Navigational experiments to verify a calculational approach for **riprap bank protections**

Department Hydraulic Engineering in Inland Areas
Section W4 - Interaction ship/waterway, field investigations

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Table of contents

Cause

Criticism of the draft version of the recommondations (issue Nov. 99)

„Design of bank and bed protections (MBB)“

concerning:

- Relevant driving situations
  (ship speed, eccentricity, draught)

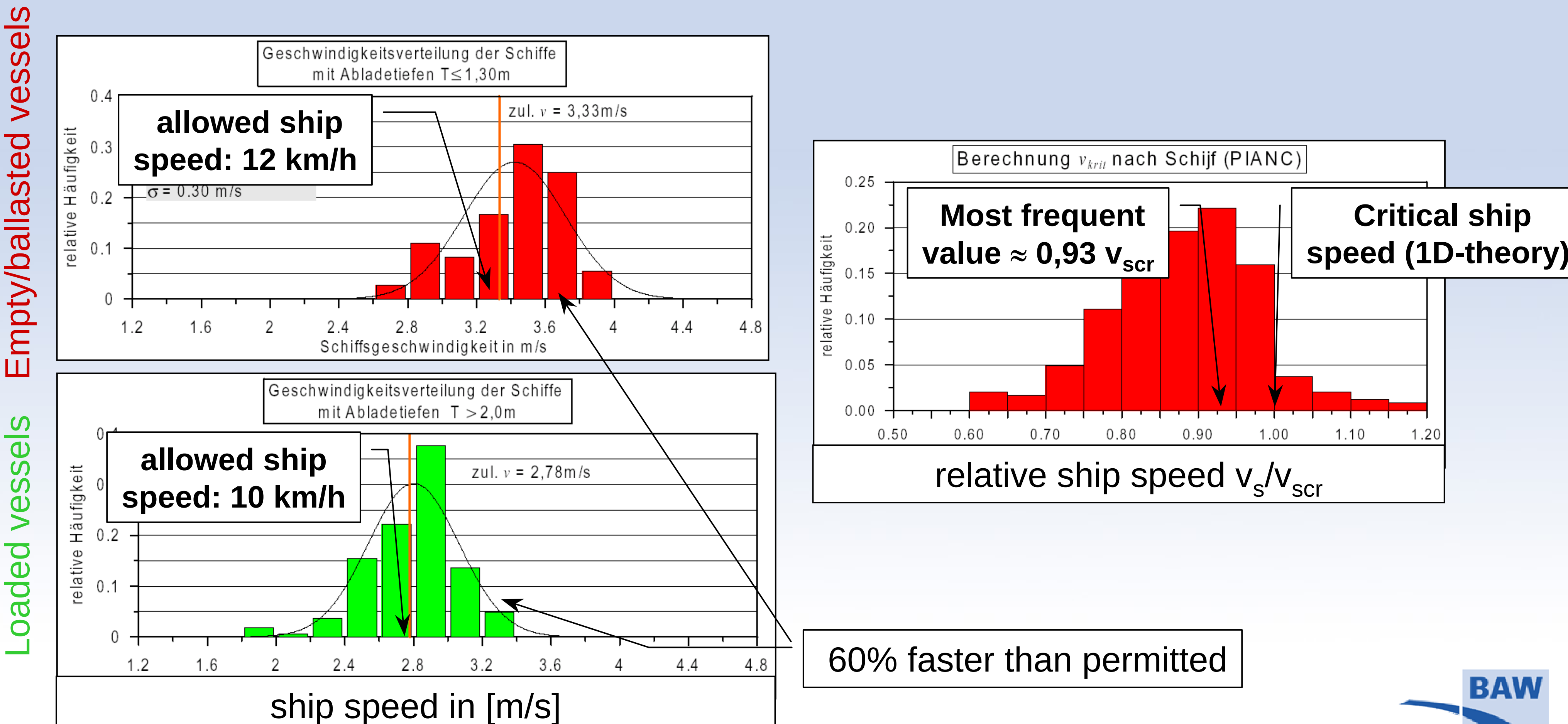
- Relevant hydraulic loads
  (bow wave, drawdown, stern wave, breaking transversal stern wave)

- Necessary minimum stone size

Performance of navigational experiments to verify and calibrate an existing calculational approach

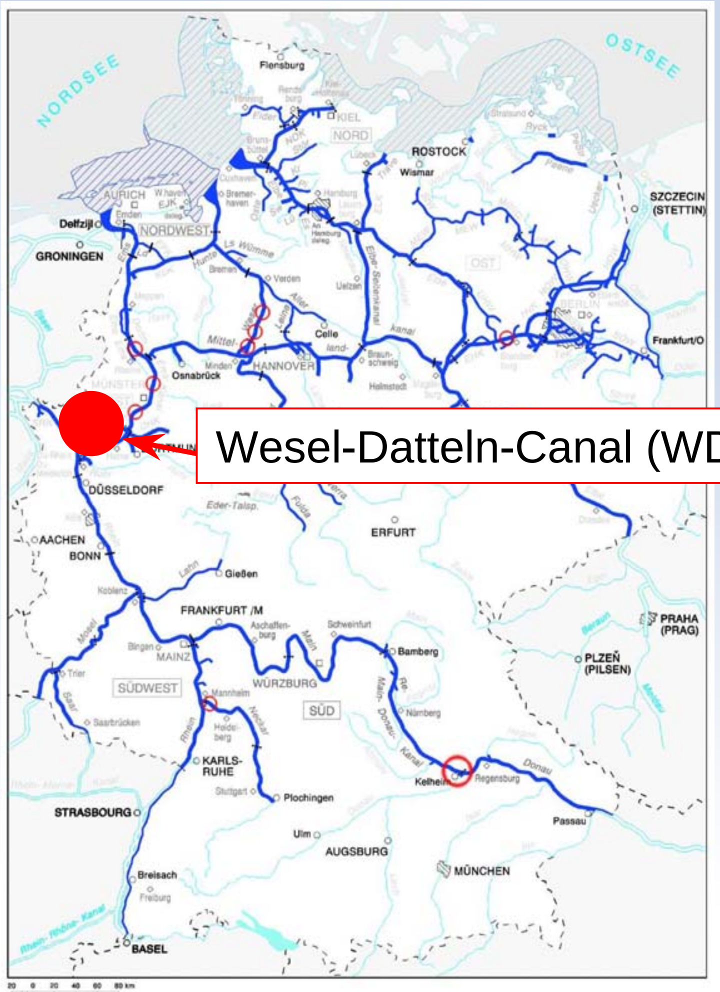
Preparatory site investigations

- real ship speed, path excentricities, wave heights
- 1 week day/night unnoticed wave and traffic observation in a canal section with riprap bank protection



Performance of the navigational experiments

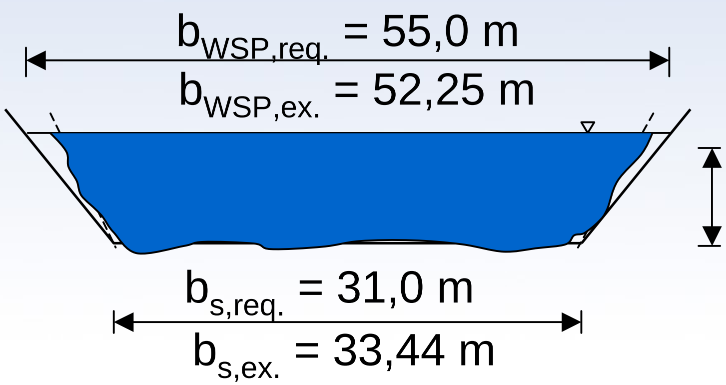
Track selection



Requirements:

- Prismatic canal ($l_S > b_{canal}$)
- low flow velocity
- low traffic
- possibility to make retests under similar conditions
- feasibility concerning measuring techniques

WDK-km 46,400 - 46,600



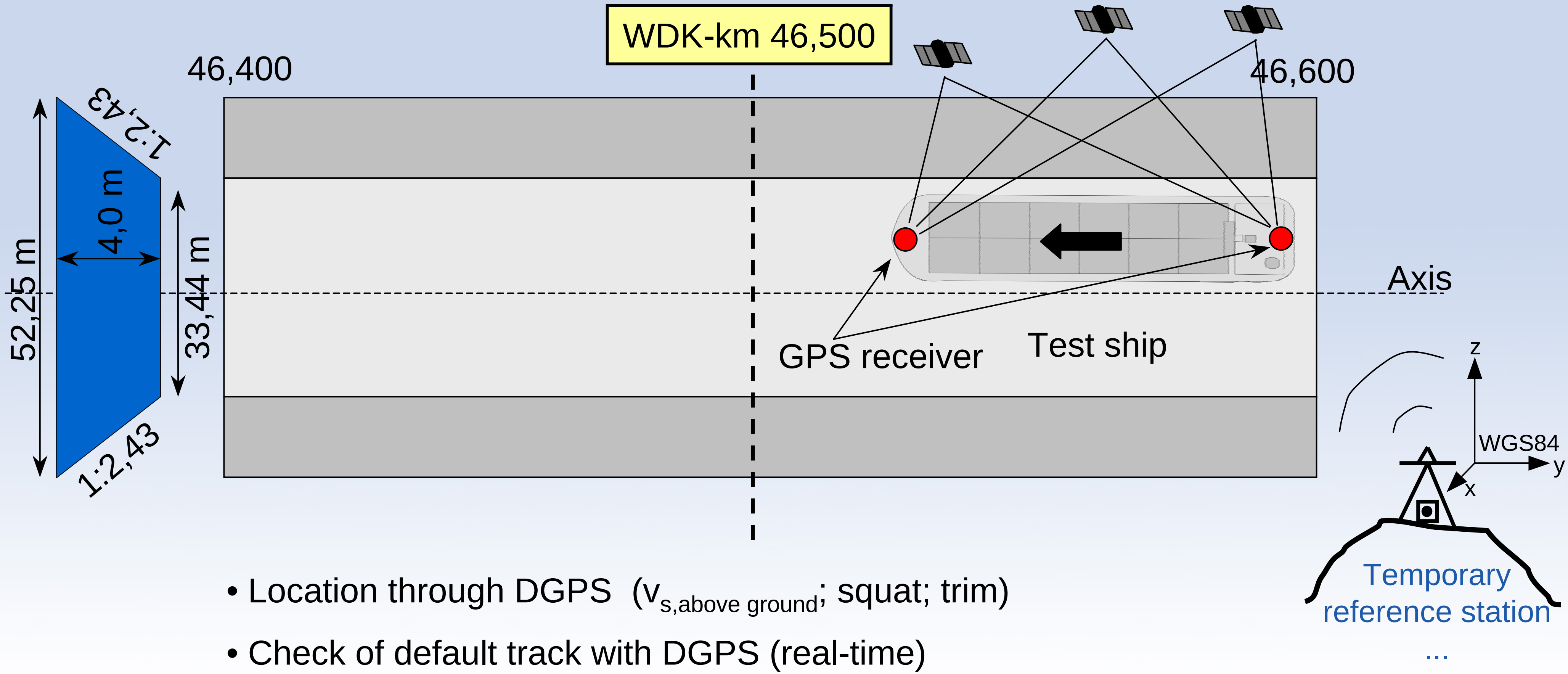
$m_{req.} = 3,00$
$m_{ex.} = 2,43$

$h_{req.} = 4,00$ m
$h_{ex.} = 3,98$ m

$A_{req.} = 172\ m^2$
$A_{ex.} = 165,8\ m^2$

Gauging methods

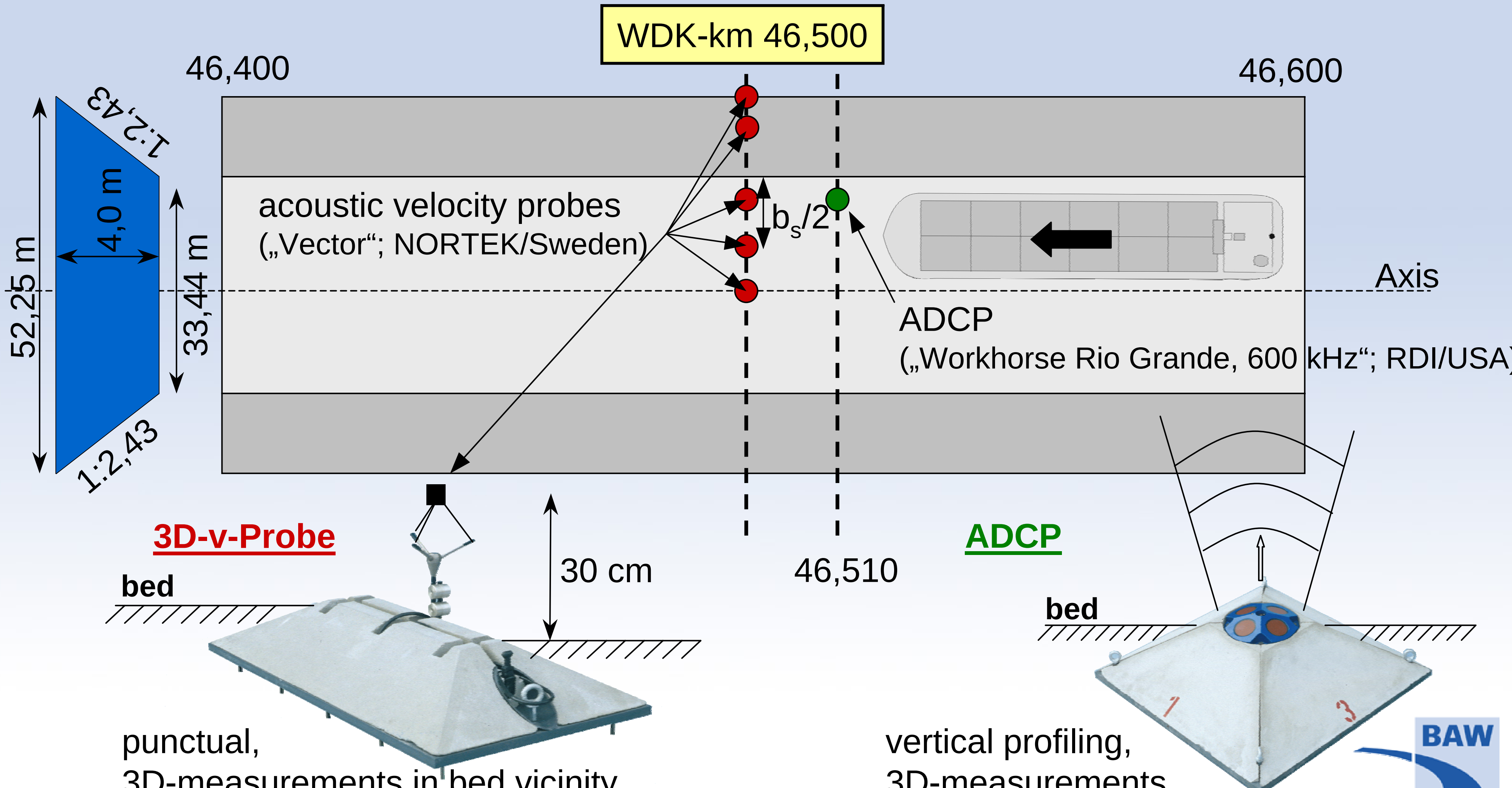
On-ship measuring devices



- Location through DGPS ($v_{s,above\ ground}$; squat; trim)
- Check of default track with DGPS (real-time)
- propeller: rate of revolutions and used power

