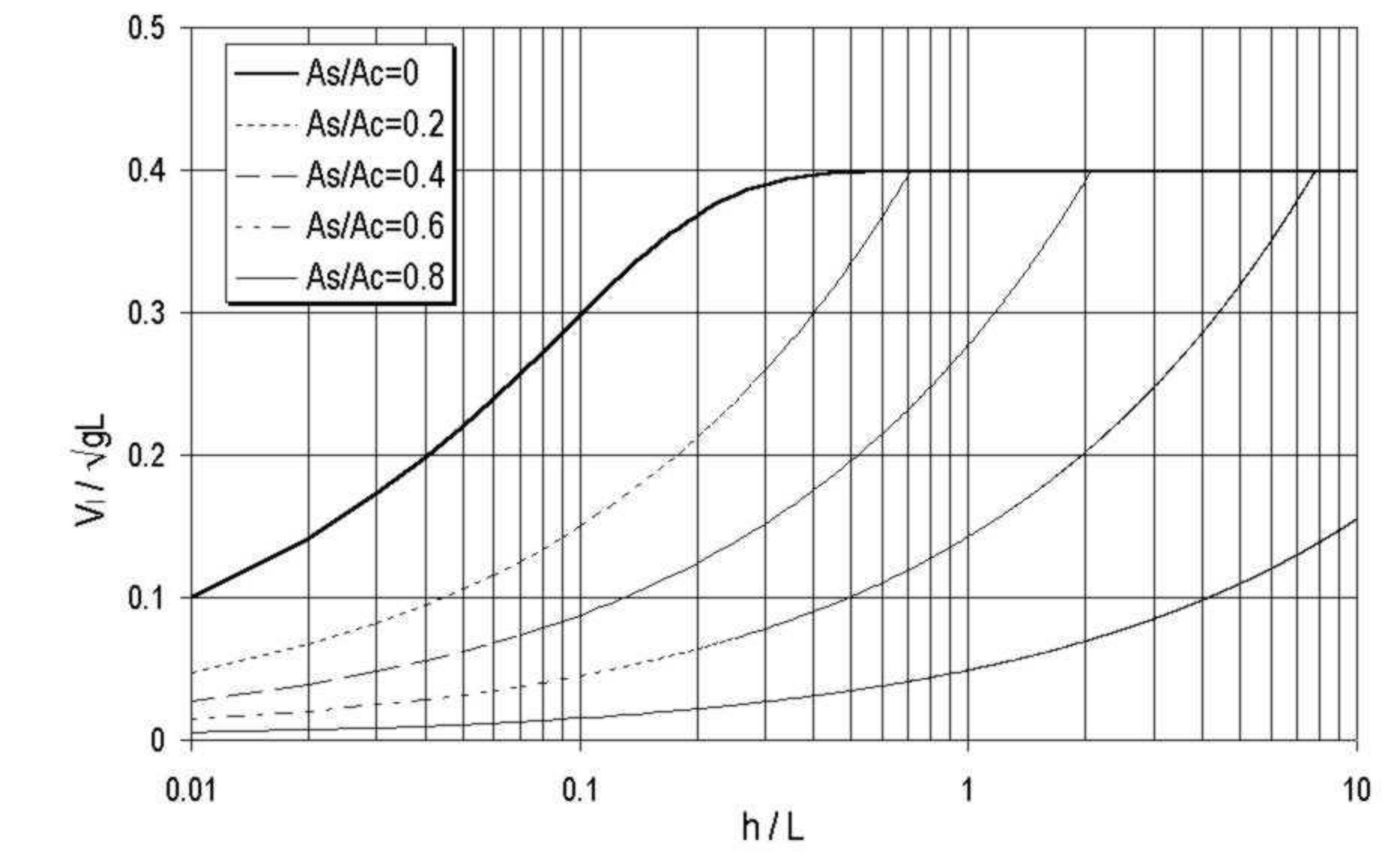
$$\frac{A_s}{A_c}-\frac{V_l^{\,2}}{2gh}+\frac{3}{2}\frac{V_l^{\,2/3}}{\left(gh\right)^{1/3}}=1$$

limit speed a a function of blockage A_s/A_c



$$\frac{A_s}{A_c} - \frac{V_l^2}{2gh} + \frac{3}{2}\frac{V_l^{2/3}}{(gh)^{1/3}} = 1$$

limit speed as a function of waterdepth and blockage

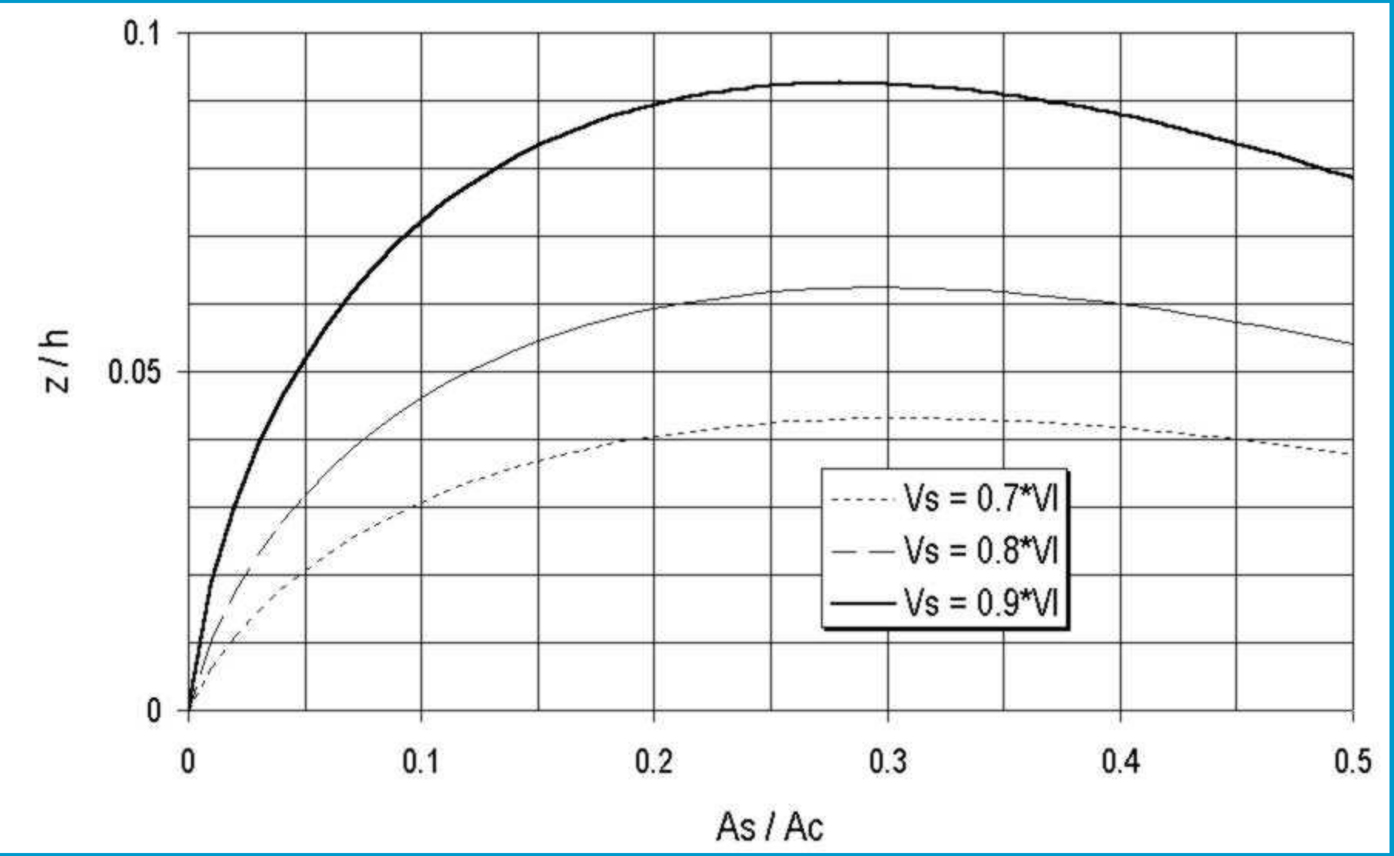


primary waves

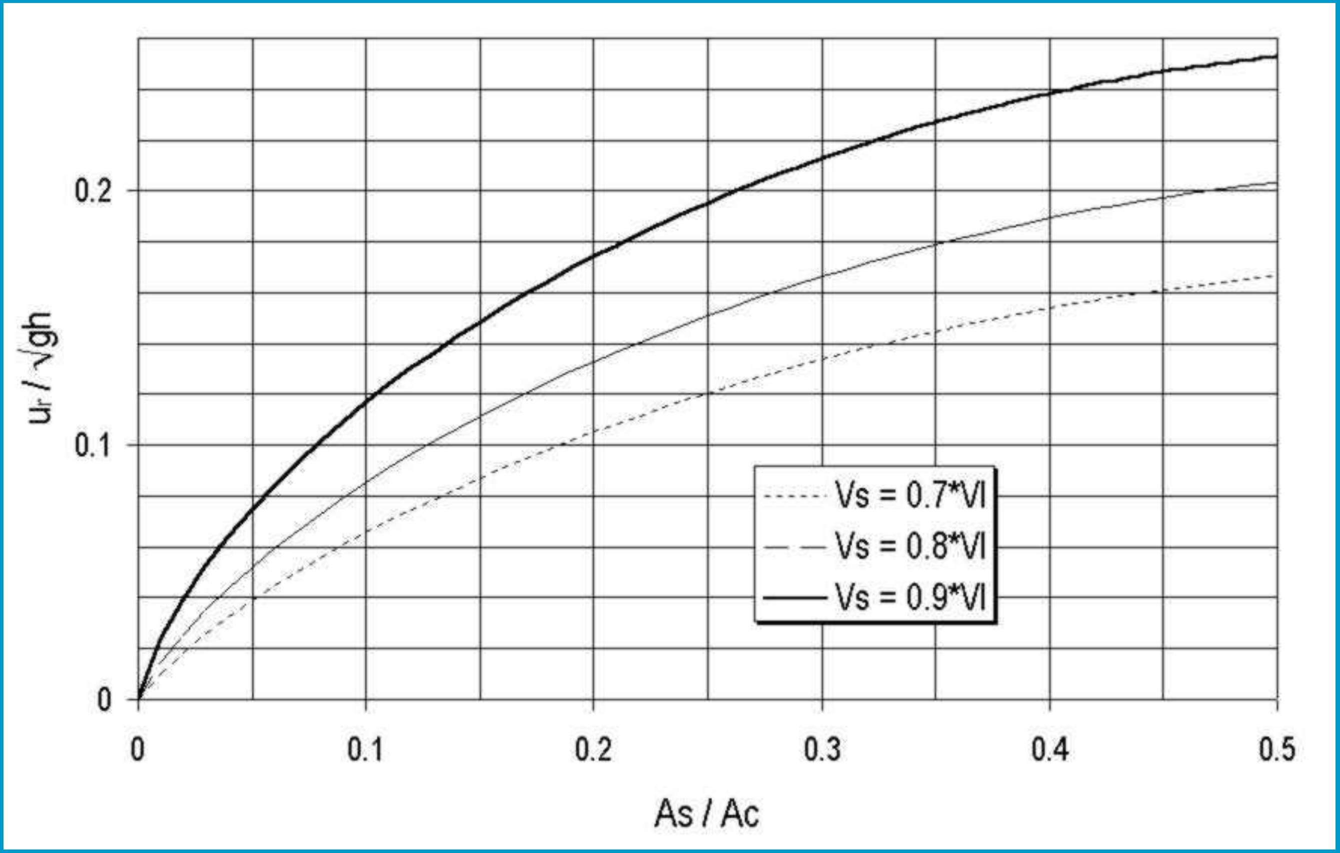
$$\frac{v_s^{\,2}}{gh} = \frac{2\,z/h}{\left(1 - A_s/A_c - z/h\right)^{-2} - 1}$$

$$\frac{u_r}{\sqrt{gh}} = \left[\frac{1}{1 - A_s/A_c - z/h} - 1\right]\frac{v_s}{\sqrt{gh}}$$

