Ship Behaviour in Shallow and Confined Water: an Overview of Hydrodynamic Effects through EFD

department
Mobility and
Public Works

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Portsmouth

EFQM
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HYDRAULICS RESEARCH

Introduction

Ship Behaviour in Shallow and Confined Water

- **Shallow and confined water areas in Flanders**
  - Canal Ghent-Terneuzen: interaction of maritime and inland fleet
  - Upper Sea-Scheldt: inland waterway
- **Effect on ship behaviour**
  - ship manoeuvring in open and shallow water
  - bank effects
  - ship-to-ship interaction
  - nautical bottom

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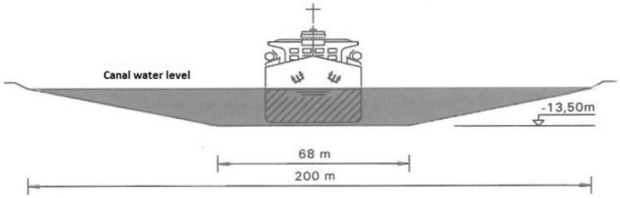
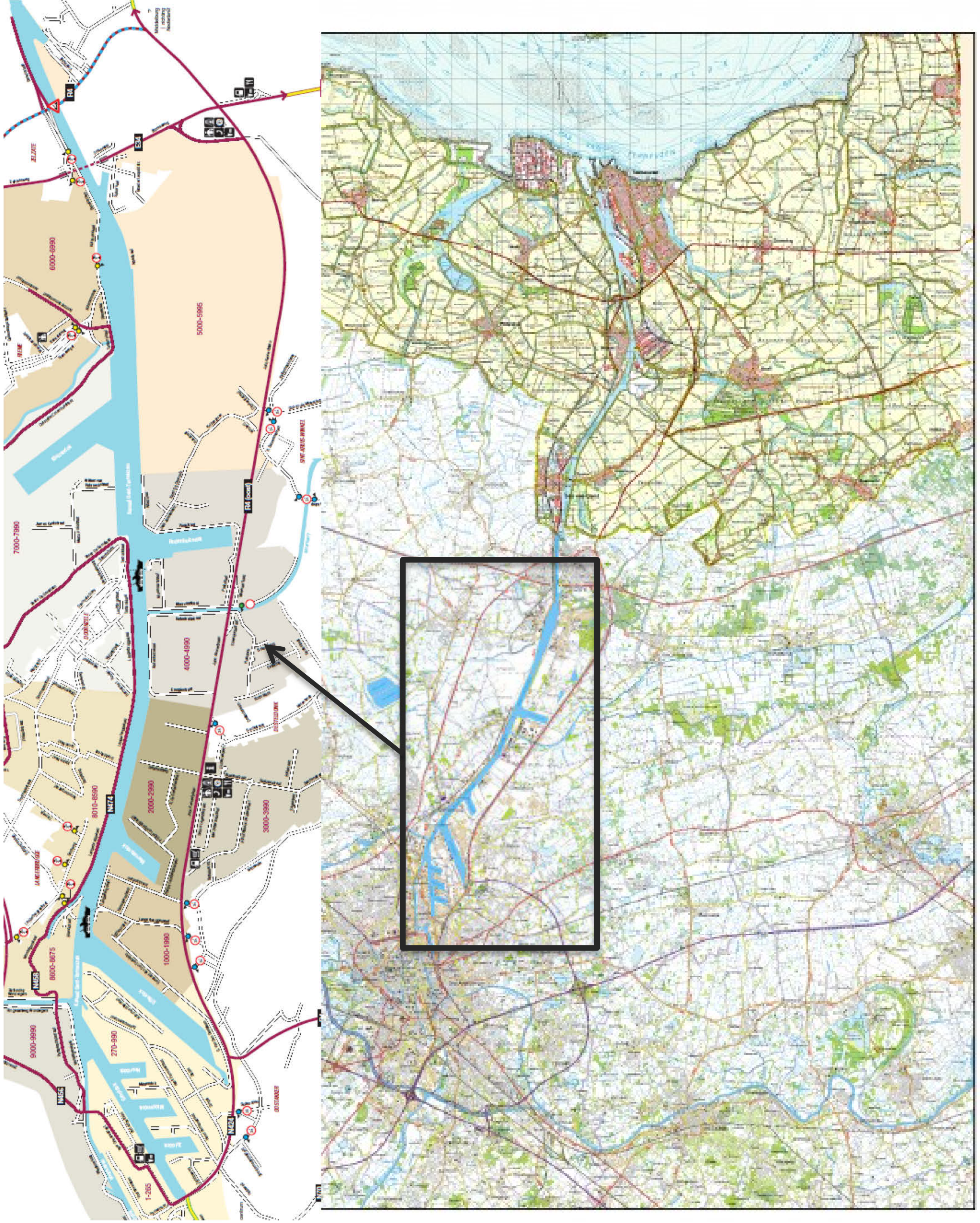
KNOWLEDGE CENTRE MANOEUVRING
IN SHALLOW AND CONFINED WATER