Gauging methods

Flow measurements

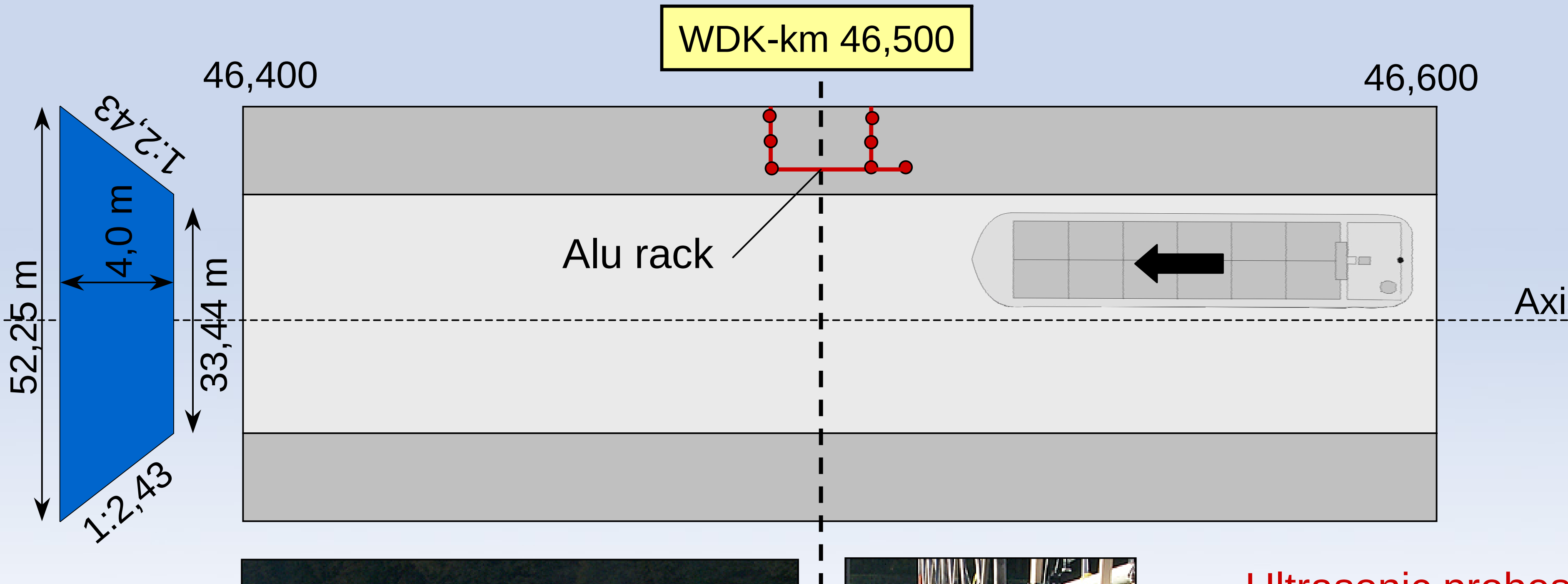


punctual,
3D-measurements in bed vicinity

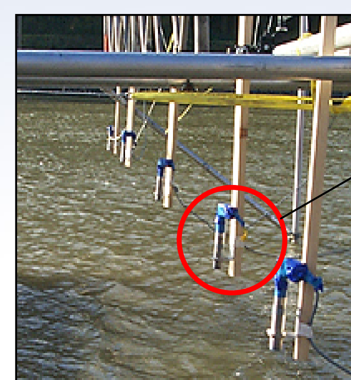
vertical profiling,
3D-measurements

Gauging methods

Measurements of ship induced waves



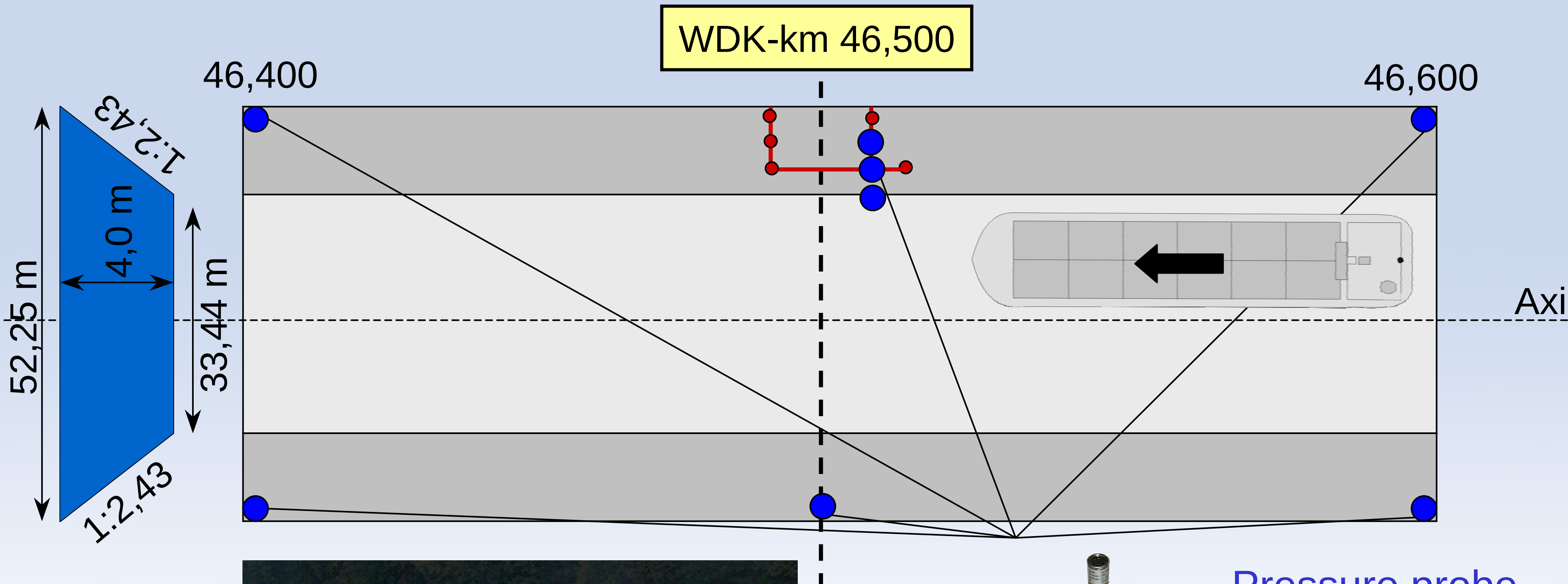
Alu rack



Ultrasonic probes:
wave heights in several distances from the bank

Gauging methods

Measurements of ship induced waves



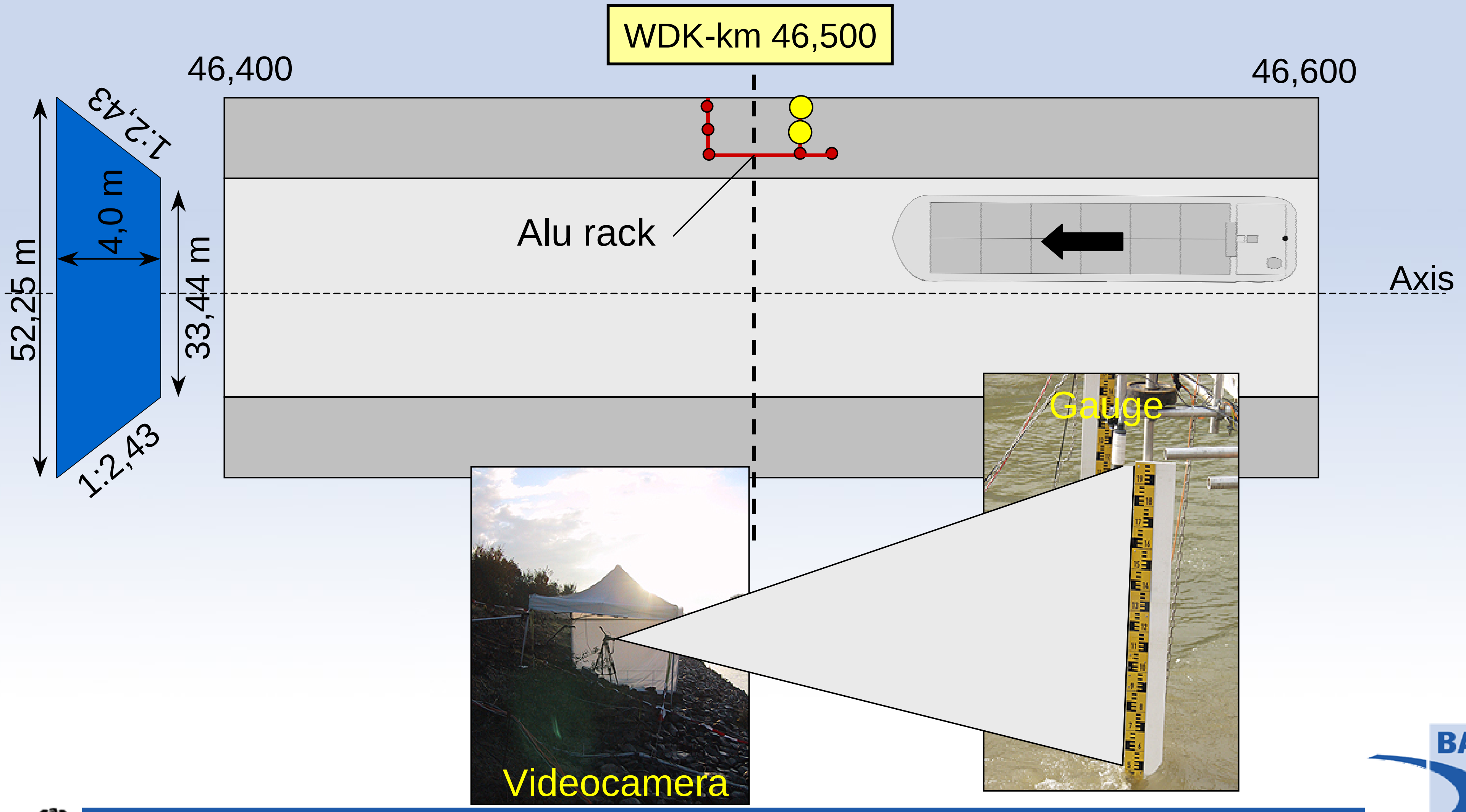
Alu rack

Pressure probe
(Driesen&Kern/Germany)