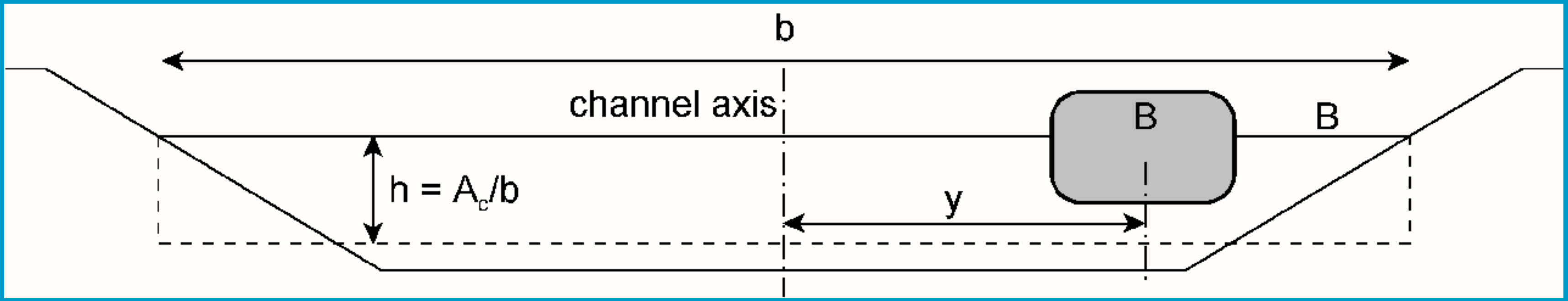
waterlevel depression as a function of blockage



return flow velocity as function of blockage



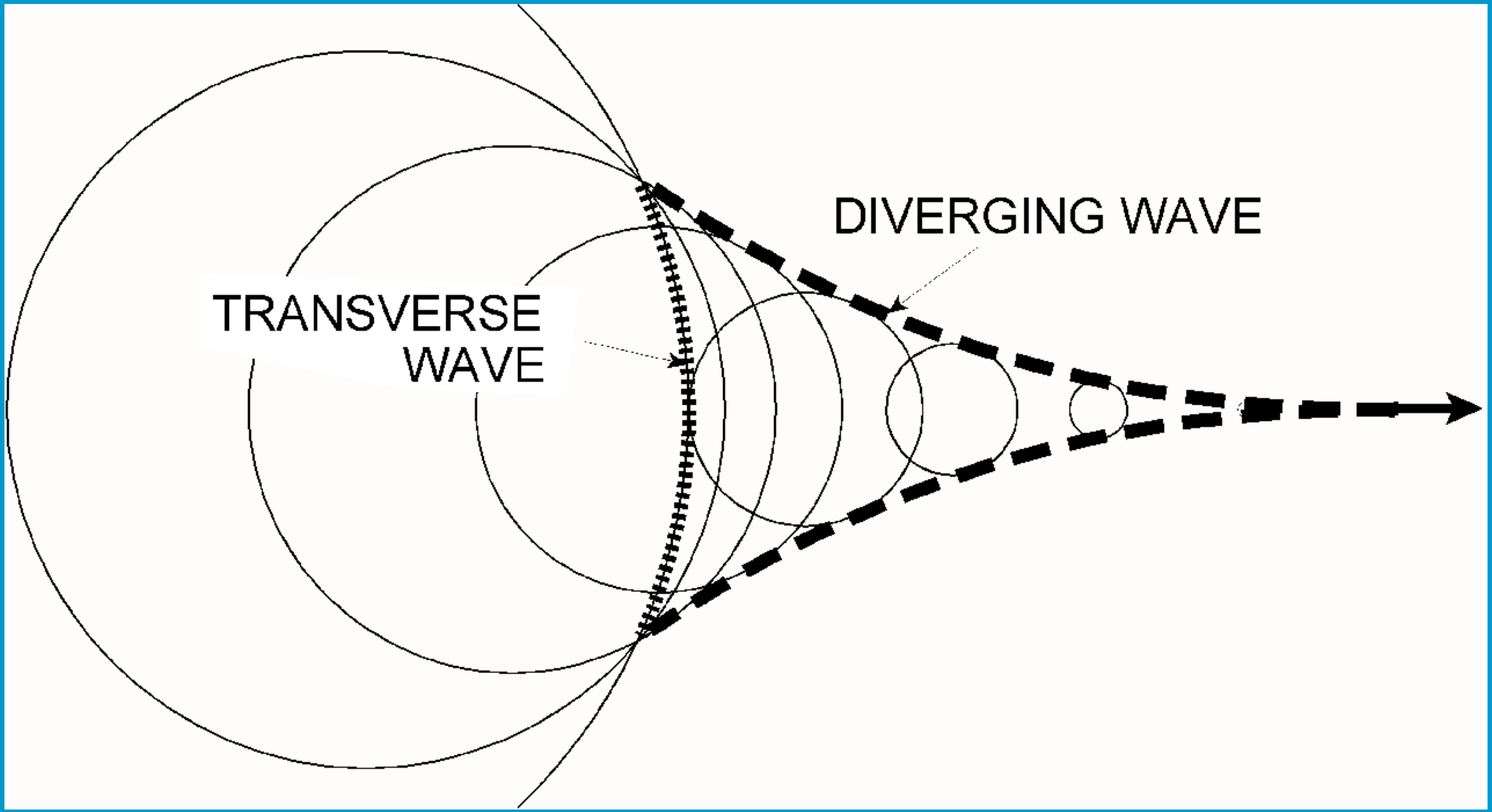
deviation from the 1-d case



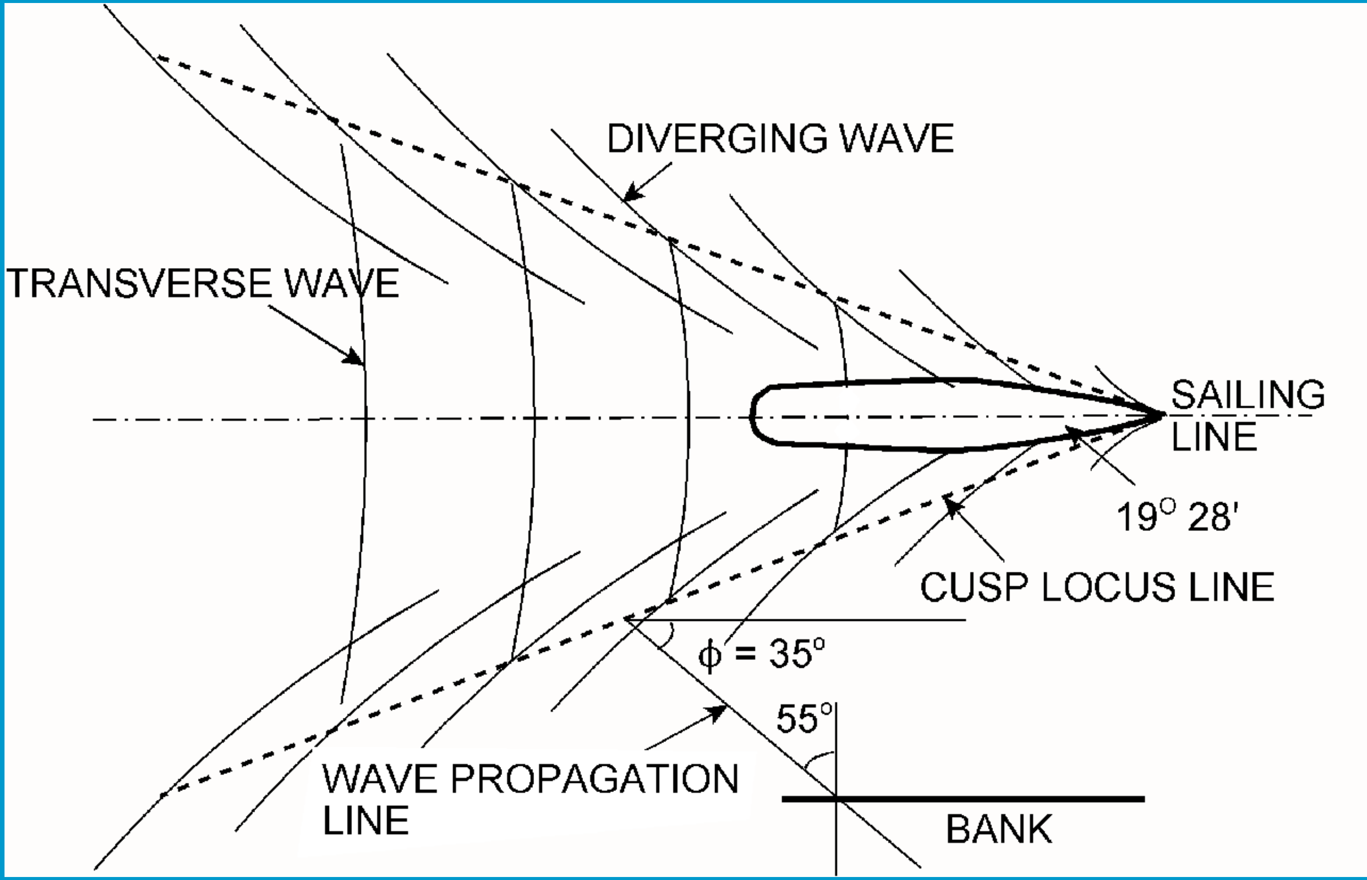
$$z_{ecc} = \left(1 + \frac{2y}{b}\right) z \qquad u_{r-ecc} = \left(1 + \frac{y}{b}\right) u_r$$