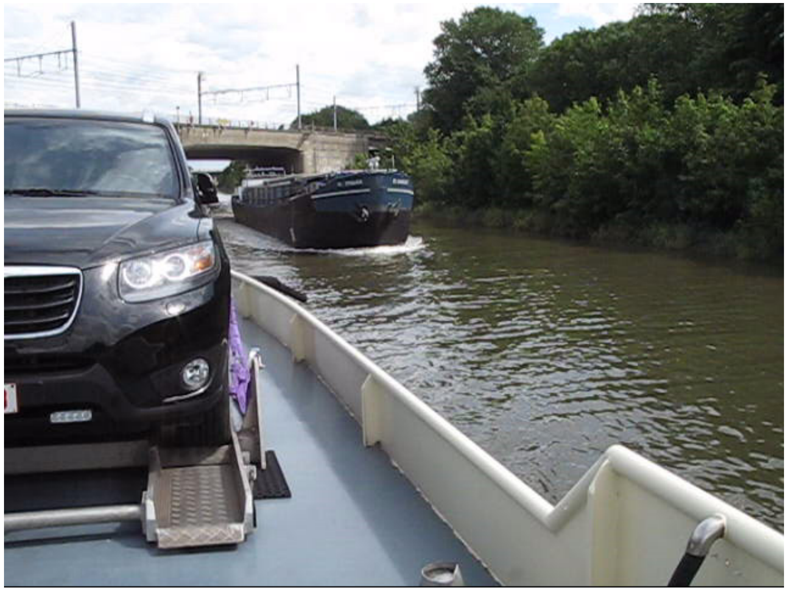
Canal Ghent-Terneuzen

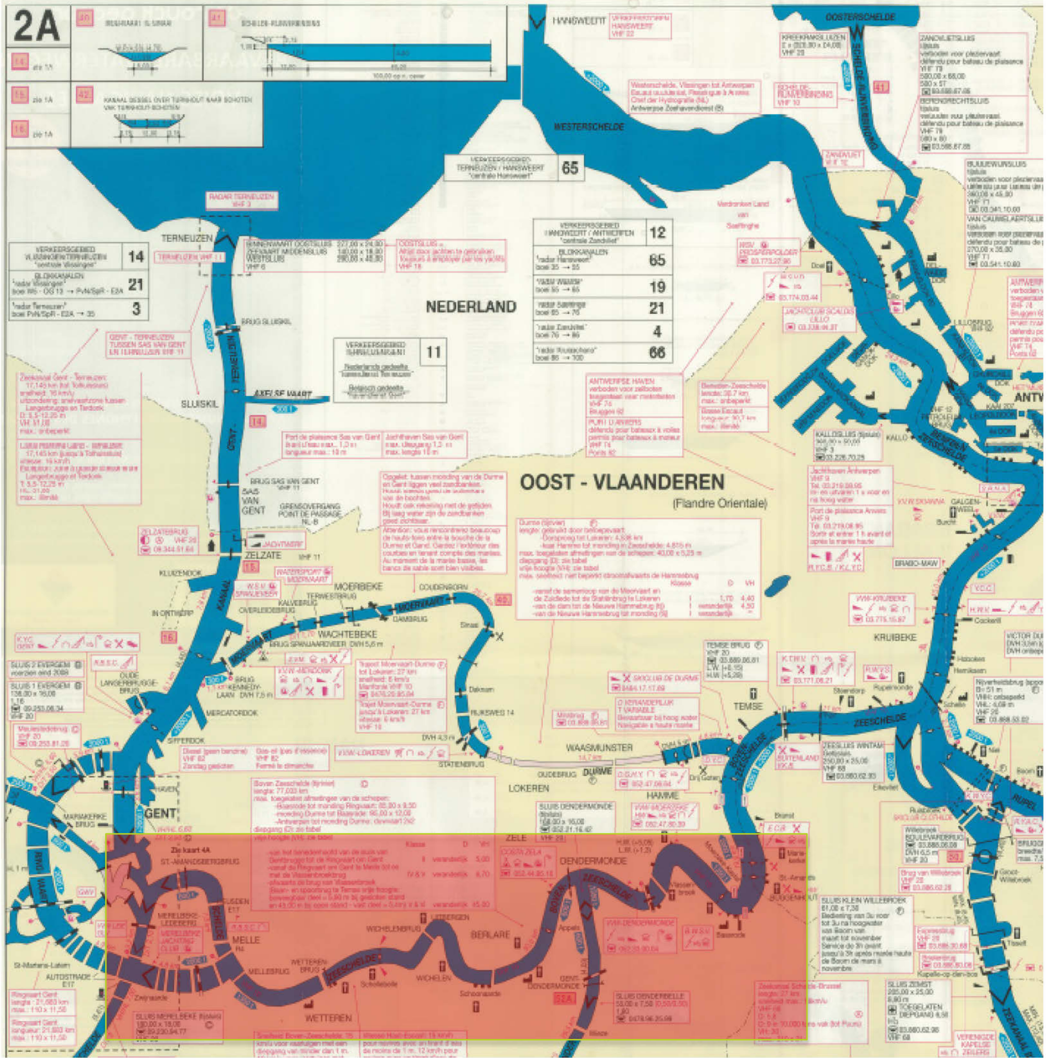


Designed for a panamax sized vessel increased to a beam of 37 m. 38 m is under investigation