sample rate 5 Hz

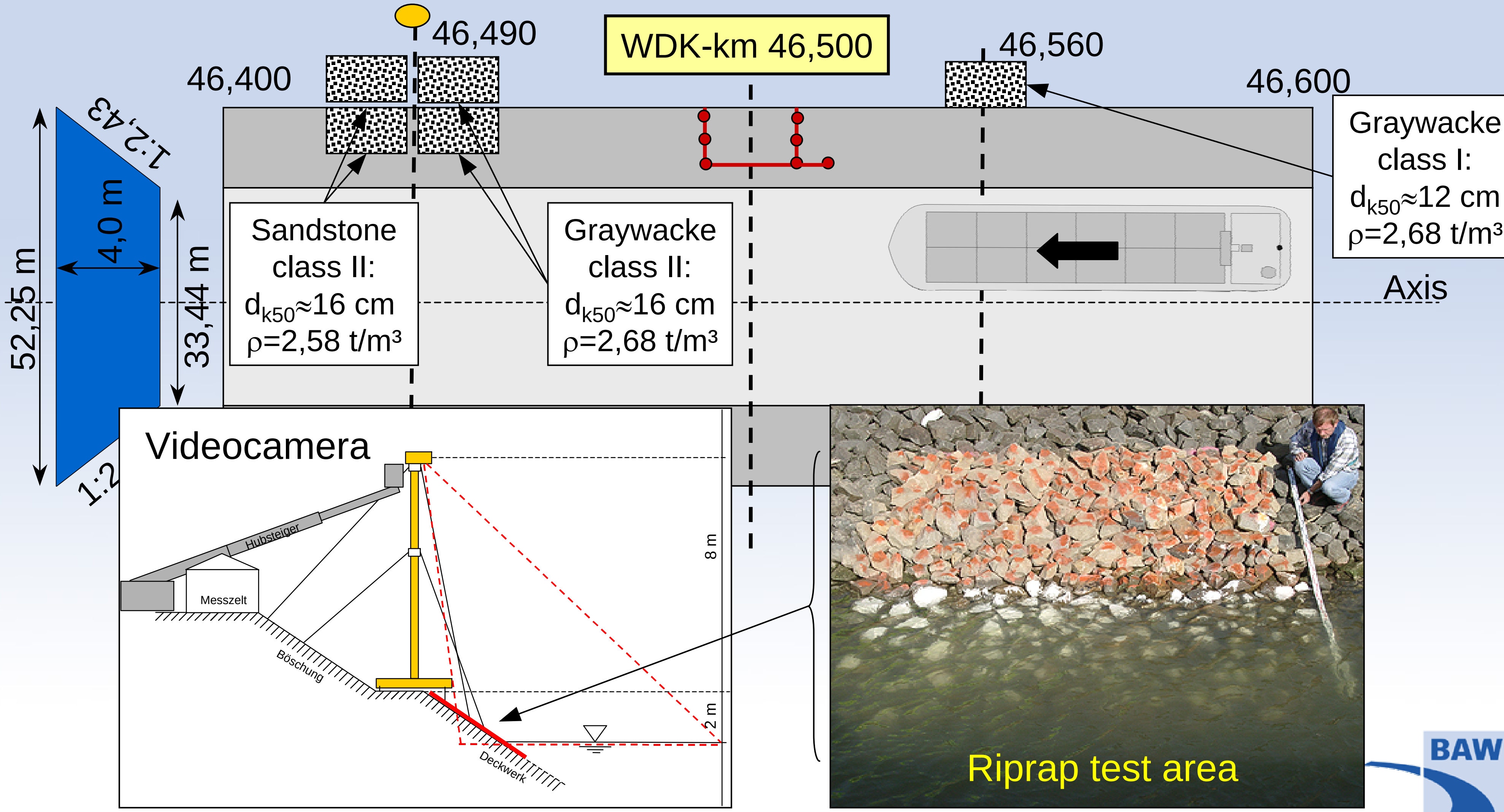
Gauging methods

Measurements of ship induced waves



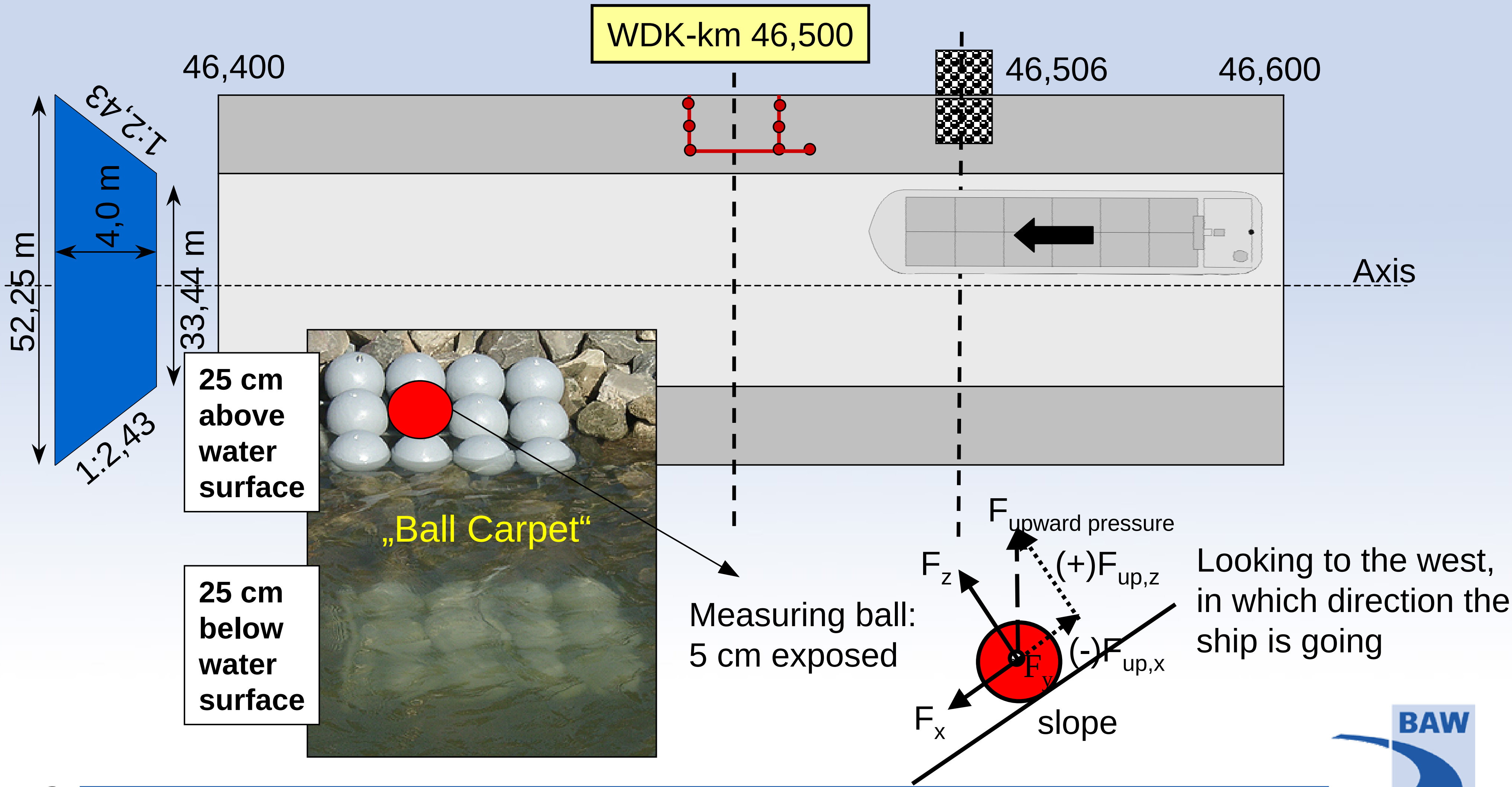
Gauging methods

Video Measurements of stone movements



Gauging methods

Force measurement on an idealized riprap element



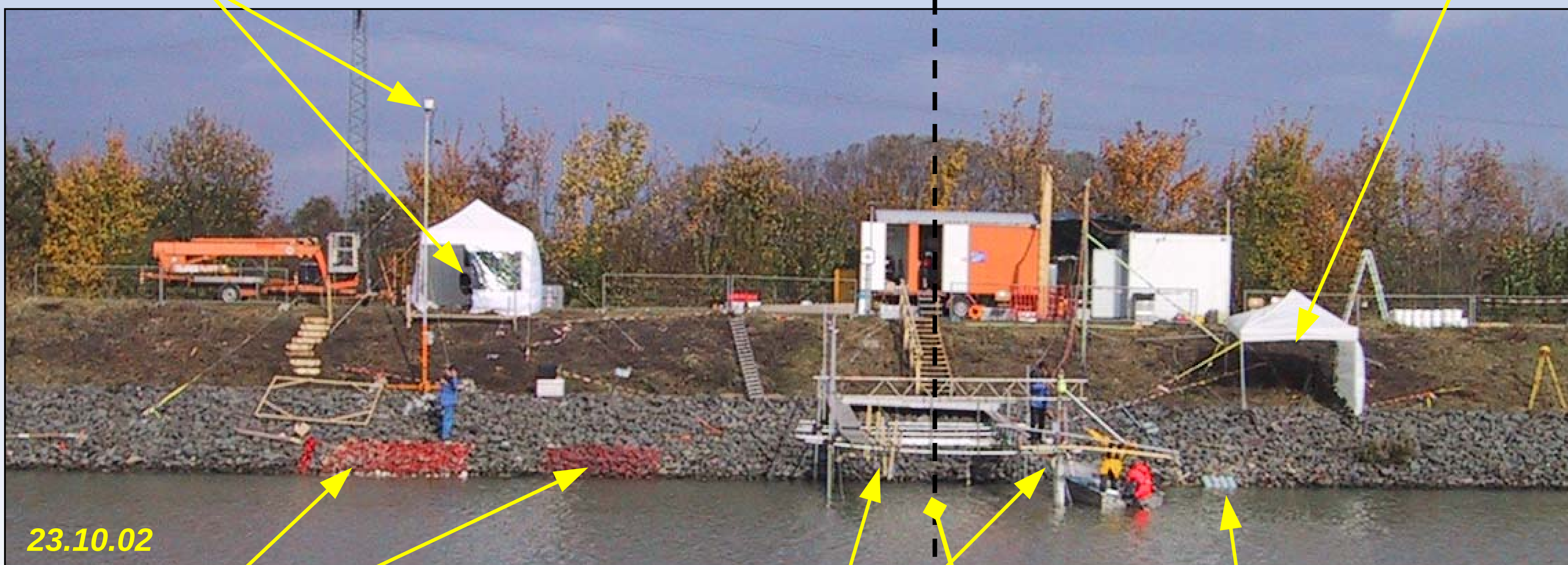
Gauging methods

Overview on measuring cross-section

video measurements of stone movements

WDK-km 46,500

video monitoring of gauge



force measurements on idealized riprap elements

coloured riprap test areas

wave height measurements

flow measurements

Performance of navigational experiments

Used vessels

Large motor vessel „Main“

L = 105,00 m
B=11,00 m
$T_{average}$ = 1,70 - 2,70 m
P_D = 1200 PS
$D_{Prop.}$ = 1,58 m
70 test runs

Tugboat „Mignon“

L = 21,00 m
B = 4,00 m
$T_{average}$ = 1,70 m
P_D = 420 PS
$D_{Prop.}$ =1,50 m
9 test runs

Police boat

L = 11,90 m
B = 3,05 m
T = 0,65 m
P_D = 250 PS

9 test runs

Variation on bank distance and ship speed

Performance of navigational experiments

Examples of test drives with surface erosion

MS Main drive
Sept. 27th 2002
$T_{average}$=1,70 m
$v_s \approx v_{scr}$= 3,11 m/s
side of ship - bank: 10 m

Threshold of stone movement

Severe erosion

Tugboat drive Sept. 28th 2002
$T_{average}$=1,70 m; v_s=3,80 m/s; v_{scr}= 4,03 m/s
side of ship - bank: 9 m

Design of bed and bank revetments in canals

Relevant vessels and impact types

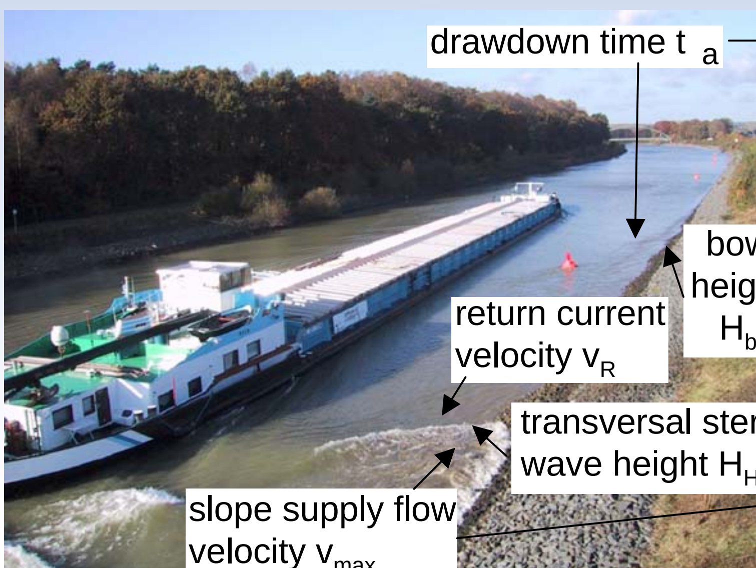
<u>Most frequent impacts from:</u>

highly powered modern motor vessels, with:

- max. permitted draught or totally empty vessel
- driving with $v_s \approx v_{scr}$
- near the banks

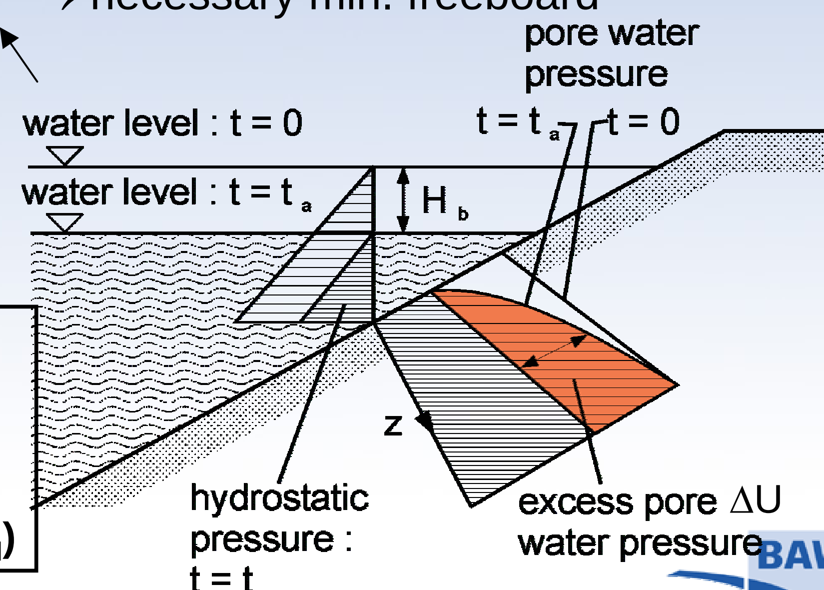
<u>Less frequent impact from:</u>

- propeller jet and scour
  → eventually clamped riprap at berthing places if necessary
- tugboats, solitary driving pushboats, recreational boats
  → necessary min. freeboard



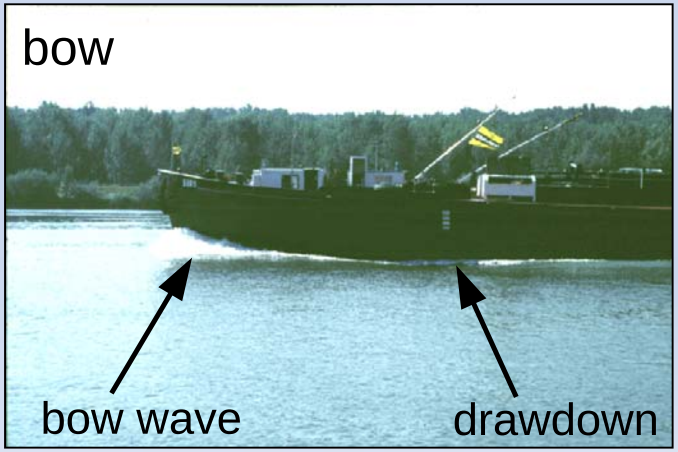
required minimum thickness of the revetment= f (t_a, H_b)

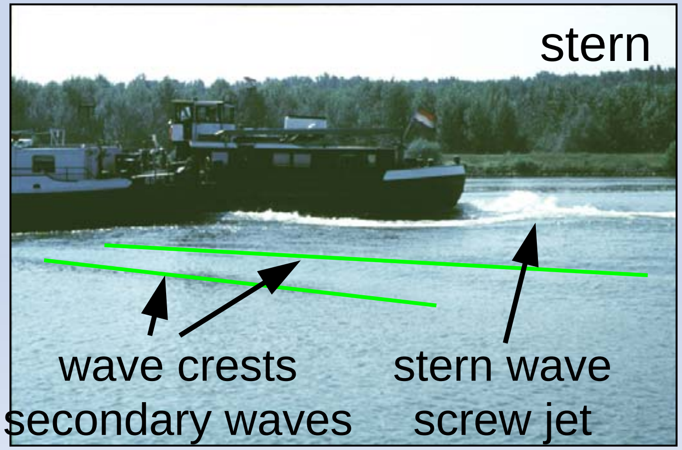
required minimum stone size/weight = f(v_{max}, v_R, H_H)