$$z_{\max} = 1.5 z_{ecc}$$

origin of diverging and transverse waves



secondary wave pattern



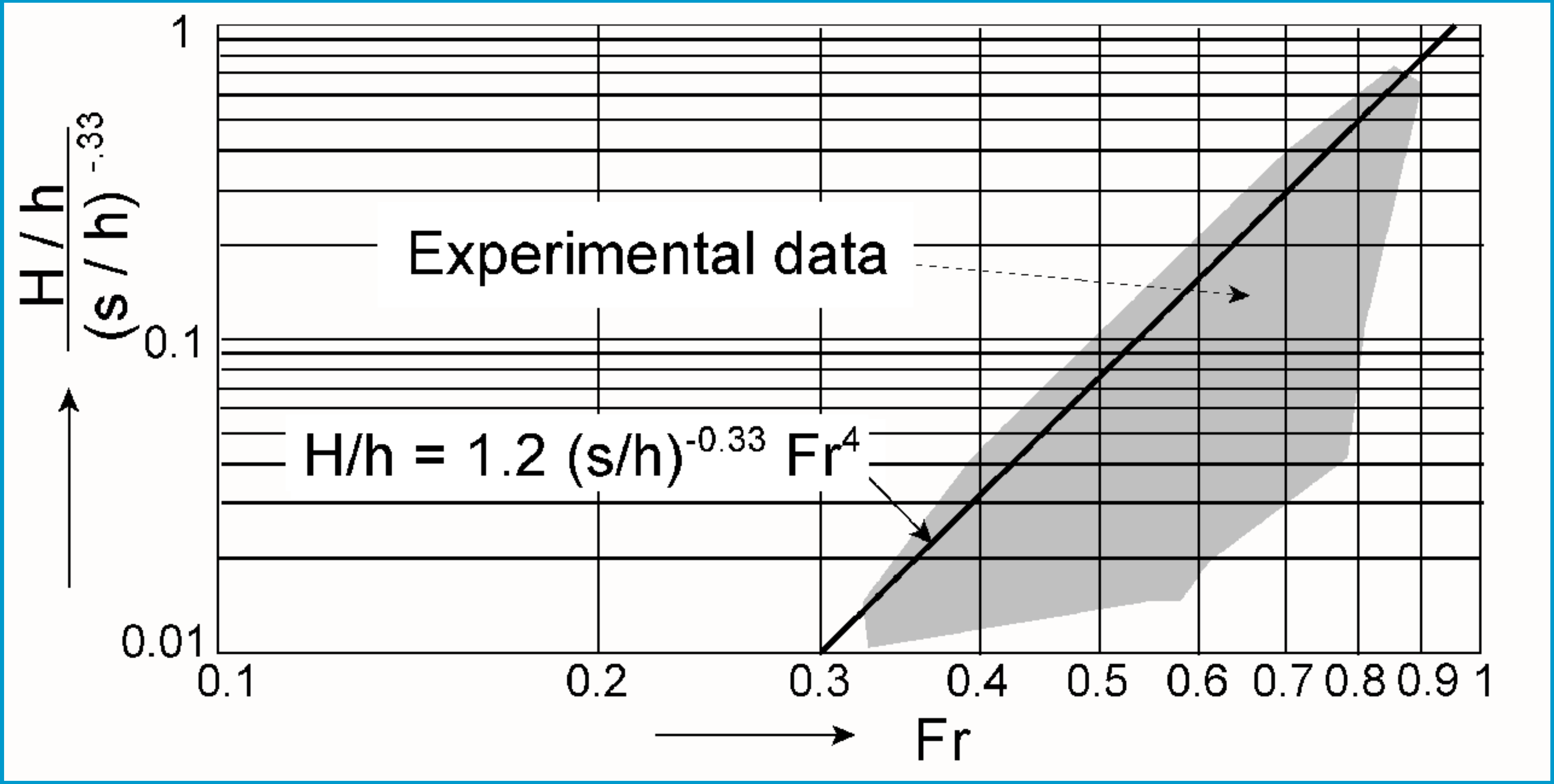
Kelvin wave

Christian Eskelund US Navy

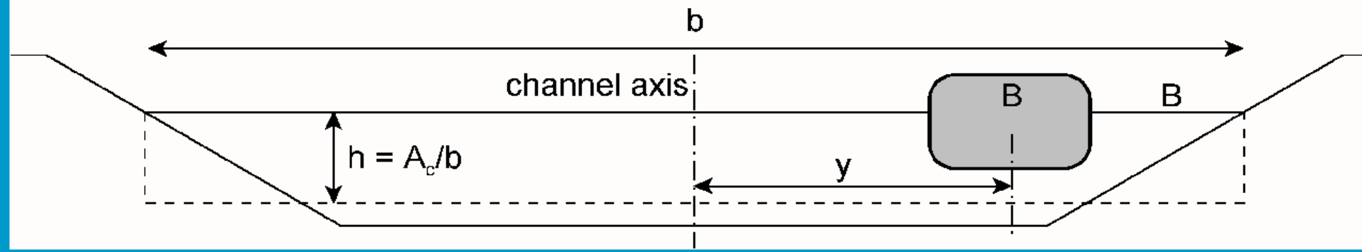
Kelvin Duck wave

M.S.Cramer, Virginia Tech Duck Pond

secondary wave height measurements



example



Given: ship 10 m wide, draught 3 m
canal 40 m wide, 5 m deep

Limit speed: $A_s/Ac = (10*3) / (40*5) = 0.15$ fig 9.4

$V_l/\sqrt{gh} = 0.55 \rightarrow V_l = 3.8$ m/s design speed 0.9*3.8=3.4 m/s

Use fig. 9.6 $z/h=0.083 \rightarrow z=0.42$ m

Ship sails 10 m from bank (y=

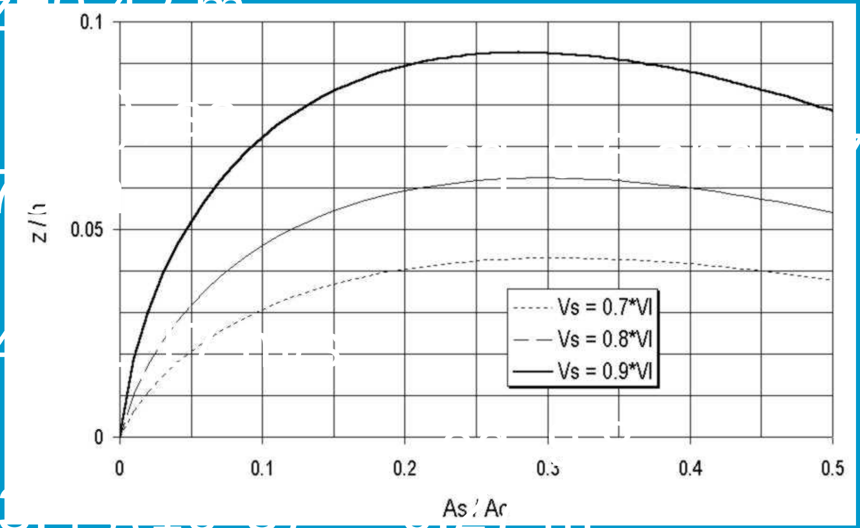
z_{max}=1.5((1+2*5/40)*0.42 = 0.7

$u_r = 0.15 *\sqrt{gh} = 1.04$ m

incl. excentricity: (1+5/40)*1.04

$H = 1.2\ h(s/h)^{-0.33}*v^4/(gh)^2 =$

$1.2*5*(10/5)^{-0.33}*$



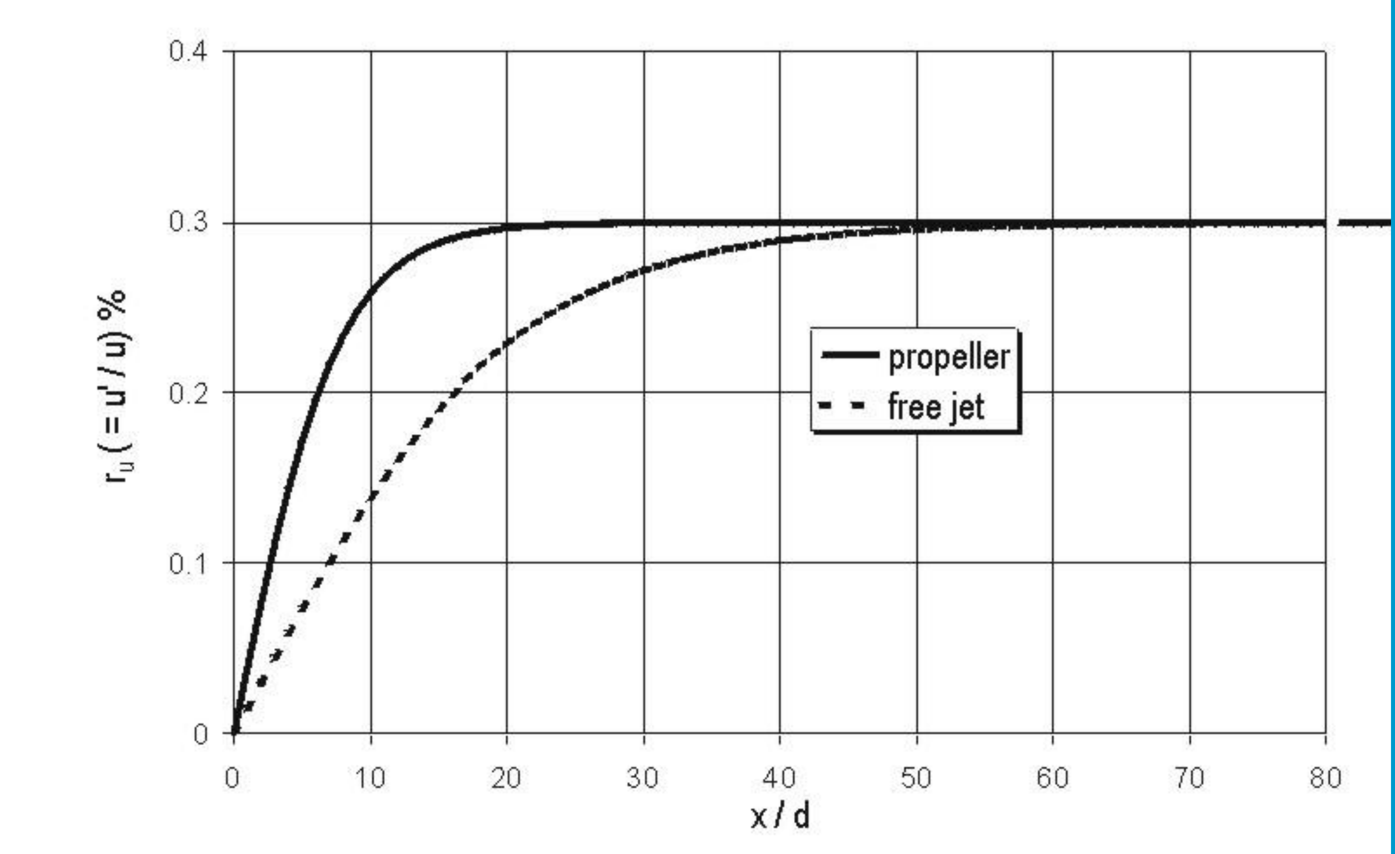
standard values in the Netherlands

	Wave heights (m)		Currents (m/s)	
	Wind waves	Ship waves	Natural current	Return current
Lakes	0.25 – 1.00	0.10 – 0.50	0.1 – 0.5	0.1 – 0.25
Canals	0.10 – 0.25	0.25 – 0.75	0.5 – 1.0	0.5 – 1.0
Rivers	0.25 – 1.00	0.25 – 0.75	1.0 – 2.0	0.5 – 1.0
Small waters	0.10 – 0.20	n.a.	0.2 – 1.0	n.a.