Upper Sea-Scheldt





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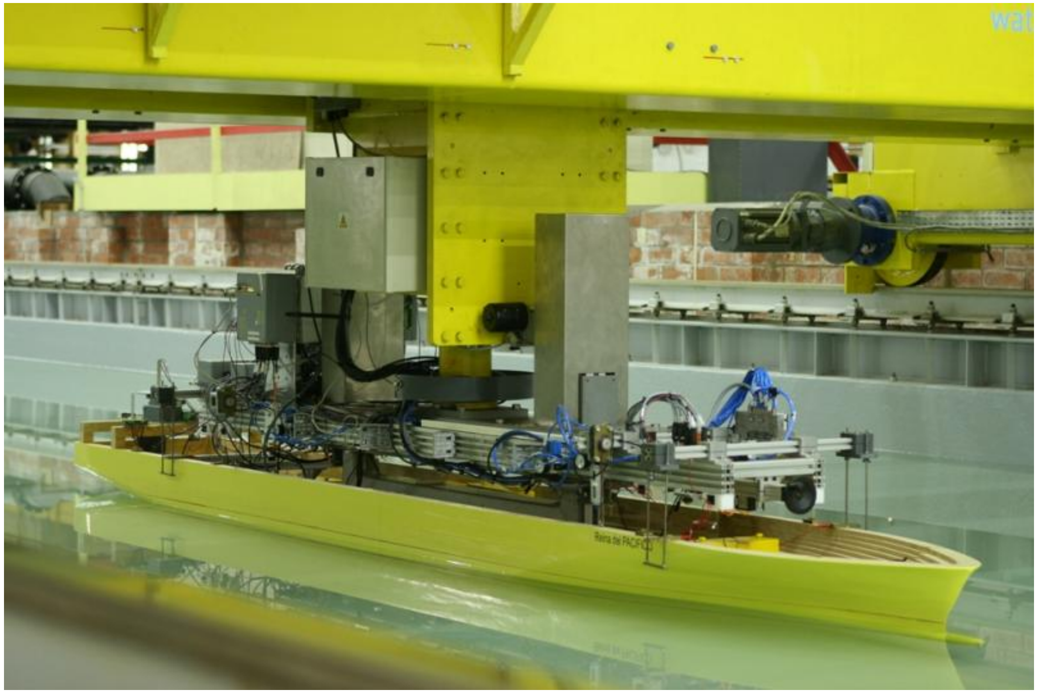
  - Canal Ghent-Terneuzen: interaction of maritime and inland fleet
  - Upper Sea-Scheldt: inland waterway
  - Port of Zeebrugge: nautical bottom – mud layer above a solid bottom

Introduction

Ship Behaviour in Shallow and Confined Water

Towing tank for manoeuvres in shallow water (co-operation Flanders Hydraulics Research – Ghent University)



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  - admittance policy
  - inland navigation

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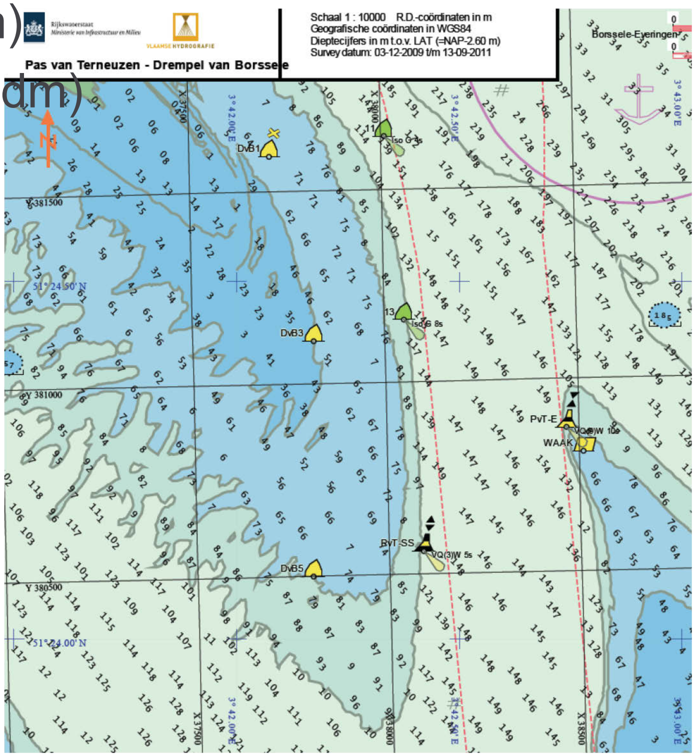
Ship Behaviour in Shallow and Confined Water

- **Effect on ship behaviour – video 38**
  - 18/04/2005 – Vlissingen – Springergeul
  - Lykes Motivator 243 m x 32 m (103 dm)
  - MSC Katherine Ann 184 m x 25 m (77 dm)
  - Zarechensk 180 m x 28 m (107 dm)