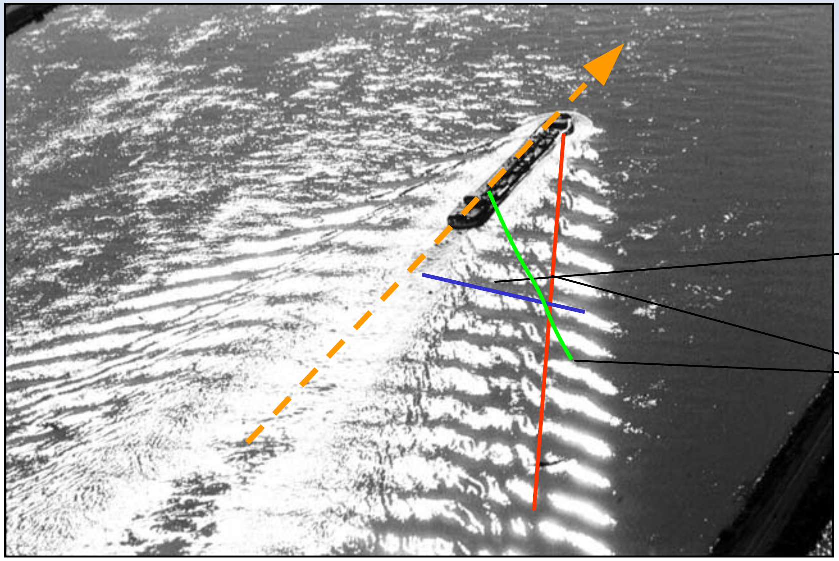


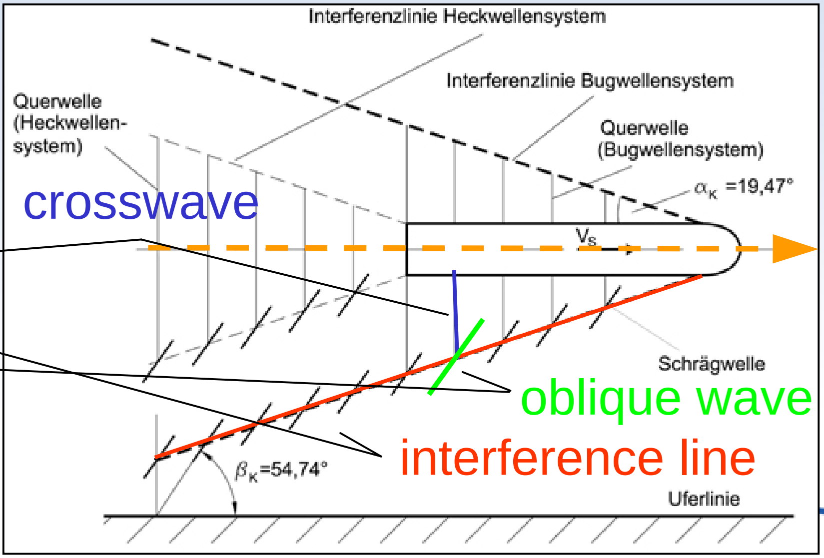
Ship induced waves

Primary & Secondary wave field









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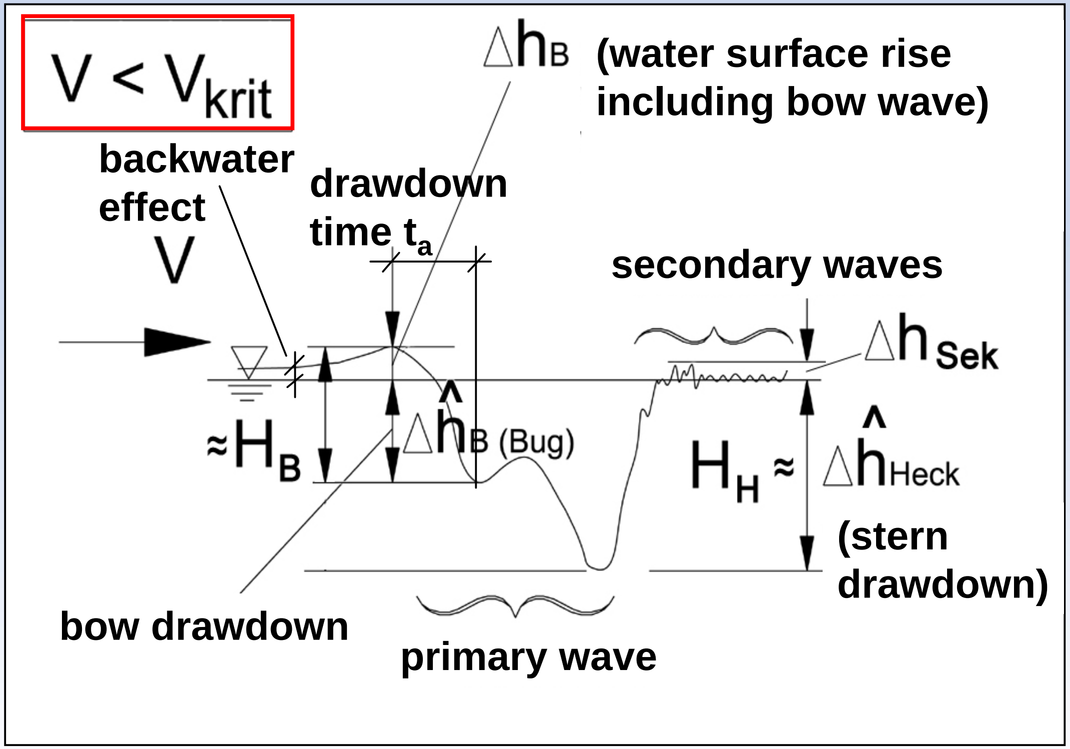
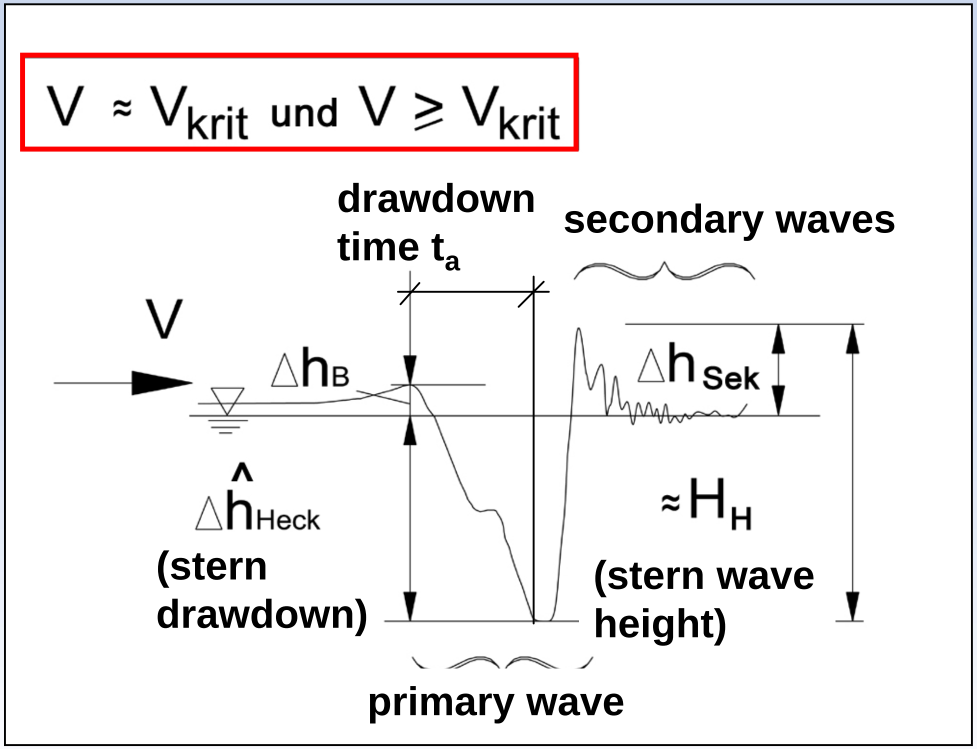
Ship induced waves

Primary & Secondary wave field





Progress lines of primary and secondary waves for different ship speeds (**stationary** observer on bank)

Analysis of the experiments

88 seperate experiments

↓

Selection of experiment with well defined conditions (no surges, no traffic ...)

↓

Analysis of 68 single navigational experiments regarding ...

flow velocities:
- return currents
- slope supply flow

sounding data:
- cross section geometry

GPS-Data:
- eccentricity
- ship speed
- critical ship speed

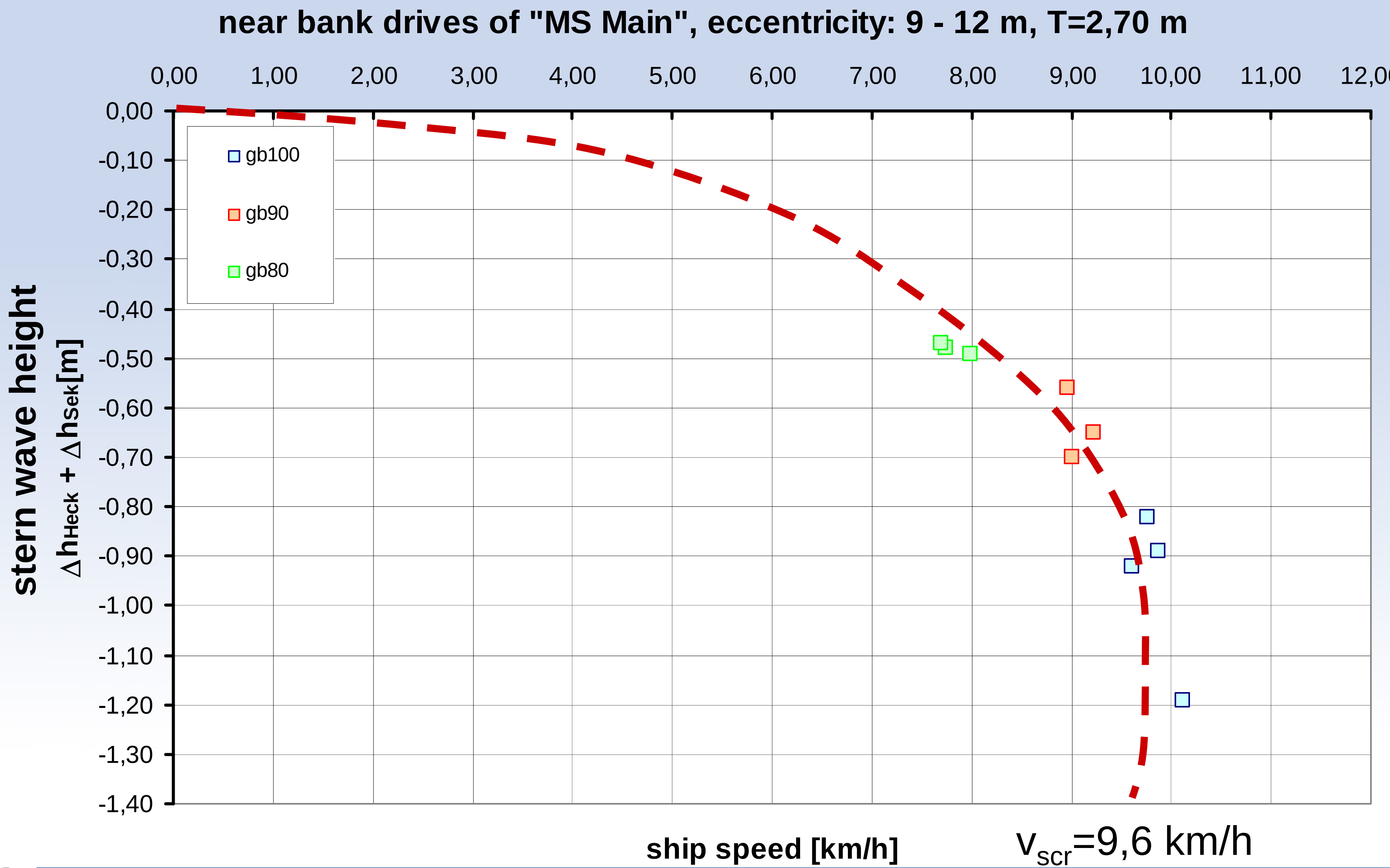
wave measurements:
- stern wave height
- bow wave height
- secondary wave height
- bow drawdown
- stern drawdown
- drawdown time

video:
- stone movement

force measurement:
- direction of impact

Analysis of the experiments

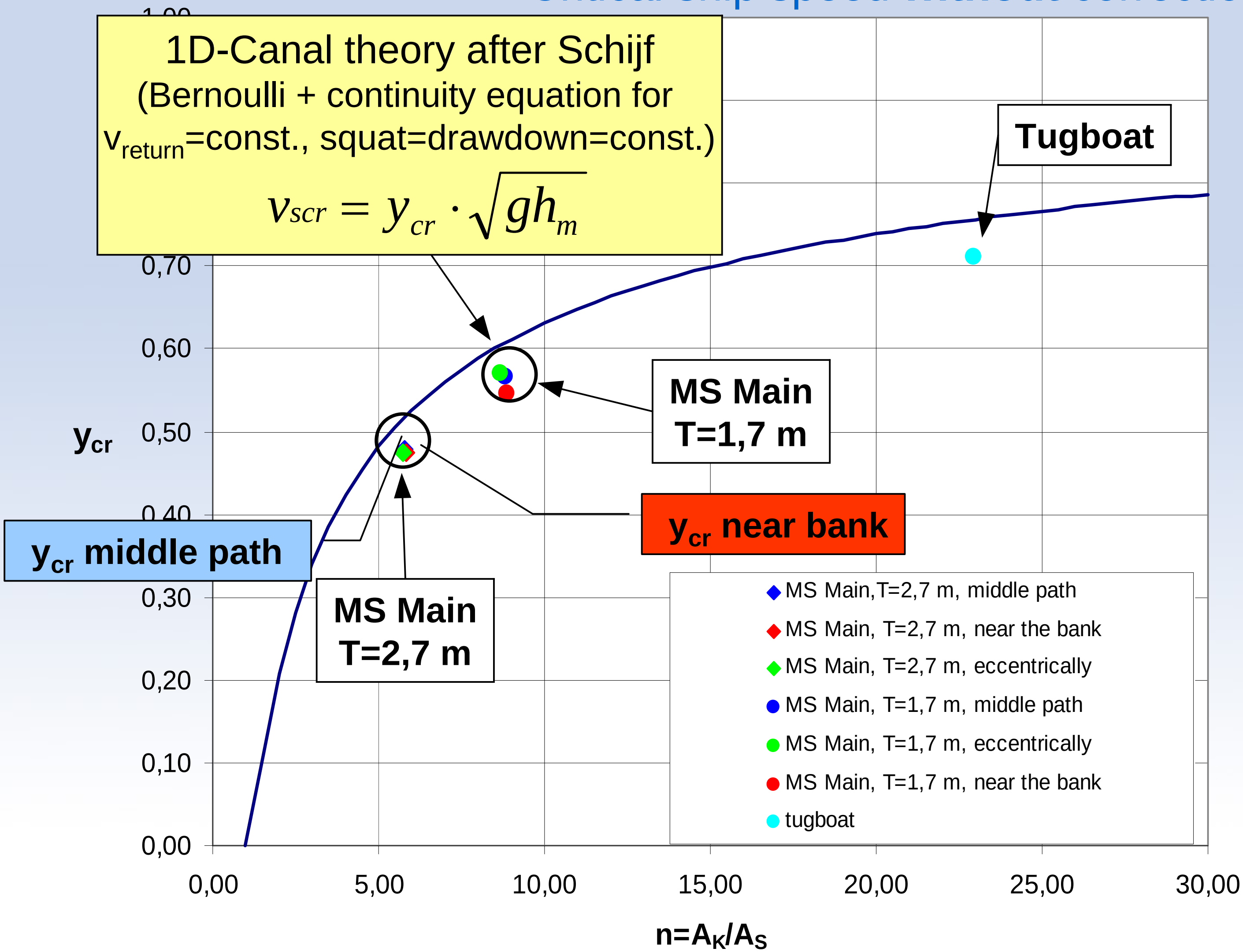
Determining critical ship speed



v_{scr}=9,6 km/h

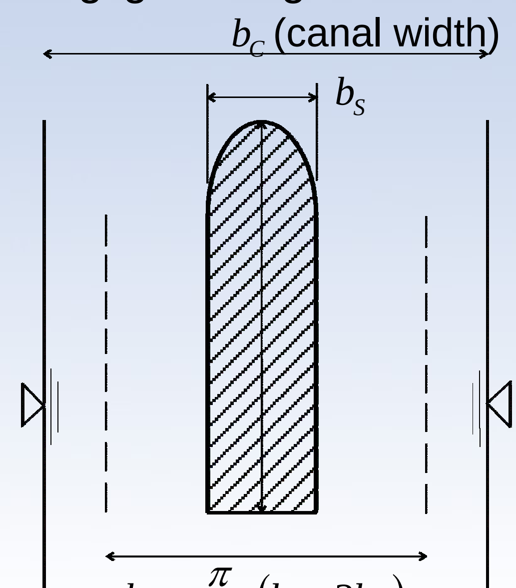
Comparison with calculational approach

Critical ship speed **without** corrections



Results:

- $v_{scr,Measurement} < v_{scr,calculation}$
- Influence of eccentricity low
- shallow water effect is not negligible: tugboat

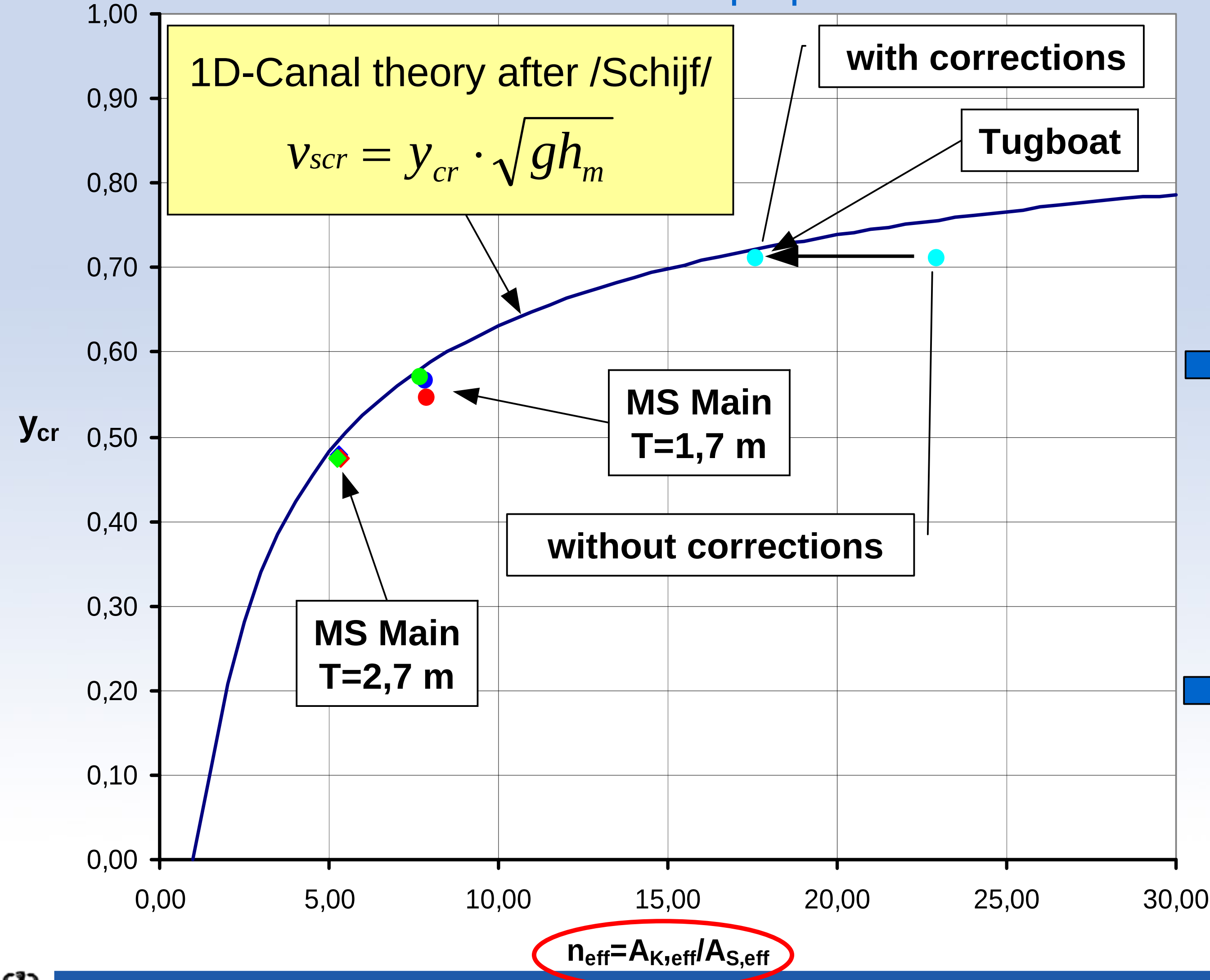


$$b_E \approx \frac{\pi}{2} \cdot (l_S + 3b_S)$$

effective width of return current field $b_E < b_C$

Comparison with calculational approach

Critical ship speed **with** corrections



Results:

- 1D-Canel theory neglects friction losses

→ considering boundary layer effects by displacement thickness ($A_{S,eff}$)

- 1D-Canal theory neglects shallow water effects

→ considering return currents effective width: $A_{K,eff} \rightarrow n_{eff}$

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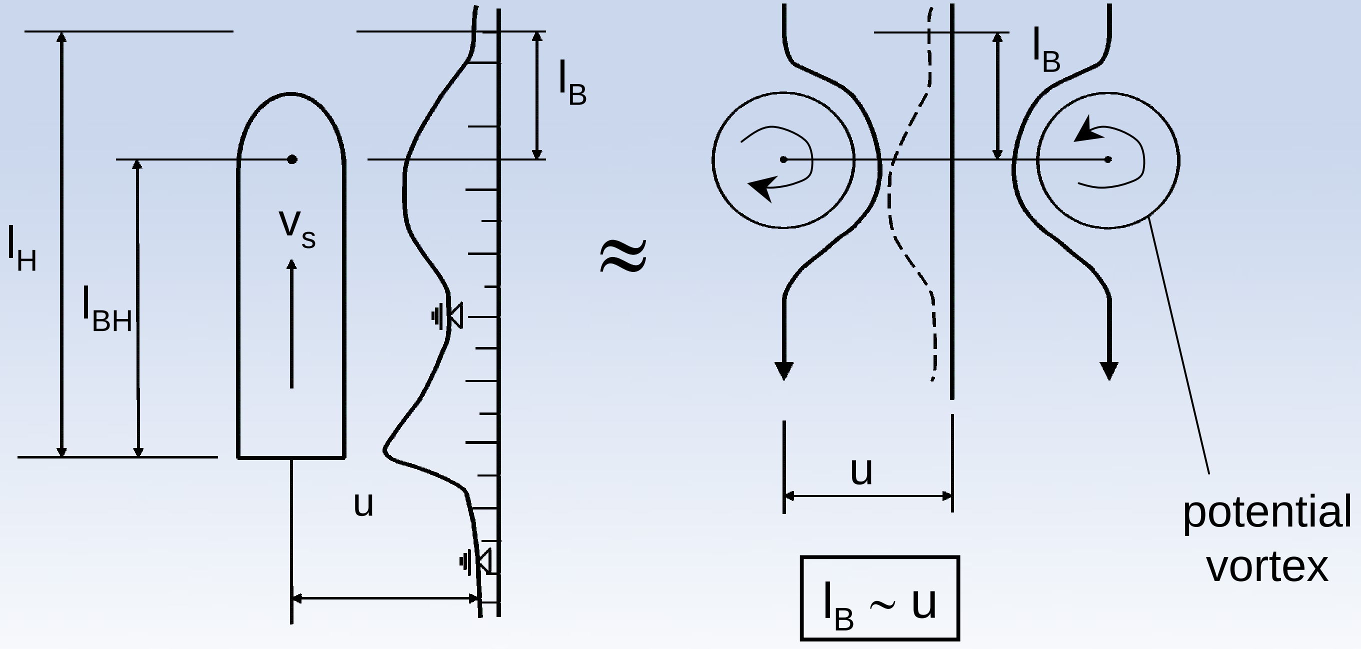
Calculational approach

Drawdown time t_a



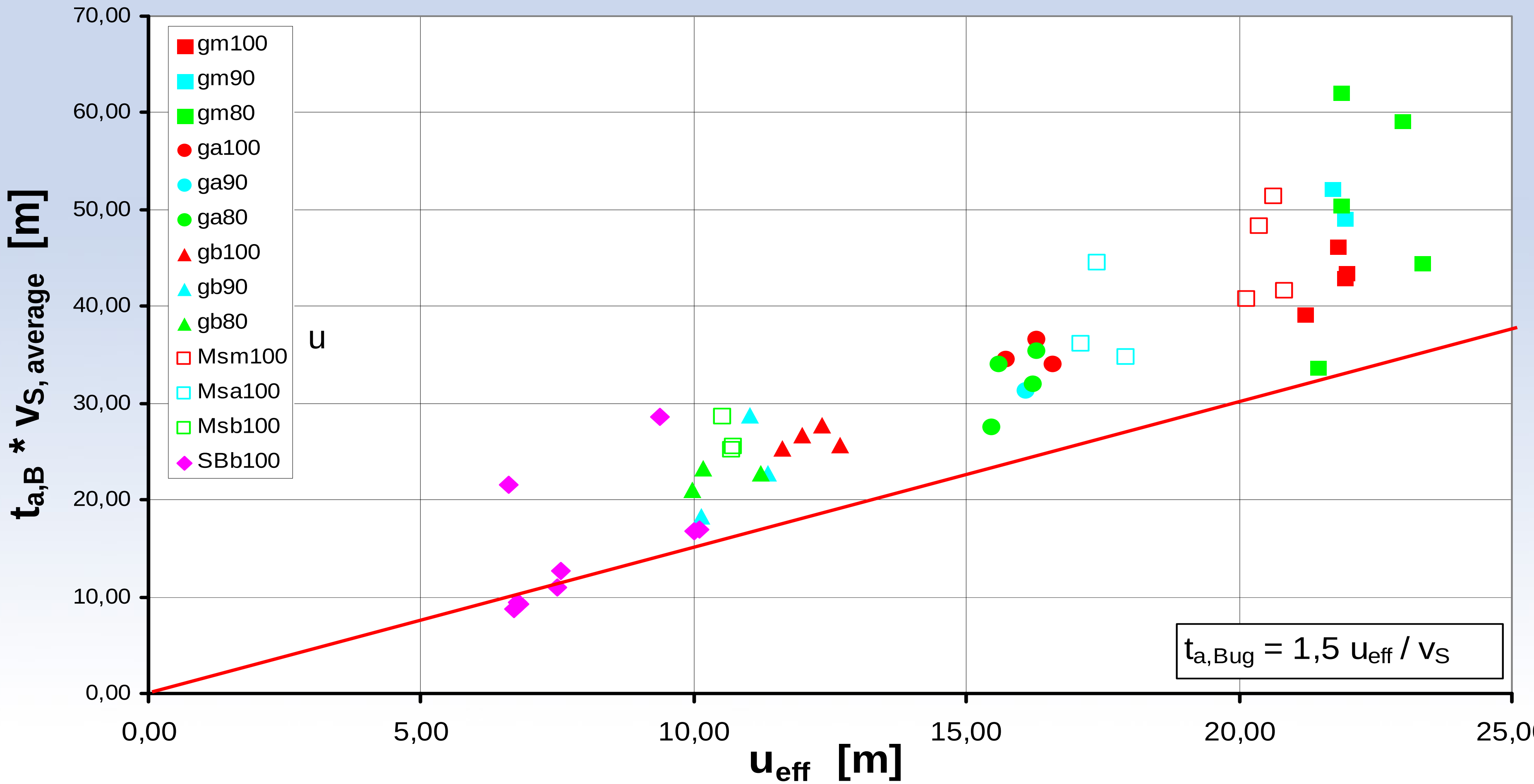
$$v_s = \frac{l_B}{t_{aB}} \sim \frac{u}{t_a}$$

$$t_{aB} = const \cdot \frac{u}{v_s}$$

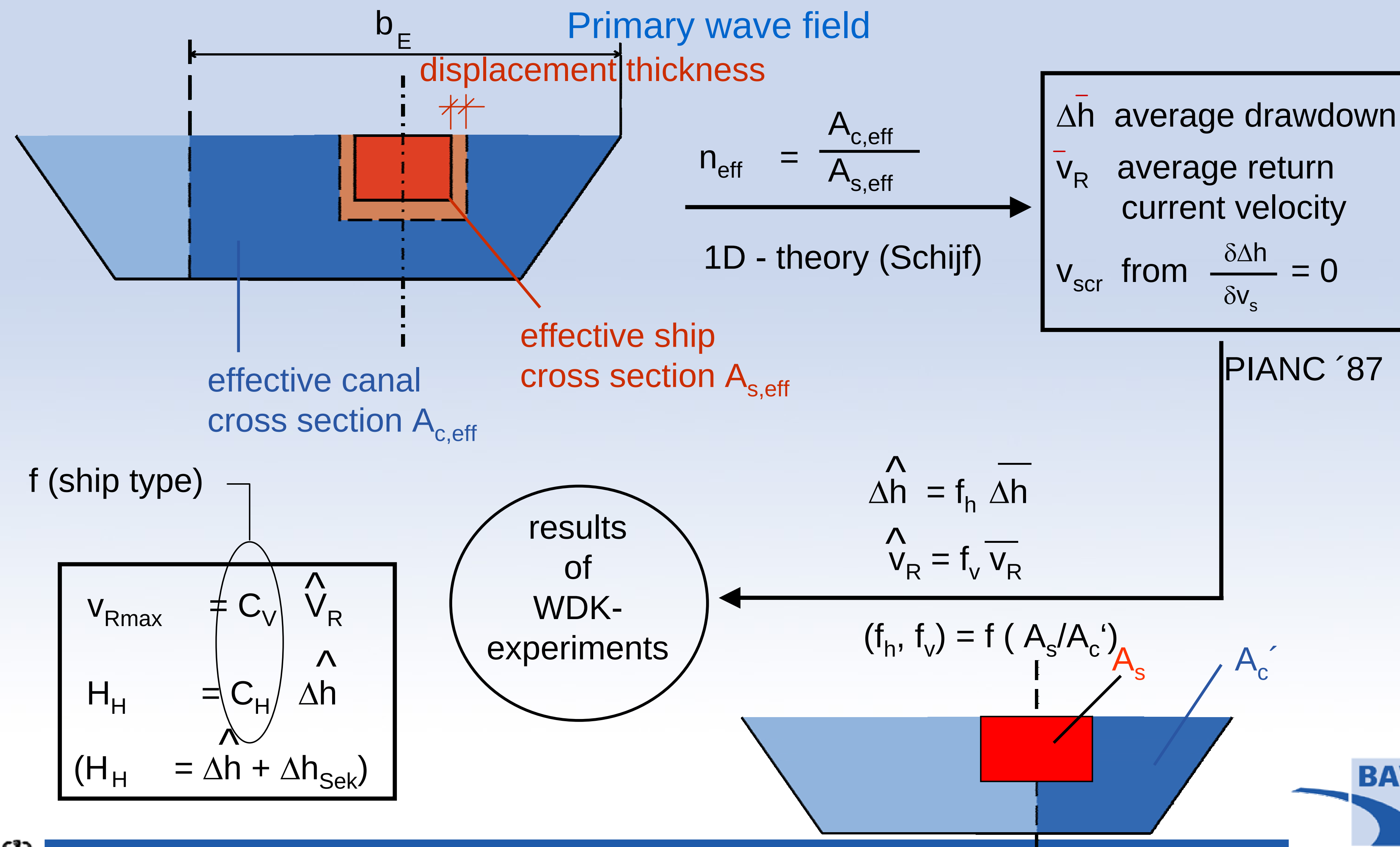
$$t_{aH} = t_{aB} + \frac{l_{BH}}{v_s}$$