Data from CUR 197
“Breuksteen in de praktijk”

Propeller action

turbulence in propeller wash and in free circular jet



equations for propeller jets

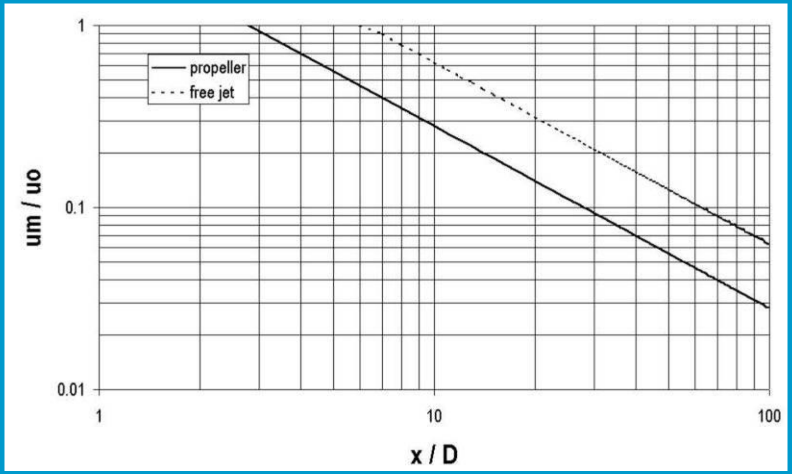
$$u_m = \frac{2.8u_0}{x/d}$$

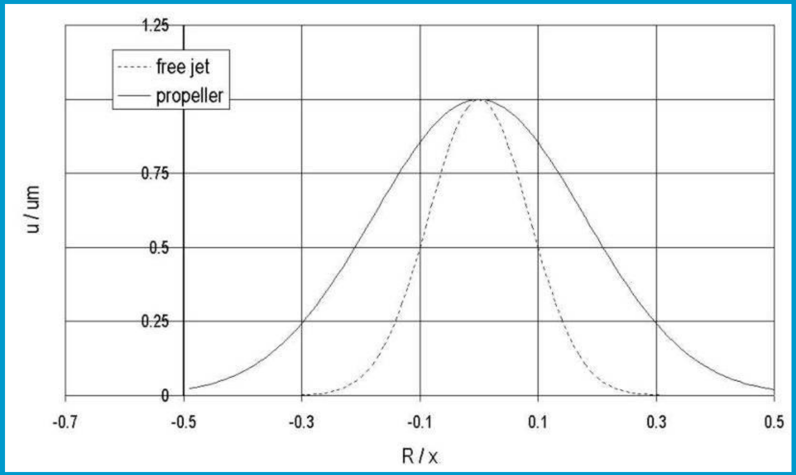
$$b = 0.21x$$

$$u = u_m e^{-0.69\left(\frac{r}{b}\right)^2}$$

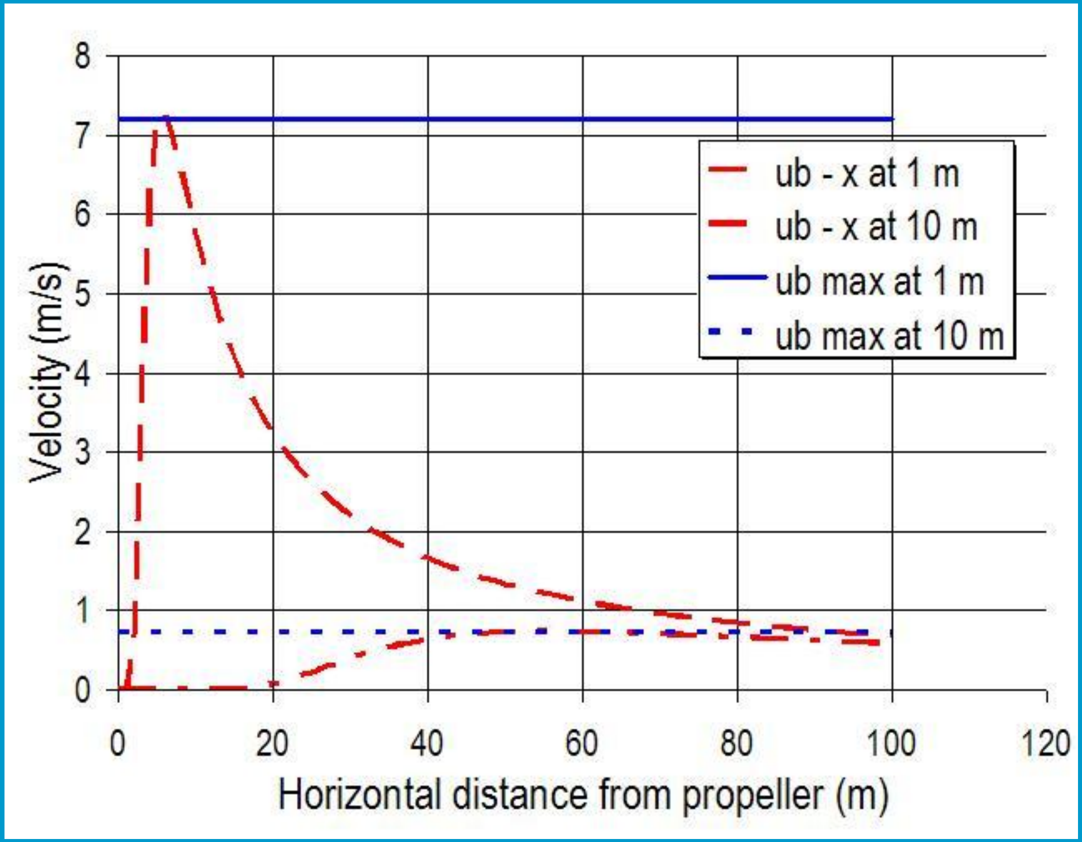
$$u = \frac{2.8u_0}{x/d} e^{-15.7\left(\frac{r}{x}\right)^2}$$

velocity distribution in propeller wash and free jets





velocities behind propeller

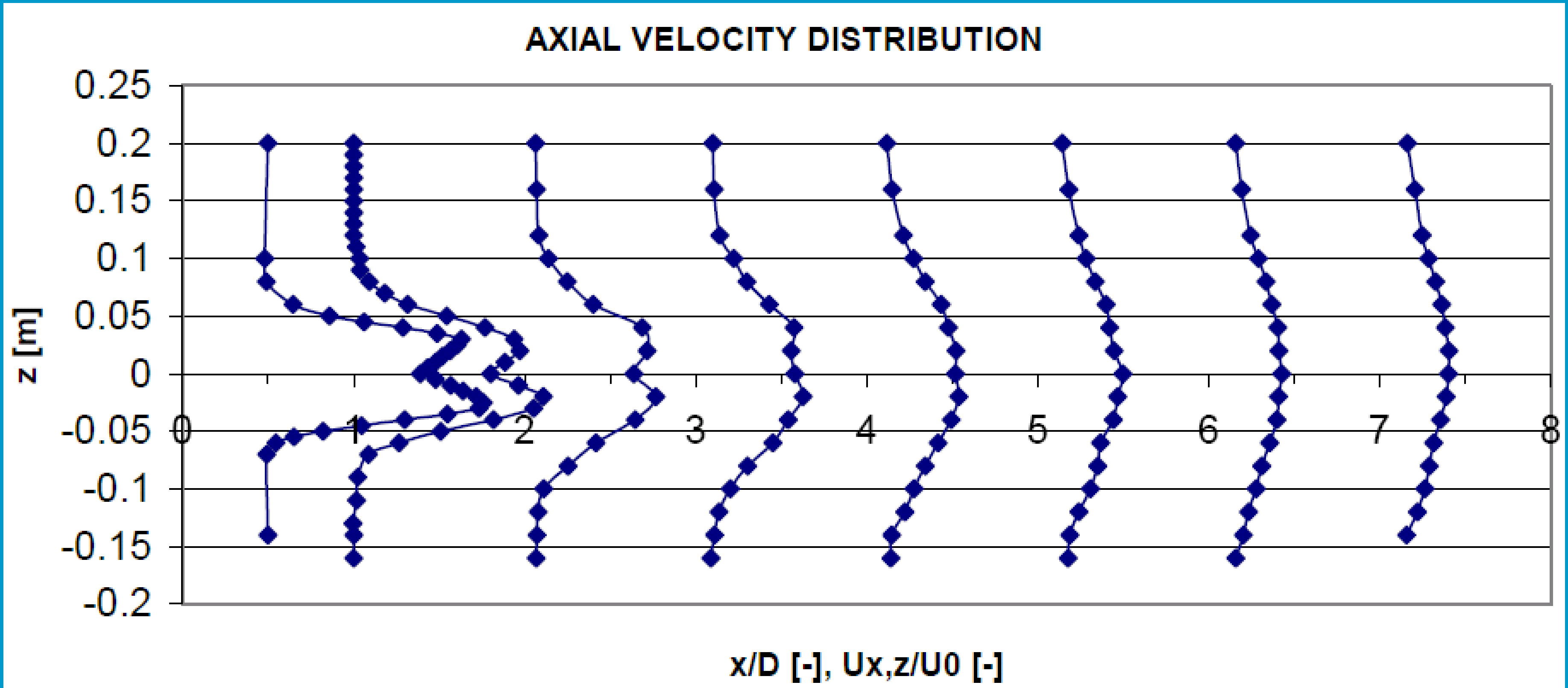


$$u_0 = 1.15 \left(\frac{P}{\rho d^2} \right)^{1/3}$$

$$u_{b-\max} = 0.3 u_0 \frac{d}{z_b}$$

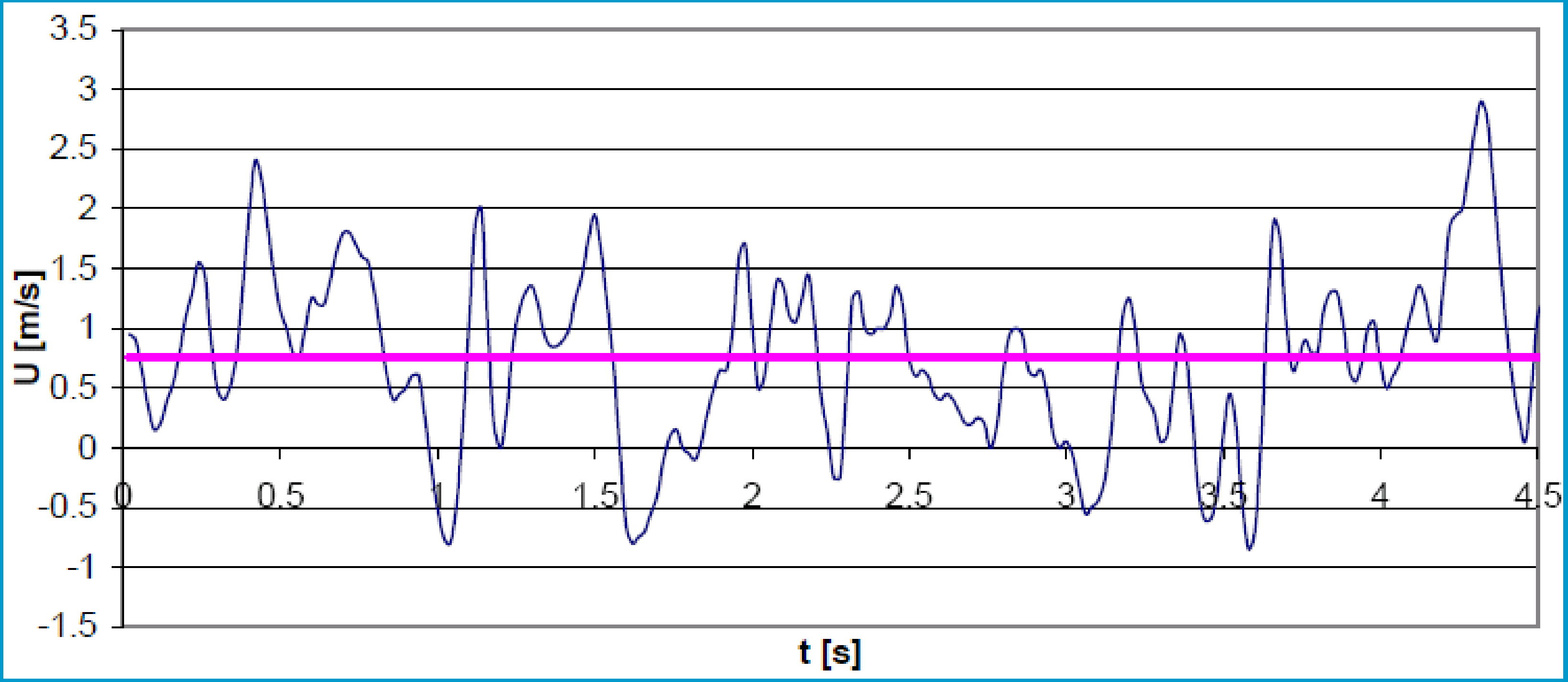
see also section 2.4.2.

measured flow in a propeller jet



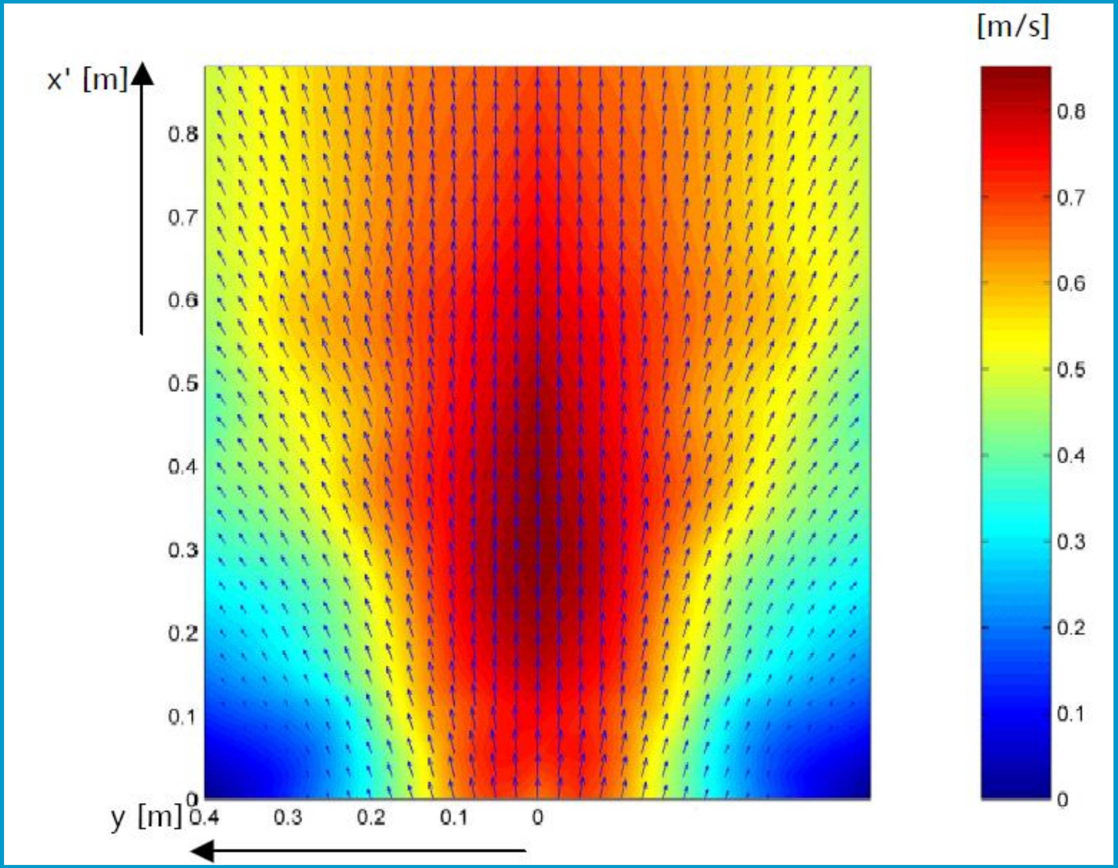
data from thesis Schokkink, 2003

Turbulence in a propeller jet



data from thesis Schokkink, 2003

Flow caused by a propeller on an inclined slope



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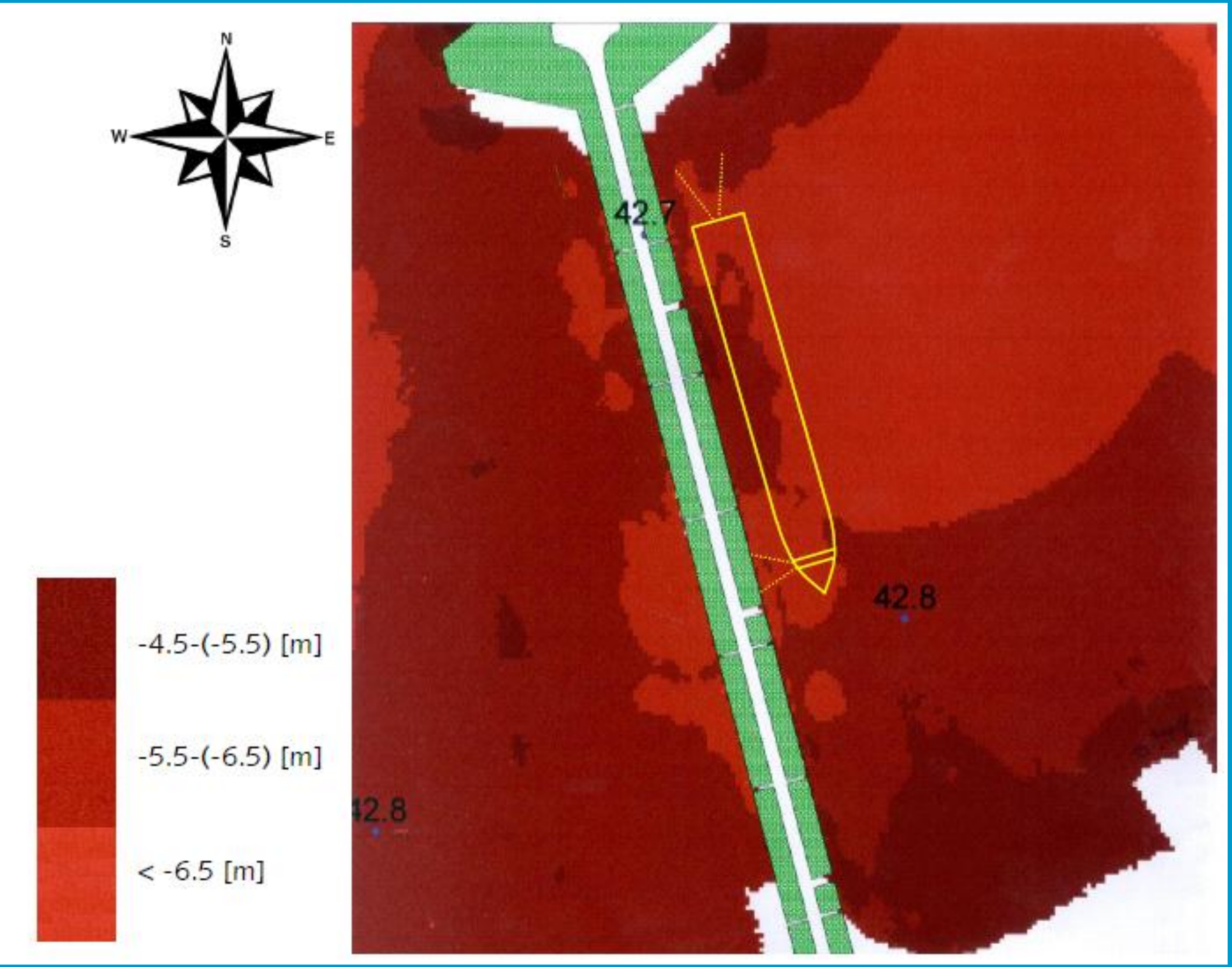
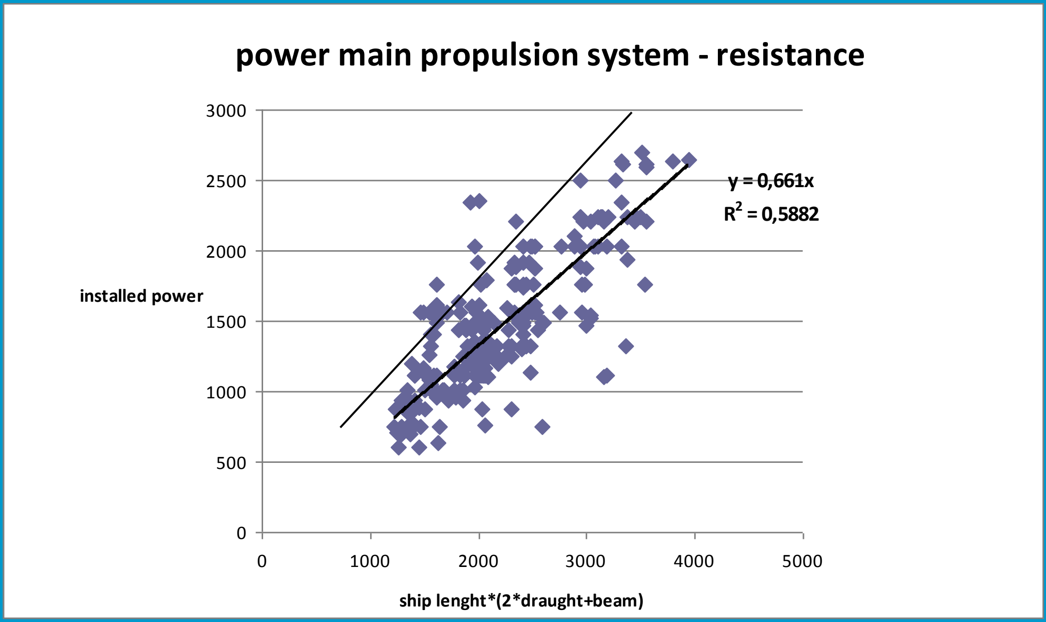
erosion due to bowthrusters