Calculational approach

Drawdown time t_a



Calculational approach



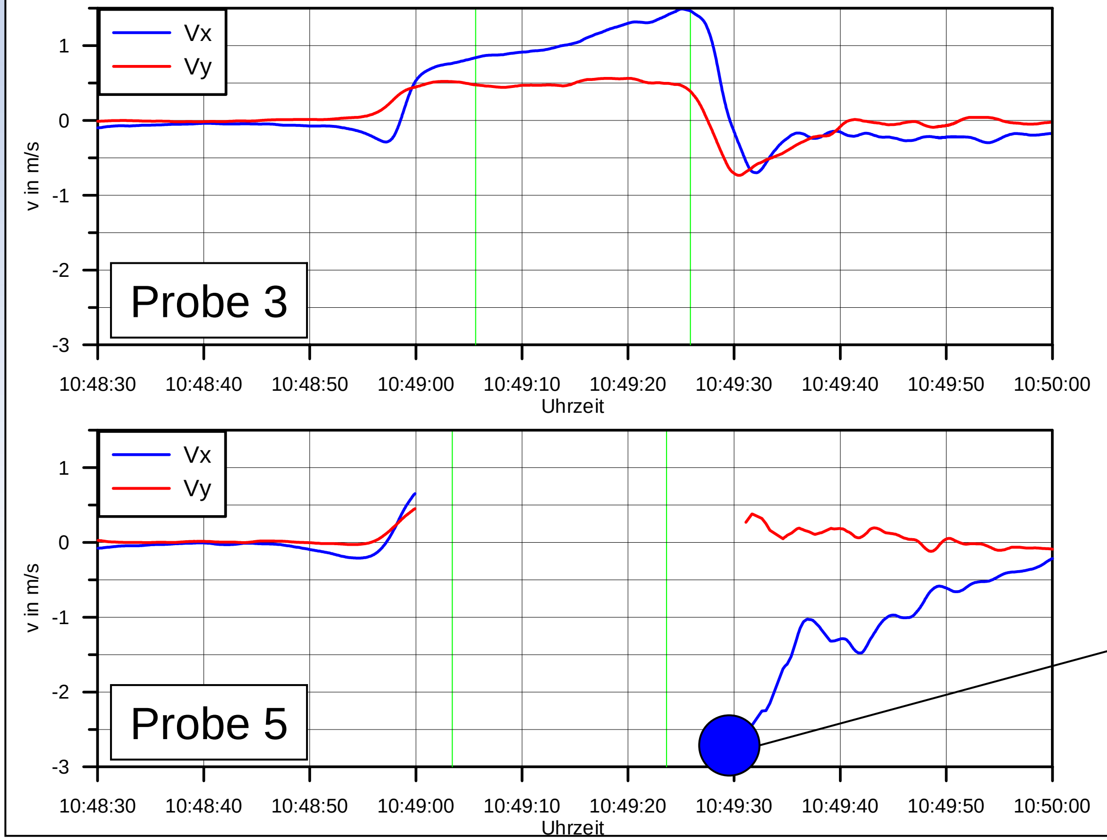
Comparison with calculational approach

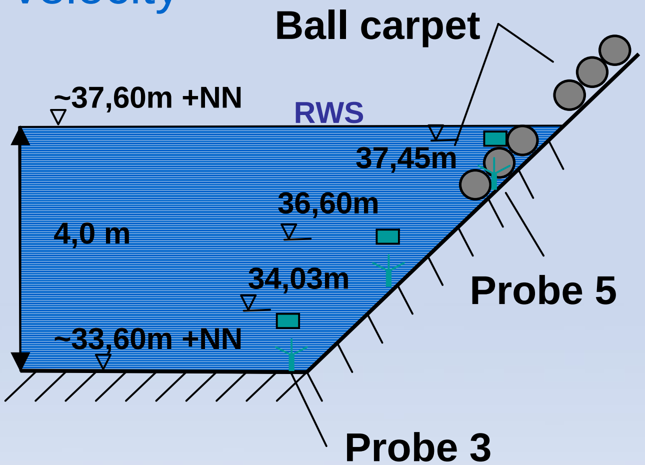
Average and maximum return current velocity

MS Main drive Sept. 27th 2003

$T_{average}$= 1,70 m; $v_s \approx v_{krit}$= 3,11 m/s

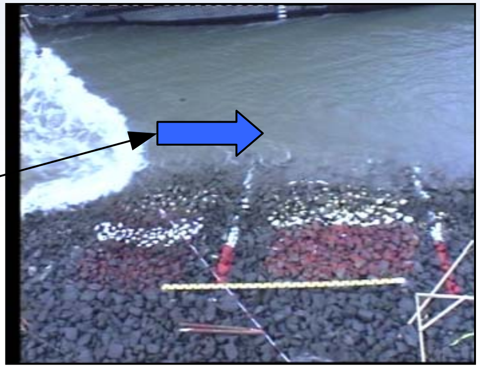
average distance side of ship - bank: 10 m





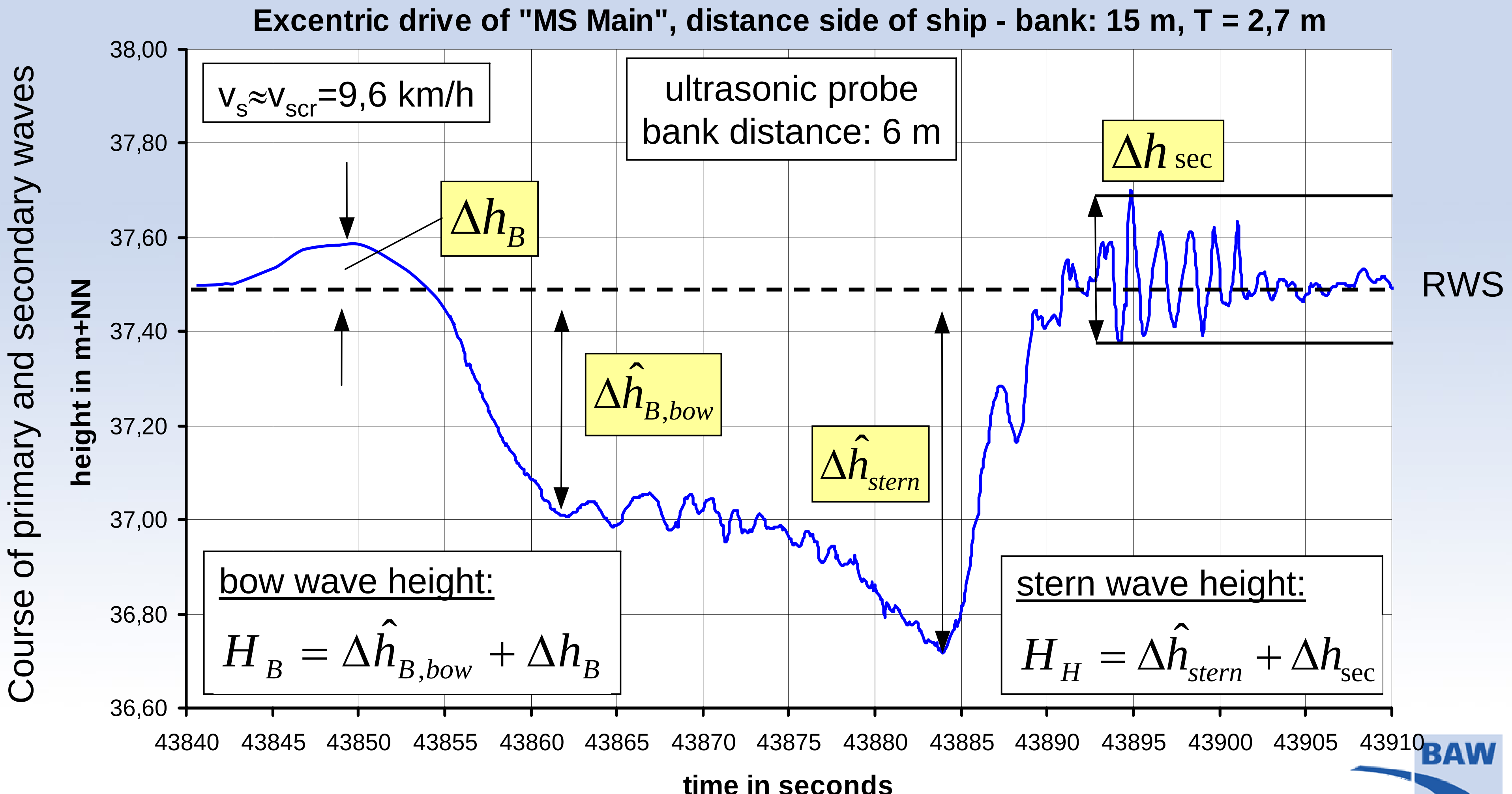
Results:

- $v_{R,average,meas.}$=1,02 m/s ≈ $v_{R,average,cal.}$=0,97 m/s
- $v_{R,\ max,meas.}$=1,35 m/s > $v_{R,max,cal.}$=1,21 m/s
- slope supply flow ≈ v_s



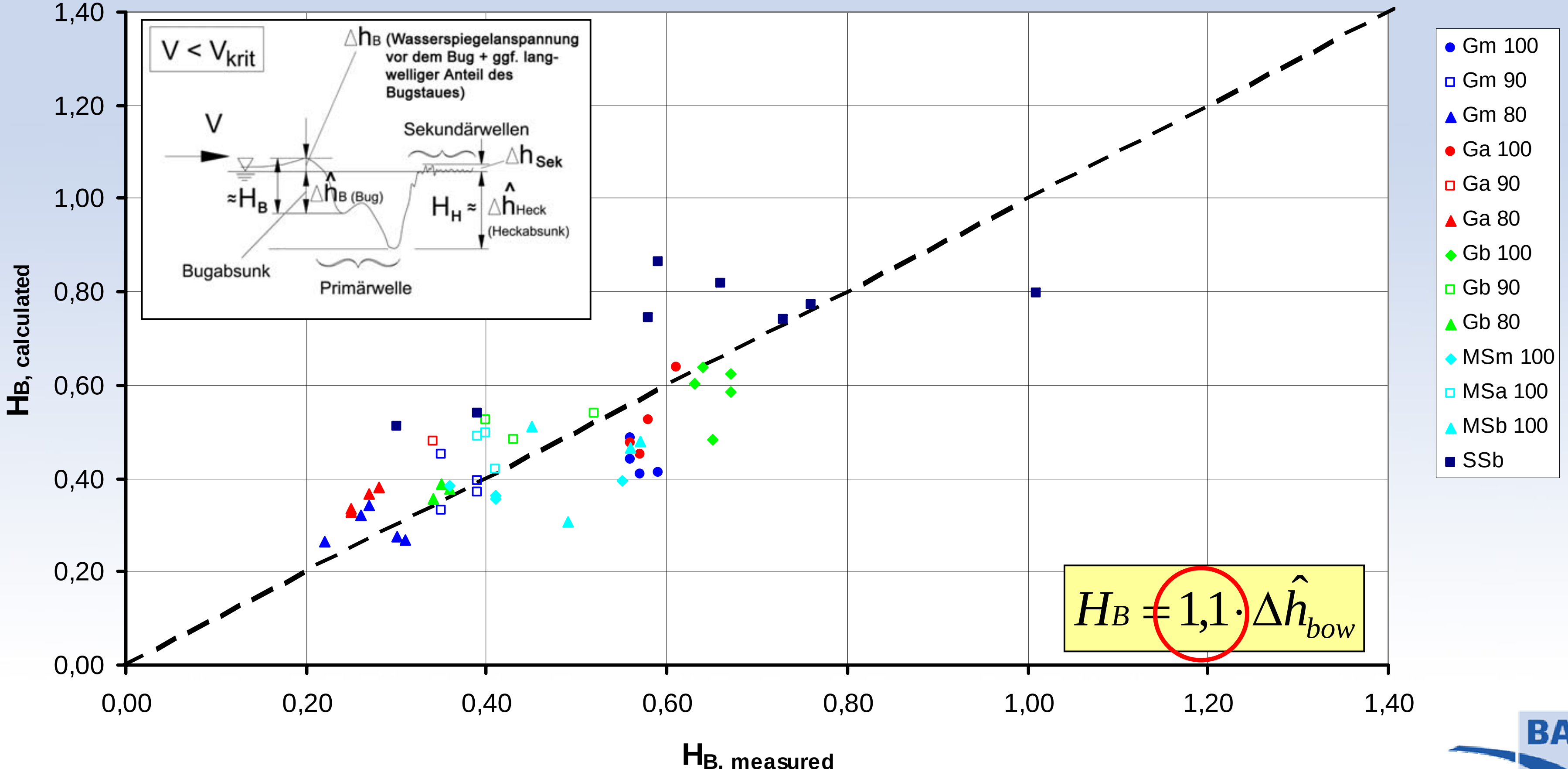
Drive evaluation

Determining wave heights



Comparison with calculational approach

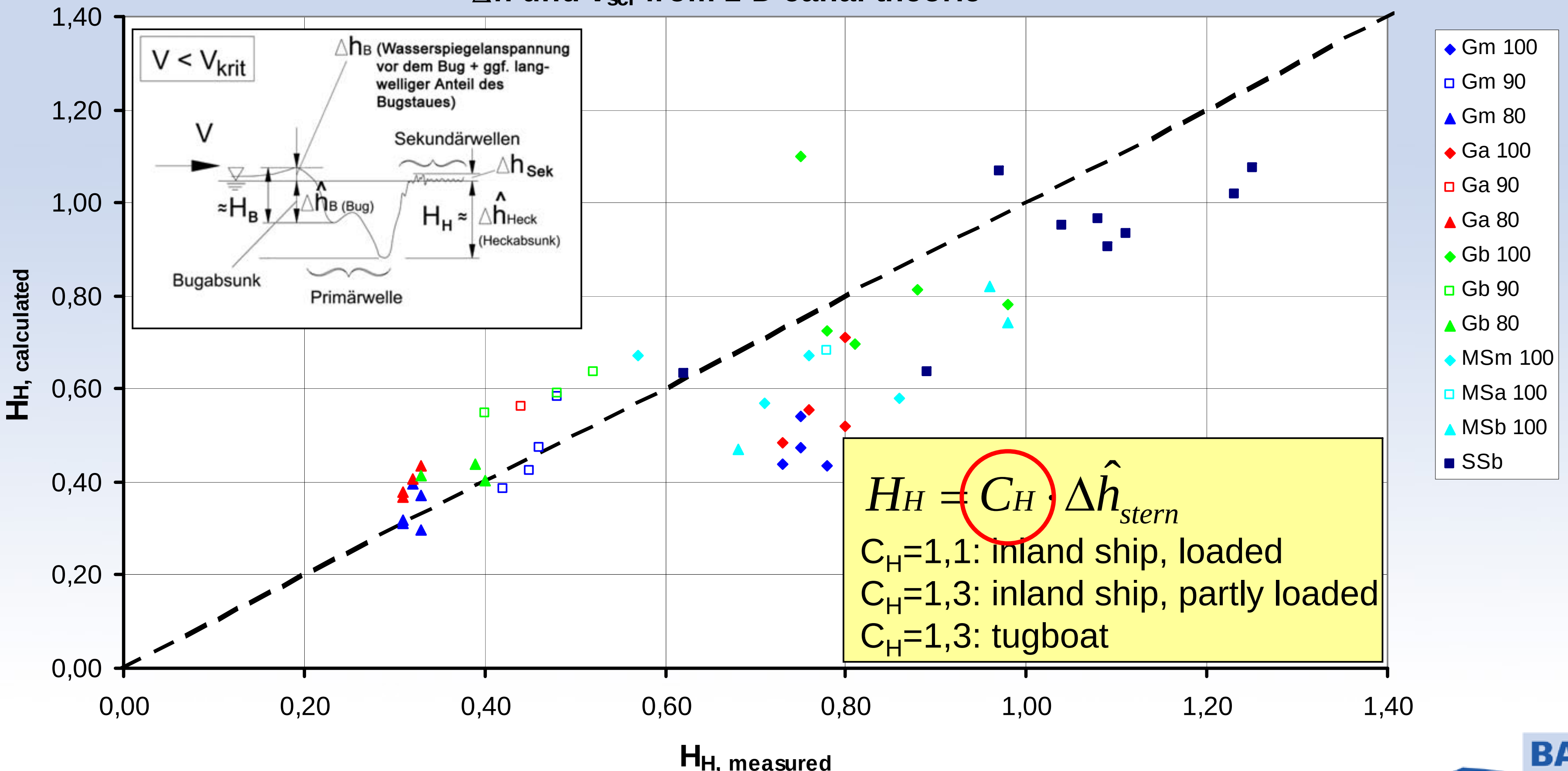
Calculation H_{bow} using measured v_s inclusive shallow water effects by n_{eff}, influence of eccentricity (f_{PIANC}) after PIANC: $H_{bow} = 1.1 * f_{PIANC} * \Delta\bar{h}$
$\Delta\bar{h}$ and v_{scr} from 1-D canal-theorie



Comparison with calculational approach

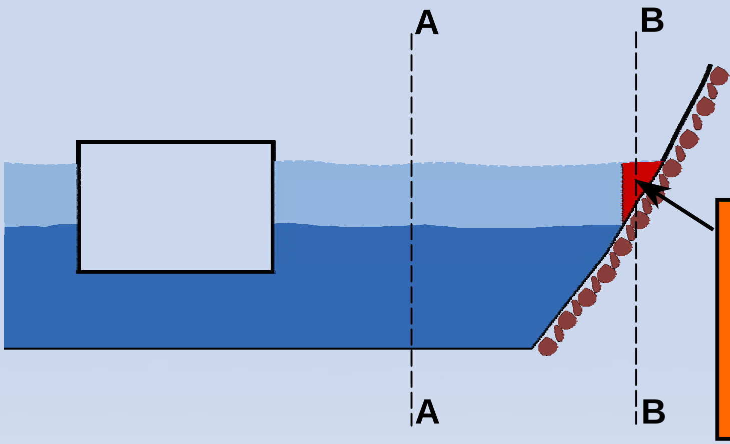
Calculation H_H using measured v_s inclusive shallow water effects by n_{eff}, influence of eccentricity (f_{PIANC}) after PIANC: H_H = 1.1 or 1.3 * f_{PIANC} * $\Delta\bar{h}$

$\Delta\bar{h}$ und v_{scr} from 1-D canal-theorie



Calculational approach

Slope supply flow



This triangle can only be refilled from the back!

wave character of the slope supply flow „tongue“:

$$c_W = c^* \cdot \sqrt{g \cdot H_H}$$ **wave celerity**

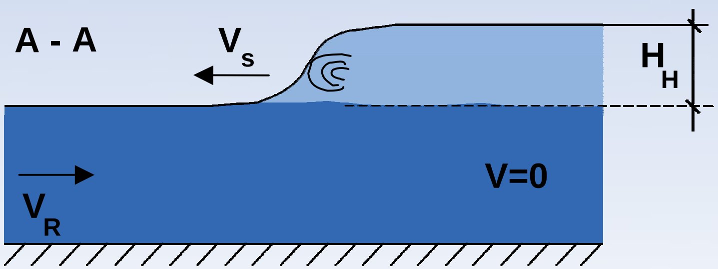
$c_W << v_S$: **unimportant slope supply flow**

$c_W \geq v_S$: **wave will overtop the ship → breaking (significant slope supply flow) for:**

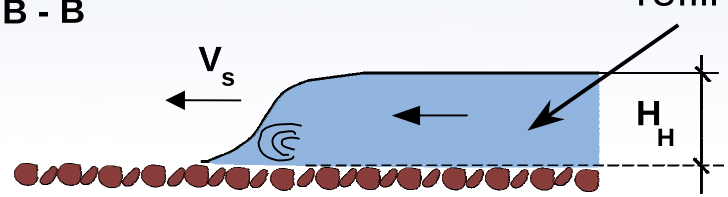
$$c_W = c^* \cdot \sqrt{g \cdot H_H} \overset{!}{=} v_s$$

$$\frac{v_s}{\sqrt{g \cdot H_H}}$$ **Parameter**

A - A



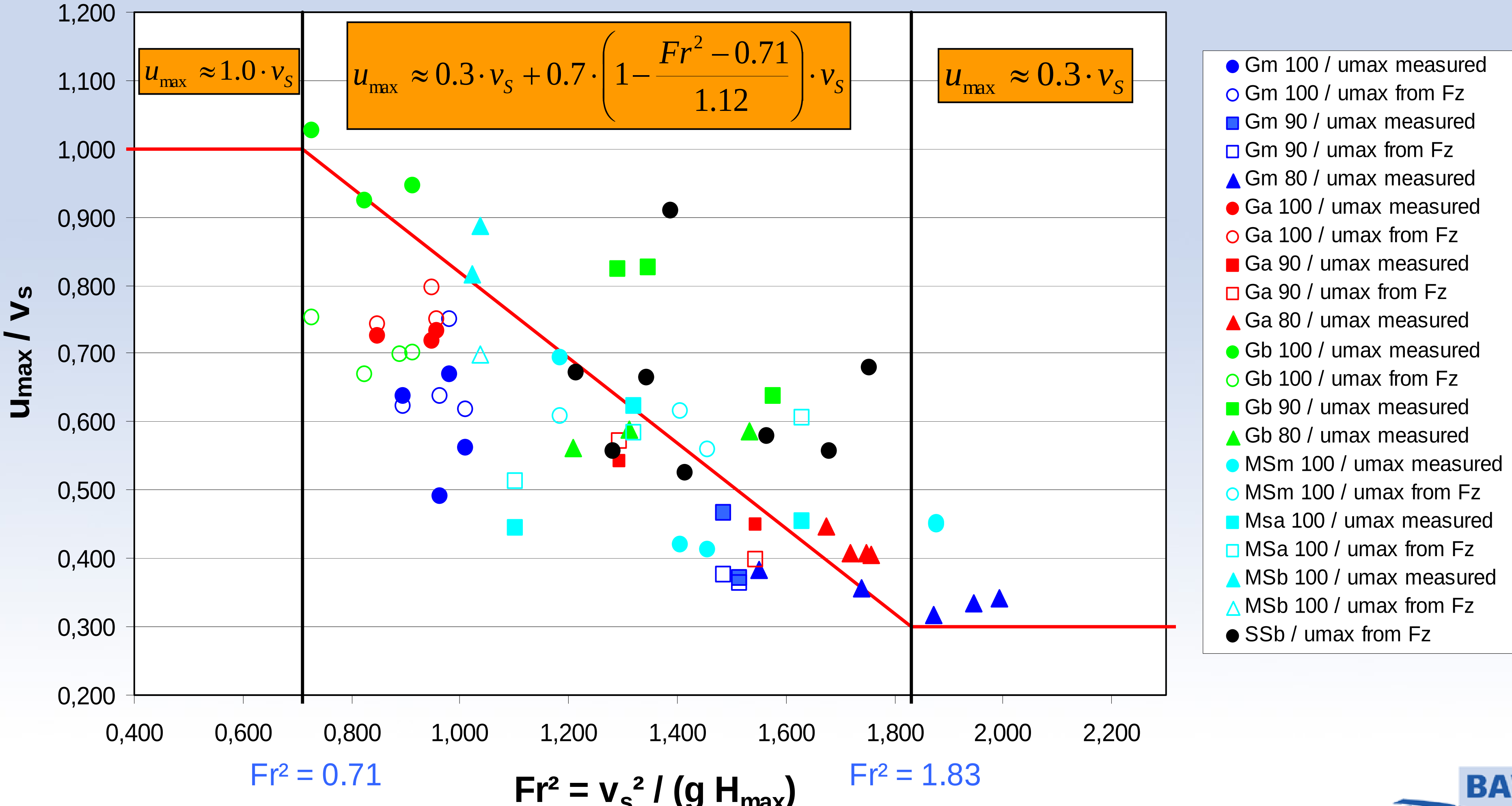
B - B



BAW

Comparison with calculational approach

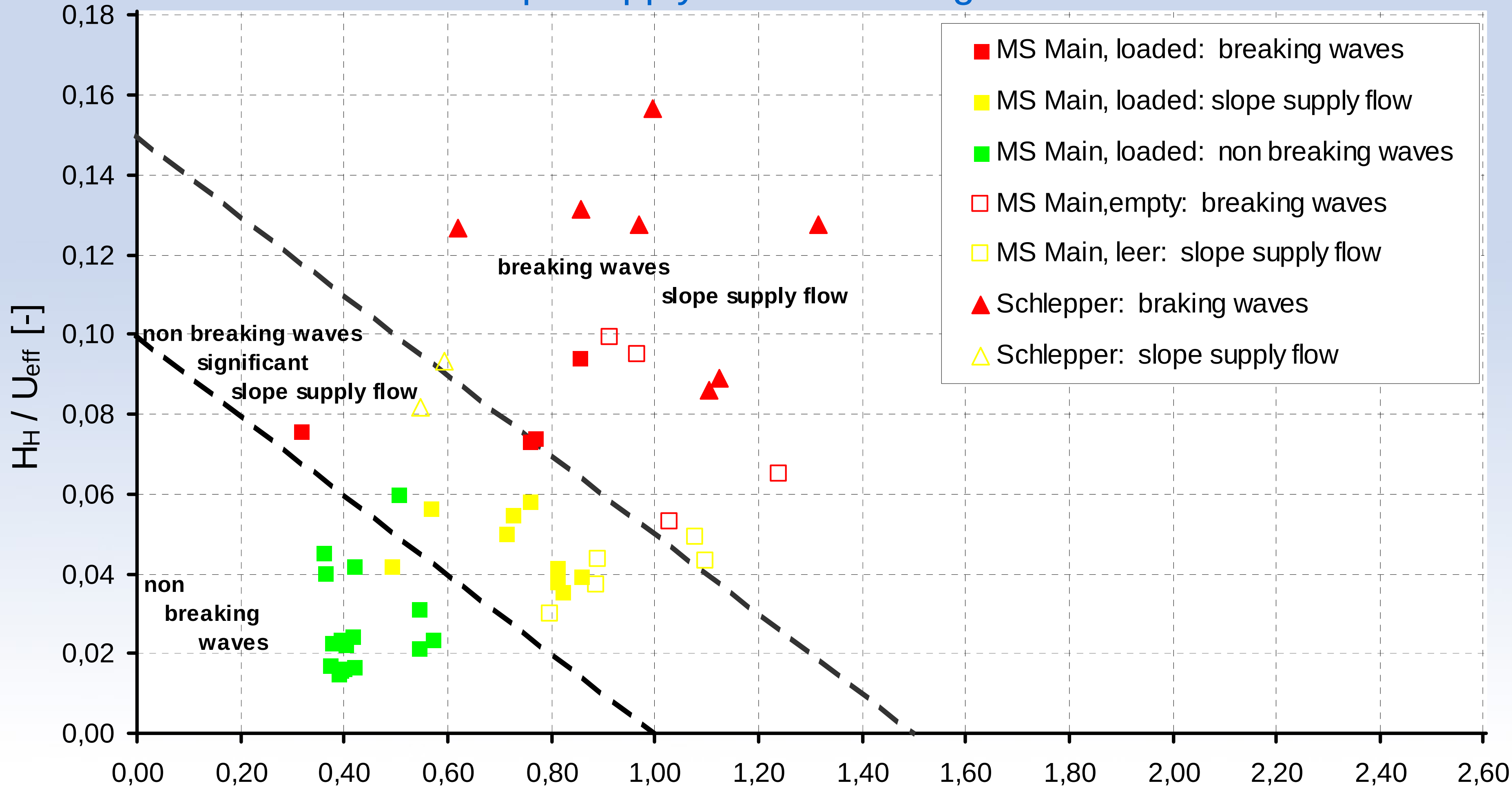
Slope supply flow - velocities u_{max}



(from $(H/h)_{break} \approx 1{,}4$ after Pilarczyk, 1995) **(from $(H/h)_{break} \approx 0{,}55$ after Nelson, 1994)**