data from thesis Schokkink, 2003
Plofsluis, Amsterdam Rijn kanaal

Ship engines

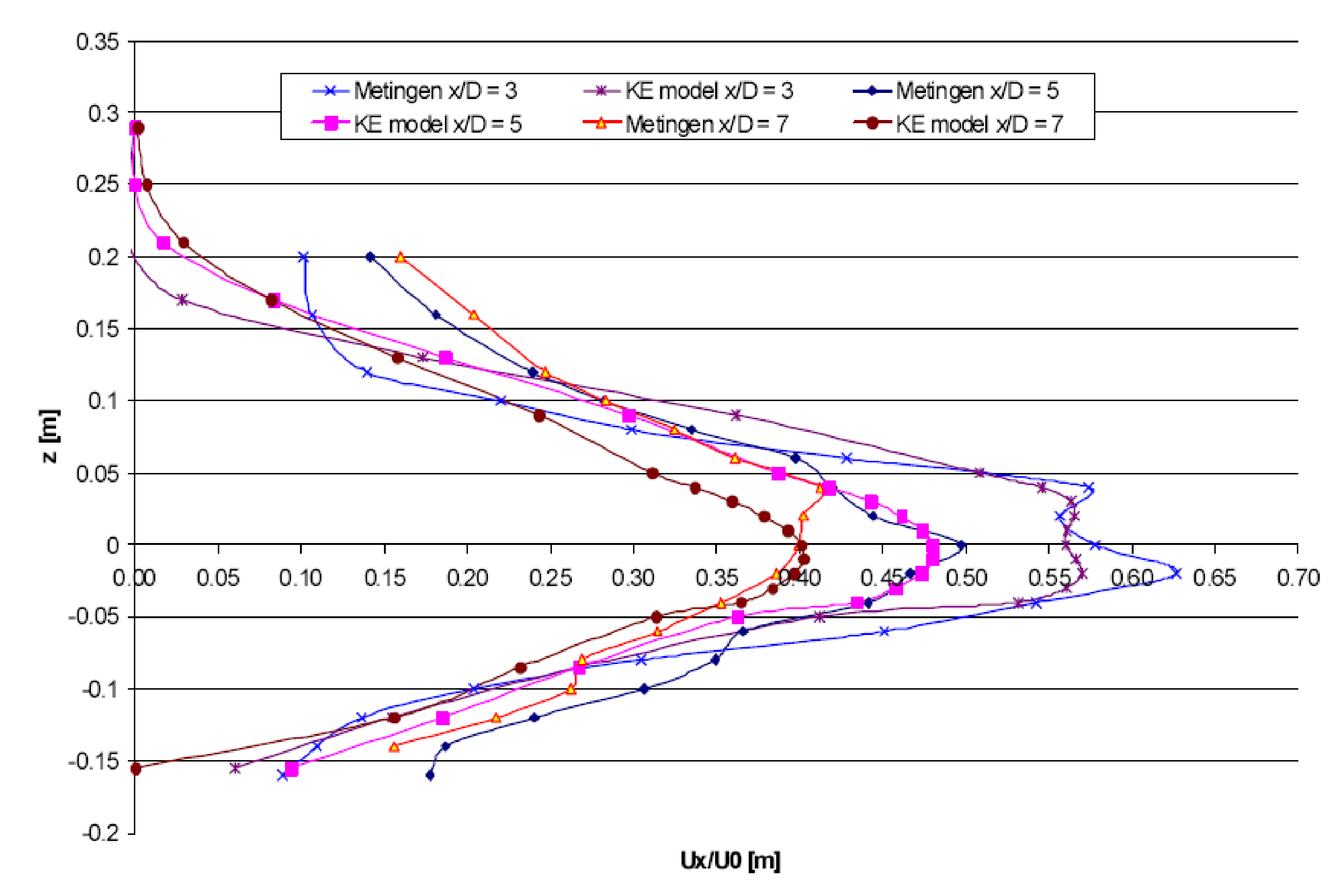


Type of ship	Power of engine (kW)
Small ships	100
Spits	200
Kempenaar	350
Dortmund-Ems Kanal	500
Rhein-Herne Kanal	700
Large Rhine vessel	1400
2 barge pushboat	1500

$$P_{mean}=0.66L(2D+B)$$
$$P_{10\%}=1.25\,P_{mean}$$

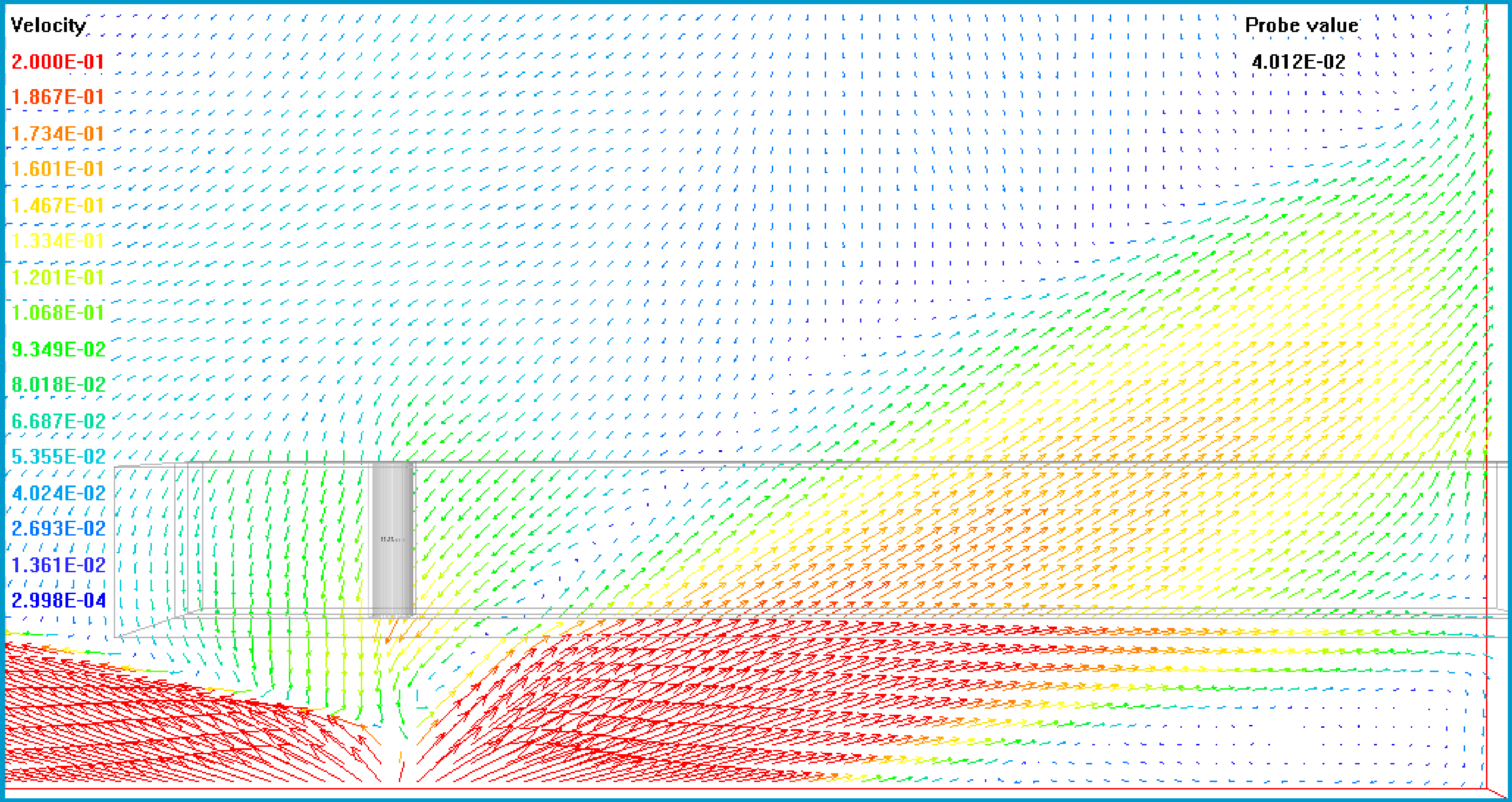
Data from Verheij (2010)

Simulation of a propeller jet



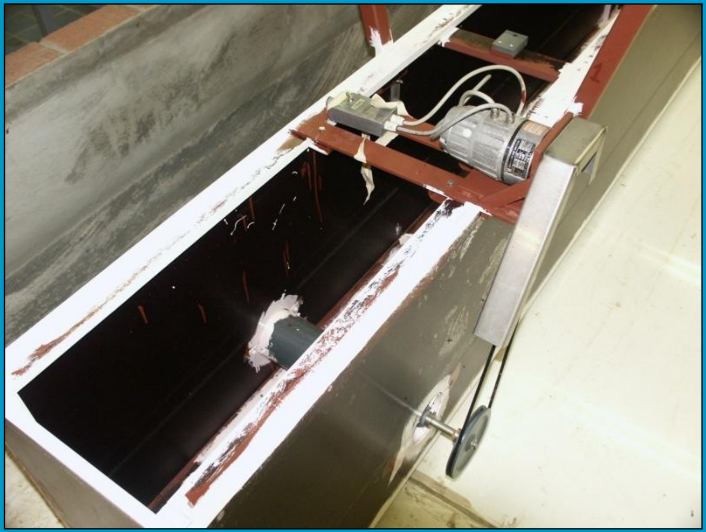
Model by De Jong [2003], measurements by Schokking [2002]

Model simulation with Phoenicx



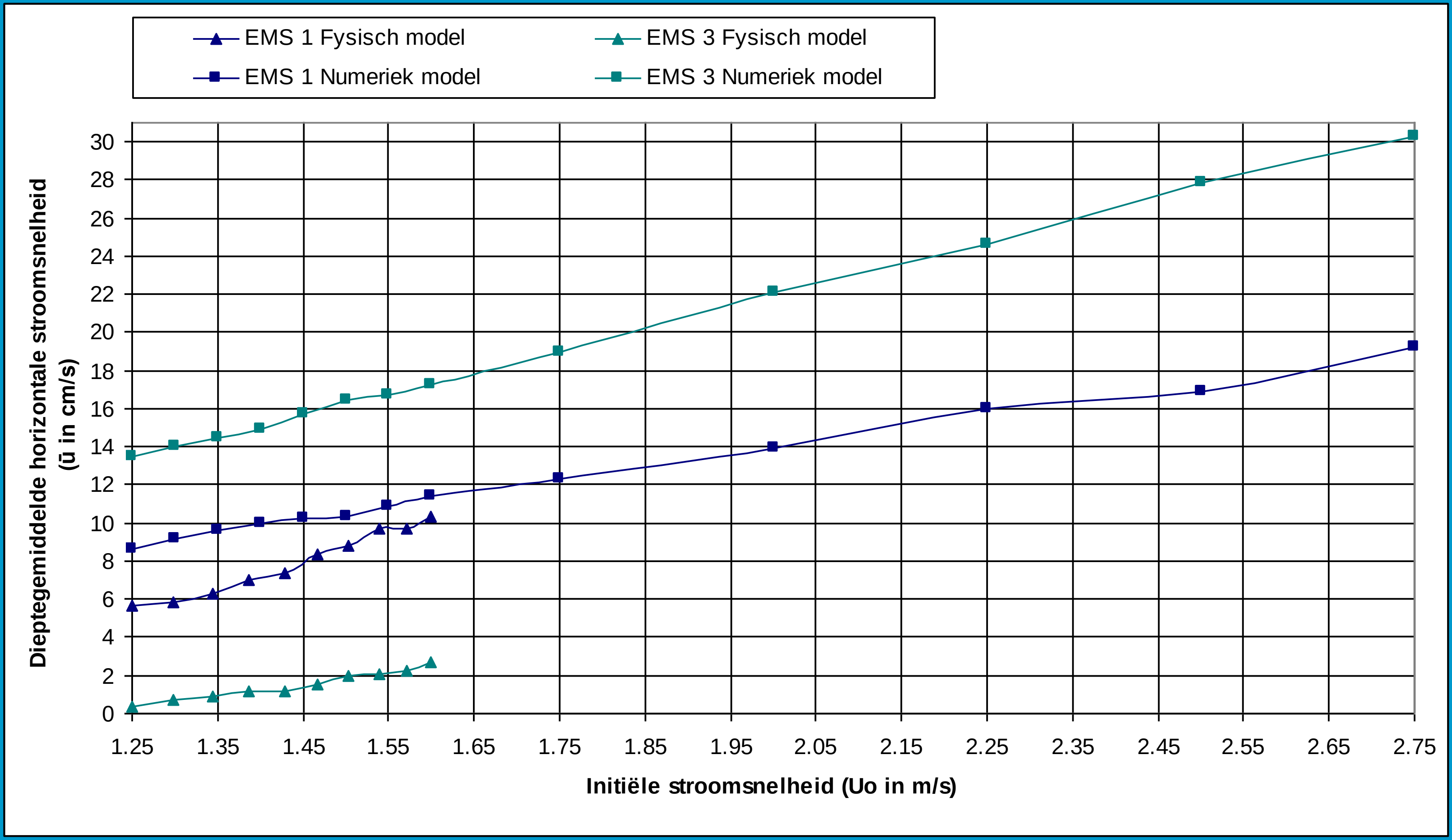
Data from Van der Laan [2005]

The physical model



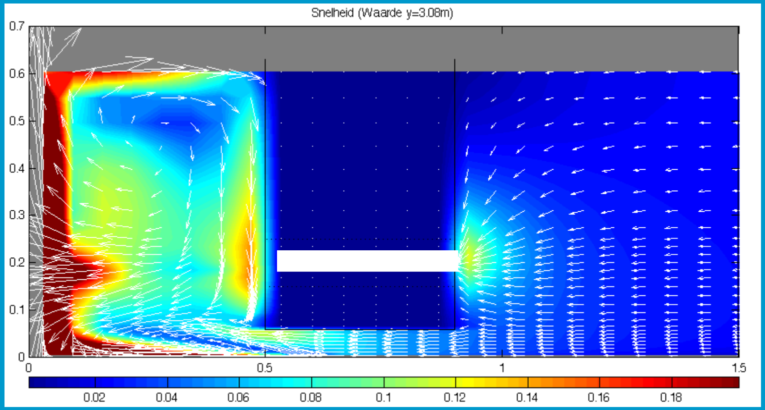
Van der Laan [2005]

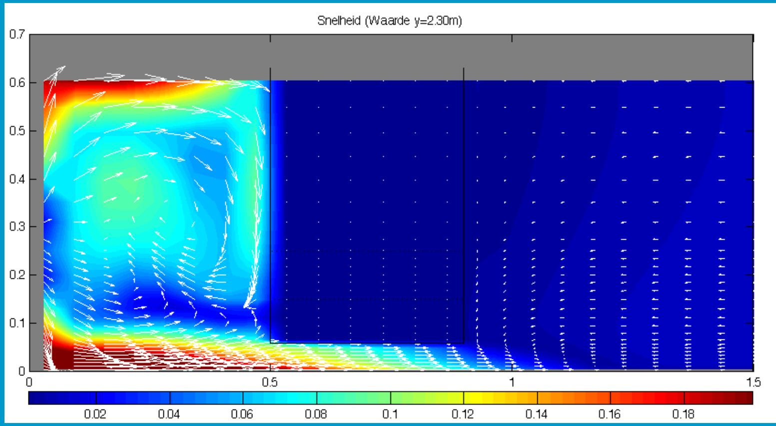
Mathematical vs. Physical model

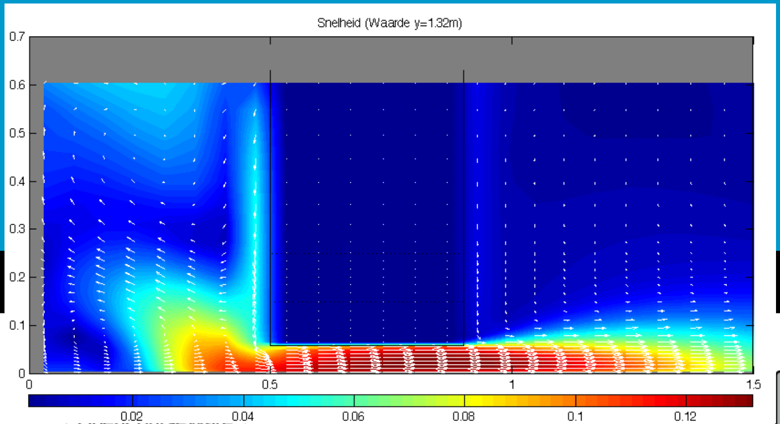


Van der Laan [2005]

flow under ship

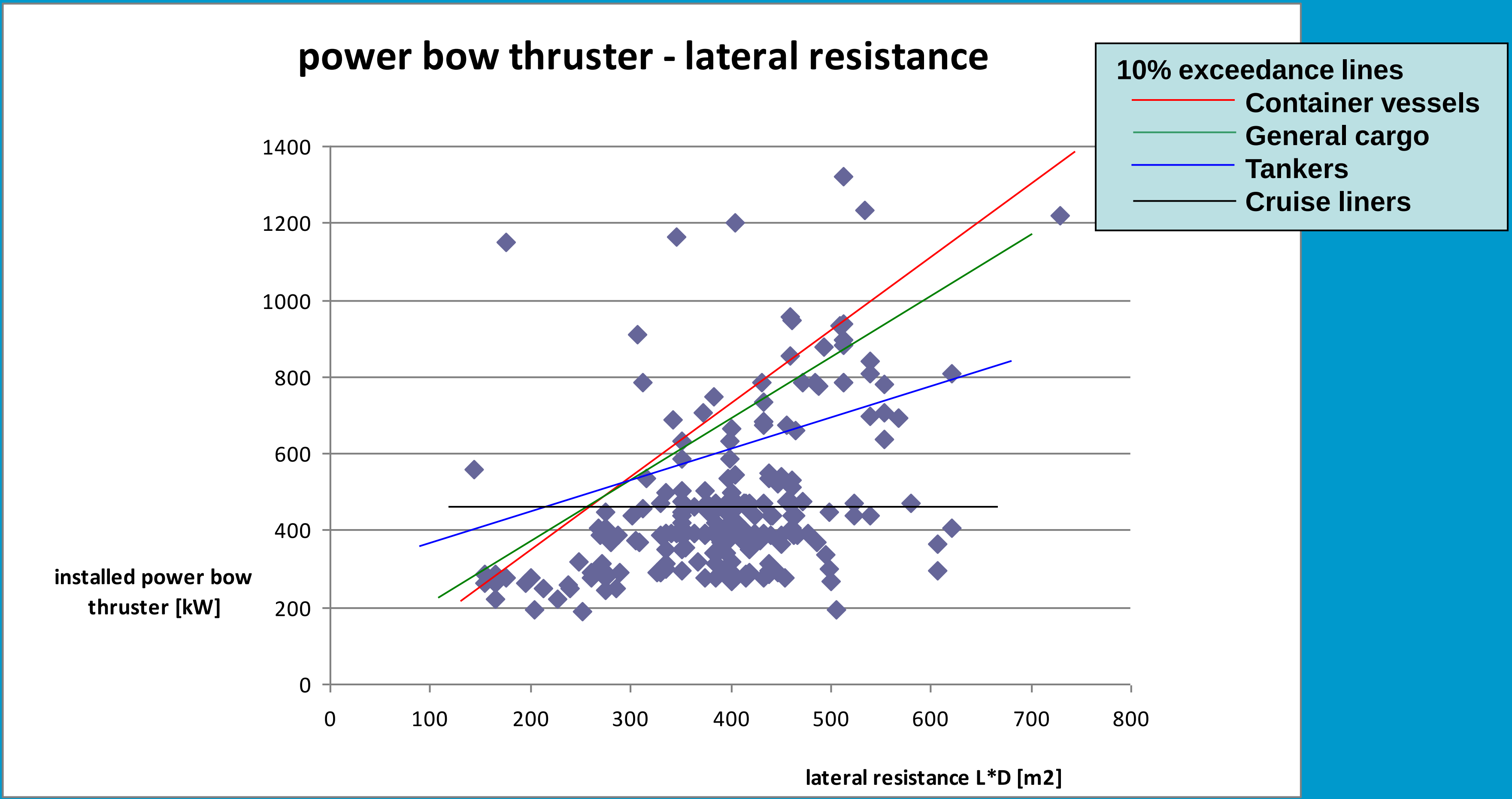






Egbert van Blaaderen, 2006

Data of all inland vessels - $P_{mean}=A_1LD+A_2$



Data from Verheij (2010)

stability of bed protection

- important are:
  - return flow
  - stern wave (depression)
  - secondary waves
  - propeller wash
- Relations based on Izbash + experimental data
- Hartelkanaal tests provided good data
  - M1115 1980-1988
  - Q908 1990
- Dipro

bow thrusters

$$P_d = A_1(LD) + A_2$$

$$D_0 = 0.068 P_d^{0.5}$$

$$v_p = 1.15\zeta\left(\frac{P_d}{D_0^2}\right)^{1/3}$$

$$v_b = 1.03 v_p \frac{D_0}{z_p}$$

P_d = Power of engine
L = lenght of ship
D = draught of ship
D_0 = diameter of propeller
v_p = velocity behind thruster
v_b = velocity near the bed
ζ = loss factor = 0.9
z_p = distance propeller axis and bottom of channel

The axis of the thruster is αD_p above the bed, but for α there is no default given.

stability (primary waves)

$$\Delta d_{n50} = 1.2 \frac{u_r^{\,2}}{2g} \frac{1}{\sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}}}$$

$$\frac{z_{\max}}{\Delta d_{n50}} = 1.8 \cot \alpha^{0.33}$$

stability (secondary waves)

$$\frac{H\sqrt{\cos 55°}}{\Delta\, d_{n50}} = 2.7\,\xi^{-0.5} \quad \rightarrow \quad \frac{H}{\Delta d_{n50}} = 3.6\,\xi^{-0.5}$$

stability (propeller wash)

$$\Delta d_{n50} = 2.5 \frac{u_b^{\ 2}}{2g} \frac{1}{\sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}}}$$

example (2)

given: depression = 0.78 m

H = 0.27 , T = 1.8 s

u_r = 1.17 m/s tanα=1/3

stern wave effect:

$$\frac{z_{\max}}{\Delta d_{n50}} = 1.8 \cot \alpha^{0.33}$$

$$d_{n50} = \frac{0.78}{1.65 * 1.8 * 3^{0.33}} = 0.18m$$

return flow effect:

$$\Delta d_{n50} = 1.2 \frac{u_r^2}{2g} \frac{1}{\sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}}}$$

$$d_{n50} = \frac{1.2 * 1.17^2}{1.65 * 2 * 9.81 * \sqrt{1 - 0.31^2}} = 0.06m$$

secondary wave effect:

$$\frac{H}{\Delta d_{n50}} = 3.6 \xi^{-0.5}$$

$$d_{n50} = \frac{0.27 \sqrt{\xi}}{1.65 * 3.6} = 0.06m$$

example (3)