Comparison with calculational approach

Slope supply flow - breaking criterion

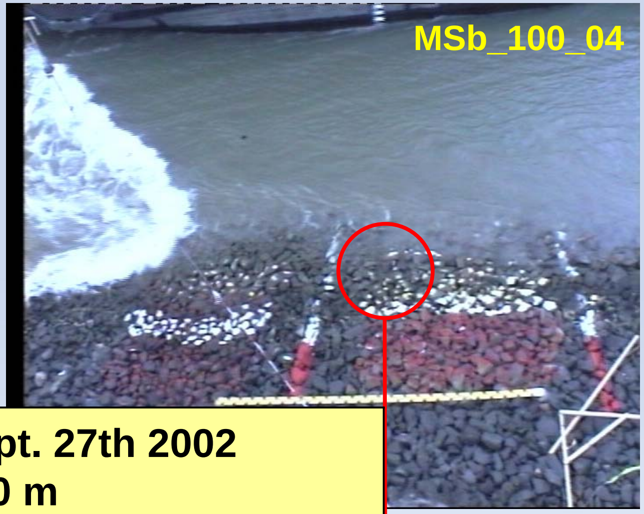


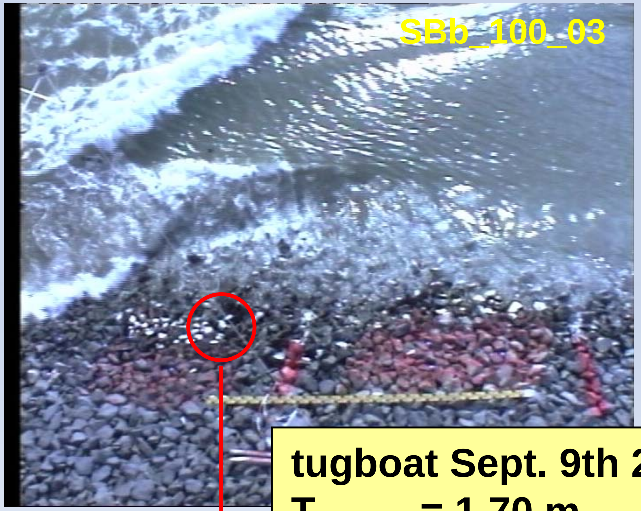
$$Fr = (v_S+v_{R,max})^2 / [g (h_m-H_H)] [-]$$

Drive evaluation

Determination of stone movements

before experiment

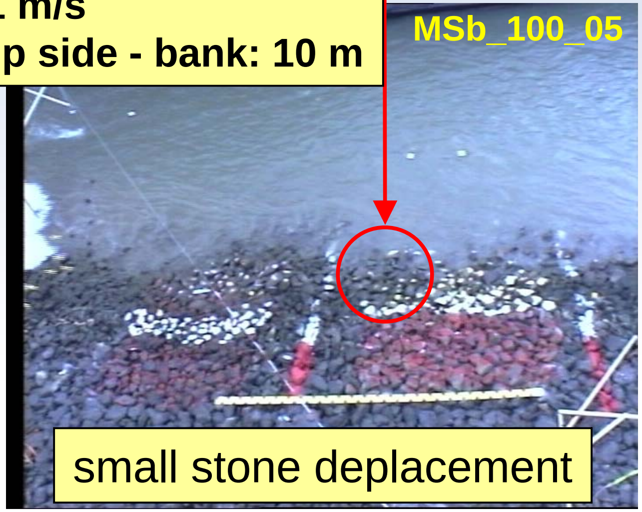




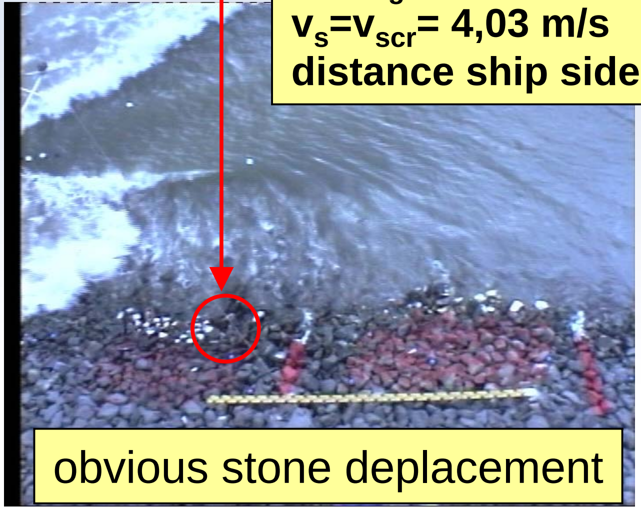
MS Main Sept. 27th 2002
$T_{average}$= 1,70 m
$v_s \approx v_{scr}$= 3,11 m/s
distance ship side - bank: 10 m

tugboat Sept. 9th 2002
$T_{average}$= 1,70 m
$v_s = v_{scr}$= 4,03 m/s
distance ship side - bank: 12,3 m

after experiment



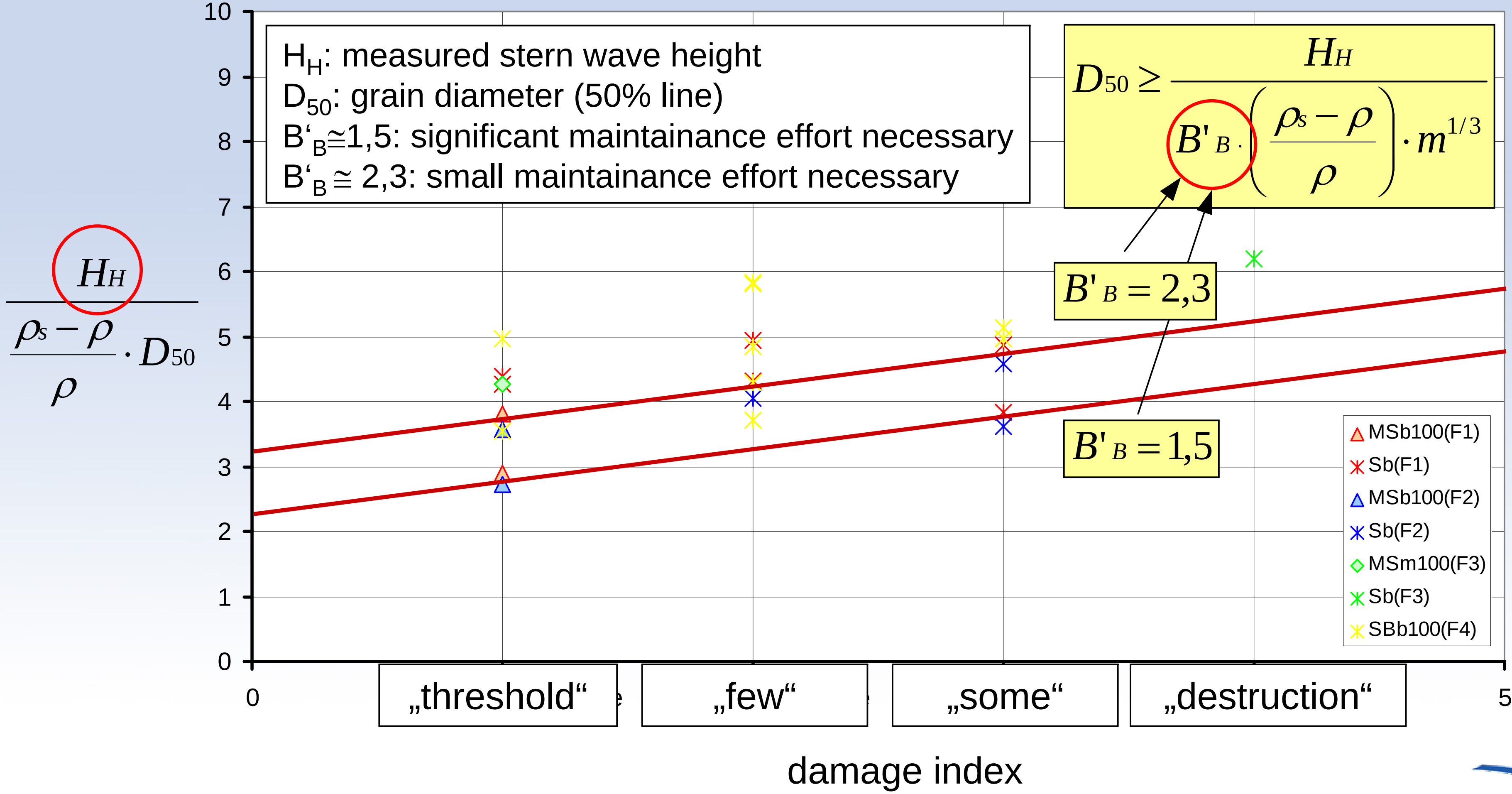
small stone deplacement



obvious stone deplacement

Drive evaluation

Required stone size to avoid erosion caused by breaking stern waves

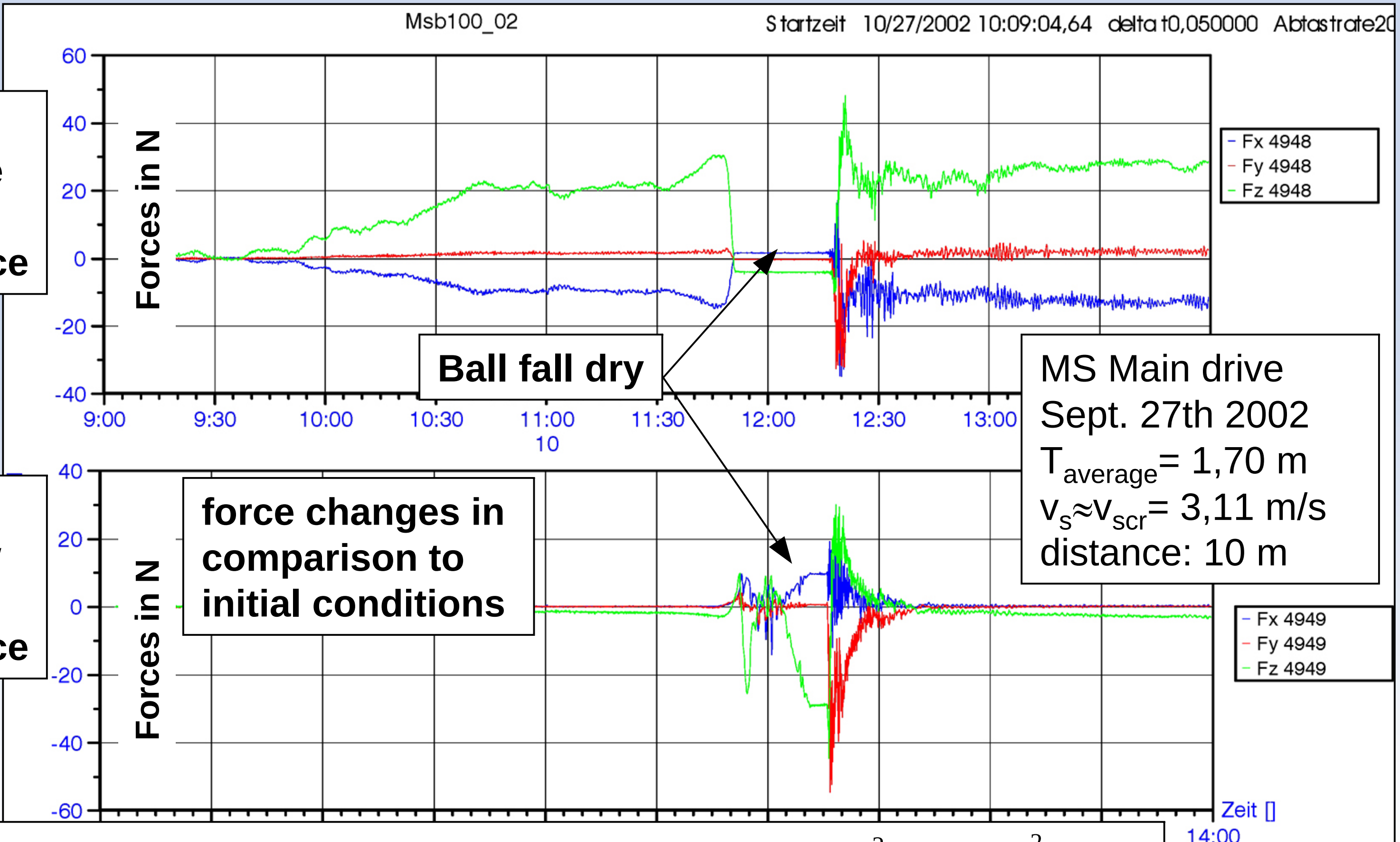


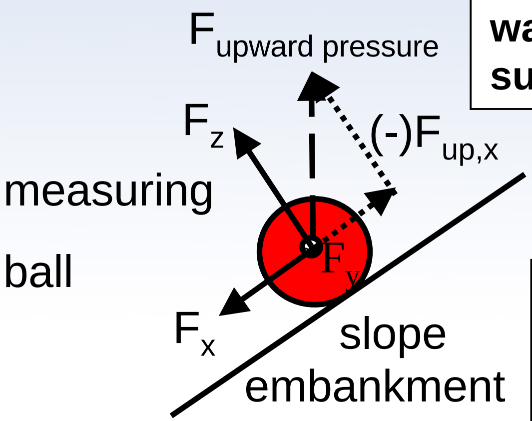
Drive evaluation

Force measurements on an idealized riprap element (ball)

4948 above water surface

4949 below water surface





Results:

- largest force ≈ parallel to bank (F_y)
- thrust- (F_y) ≈ uplift force (F_z)

$$F_y = \frac{\pi \cdot D^2}{4} \cdot \rho \cdot \frac{v_s^2}{2} \cdot c_w$$

$$c_w \approx 0{,}35$$

Conclusions

... from comparison calculated - measured

v_{scr}

• critical ship speed in canals are overestimated in 1D-canal theory (approach MBB, issue Nov. 1999).

➡ boundary layer and shallow water effects are to be considered, for example via n_{eff} (approach MBB, issue Aug. 2003)

H_H, H_B

• observed wave heights (in particular bank near drives with $v_s \geq v_{krit}$) are larger than in MBB, issue Nov. 1999.

➡ considering parameters depending on T/H and eccentricity, seperating bow- and stern waves (approach MBB, issue Aug. 2003)

$D_{50,req.}$

• The formula for needed stone size after MBB, issue Nov. 1999 overpredicts the stone size (coefficient B'_B). Beside wave height the needed stone size is also defined by the „refill current“ of the breaking stern waves.

➡ calibrating coefficients due to registered stone movement in MBB, issue Aug. 2003