- stern wave dominates problem
- action of stern wave only at waterline
- at deeper water return flow dominates
- at more spacious water bodies secondary waves become dominant

example (4)

Ship 10 m wide, d3 m draught, 1000 kW engine (1370 hp), propeller diameter 1.4 m, propeller 1.5 m above bed

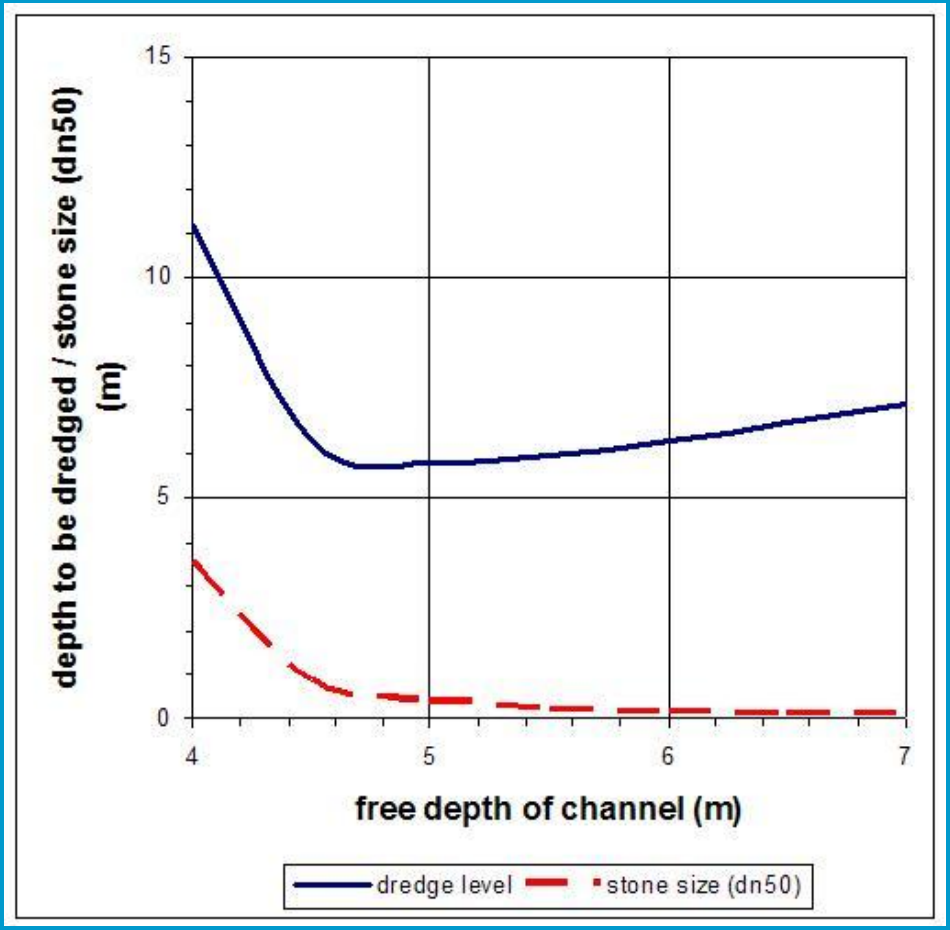
Effective jet = 70% of real diameter, so d = 1 m

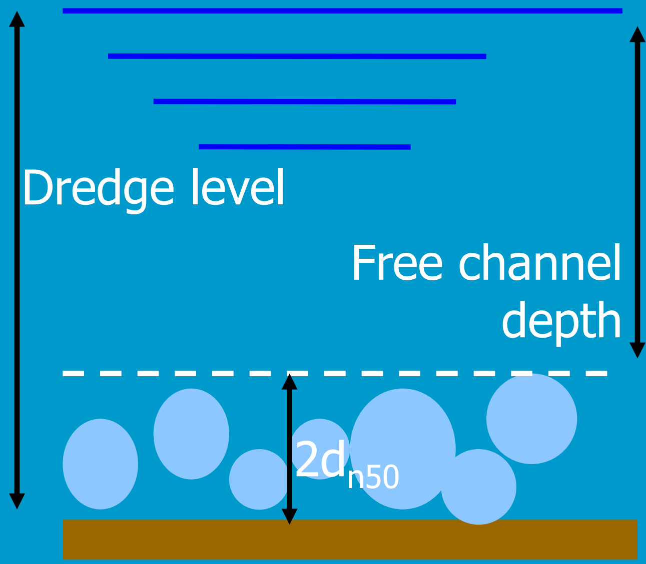
$$u_0 = 1.15 \left(\frac{P}{\rho d^2} \right)^{1/3} \qquad u_0 = 1.15 \left(\frac{10^6}{1000 * 1^2} \right)^{0.33} = 11.2 \ m/s$$

$$u_{b-\max} = 0.3 u_0 \frac{d}{z_b} \qquad u_b = 0.3 * 11.2 \frac{1}{1.5} = 2.25 \ m/s$$

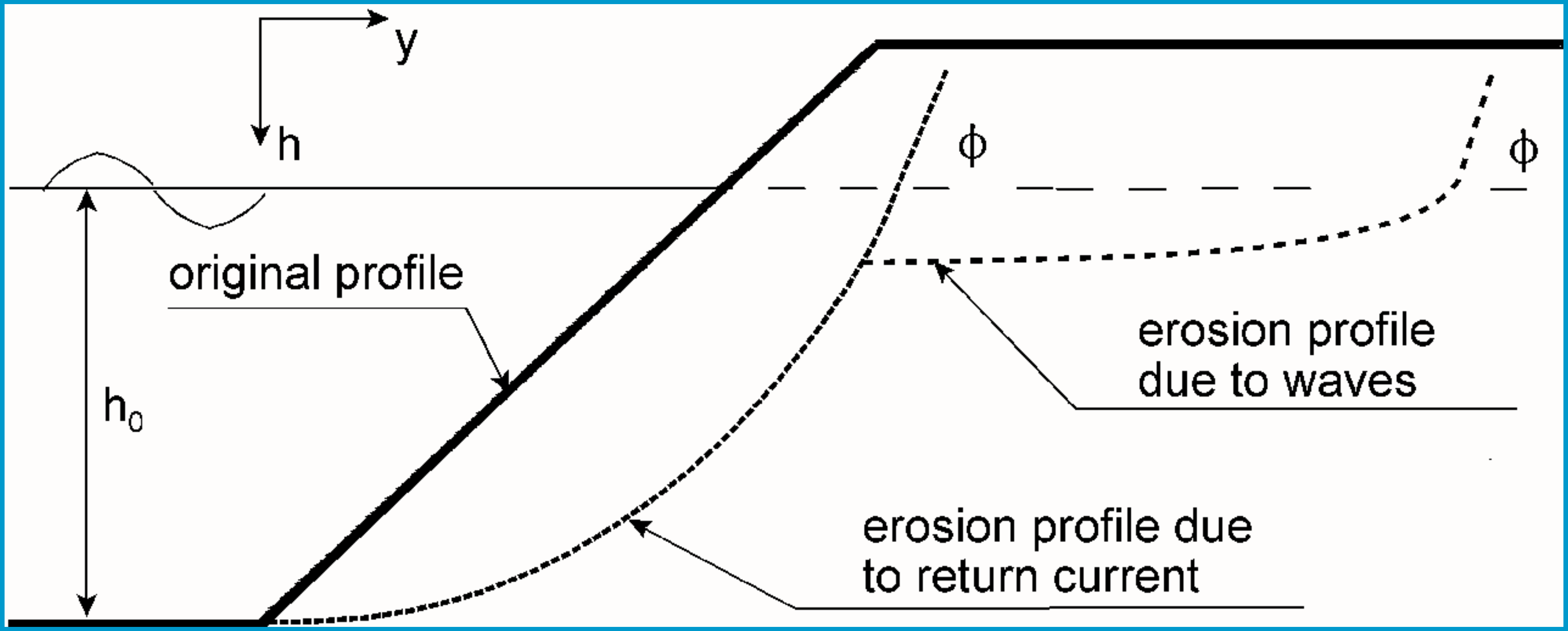
$$\Delta d_{n50} = 2.5 \frac{{u_b}^2}{2g} \frac{1}{\sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}}} \qquad d_{n50} = \frac{2.5 * 2.25^2}{1.65 * 9.8} = 0.4 \ m \ \left(60/300 kg \right)$$

Optimal depth of a channel



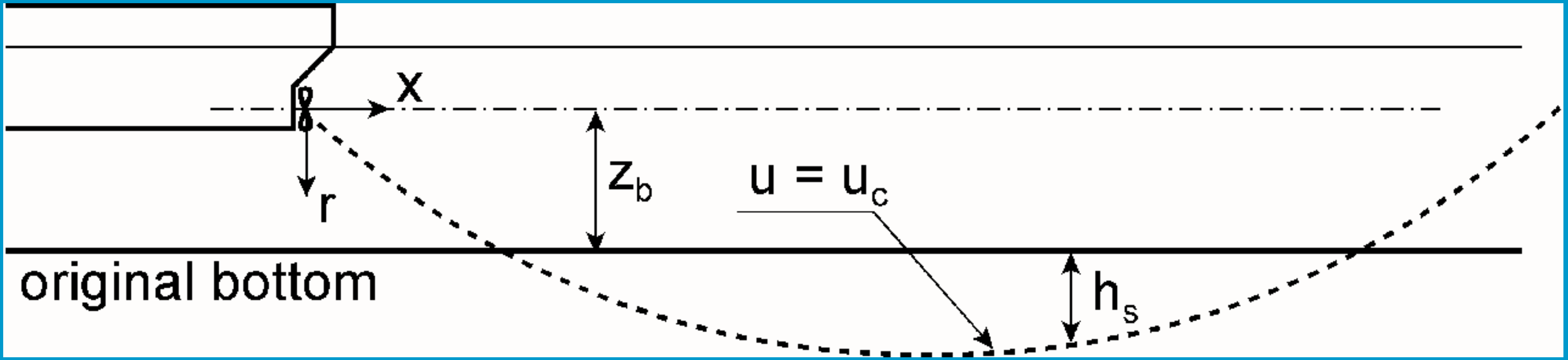


erosion



$$h = h_0 \cos\left(\tan(\phi)\frac{y}{h_0}\right)$$

bed erosion due to propeller wash



$$h_s = x\sqrt{\frac{-\ln\left(\frac{u_c x}{5.6 u_0 d}\right)}{15.7}} - z_b$$

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