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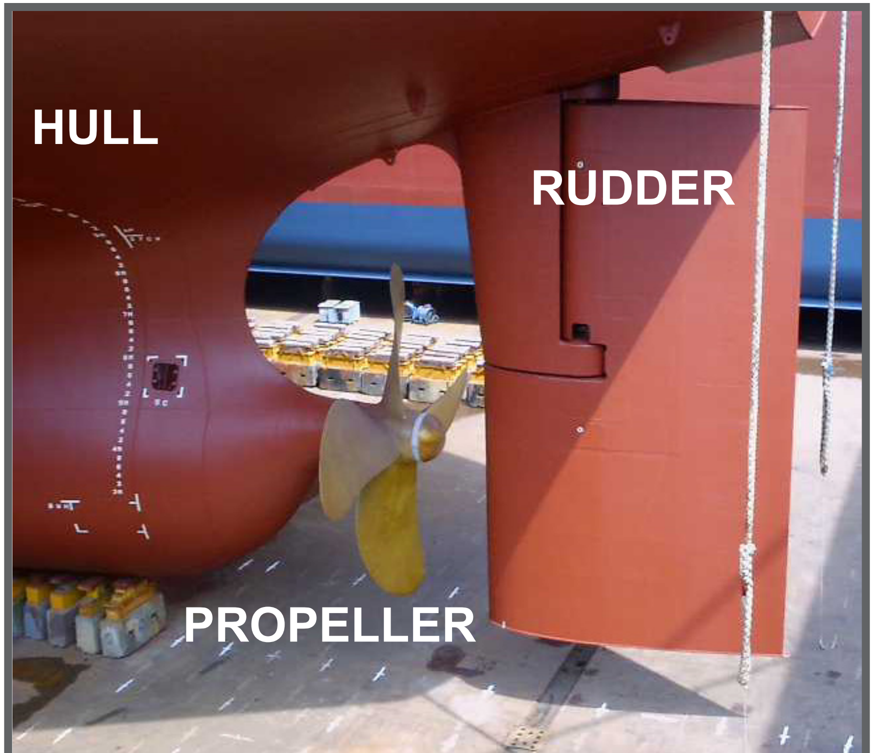
Ship manoeuvring in shallow water

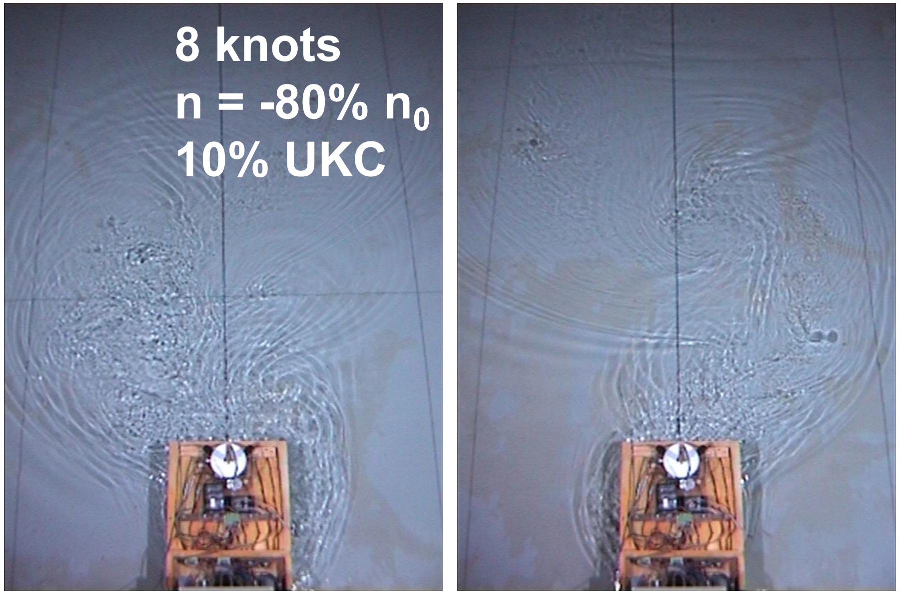
- Literature review: manoeuvring performance
  - **Ankudinov:** “*concept of modularity based on a separate representation of elements of the manoeuvring model*”
  - **Japan Towing Tank Committee:** MMG model

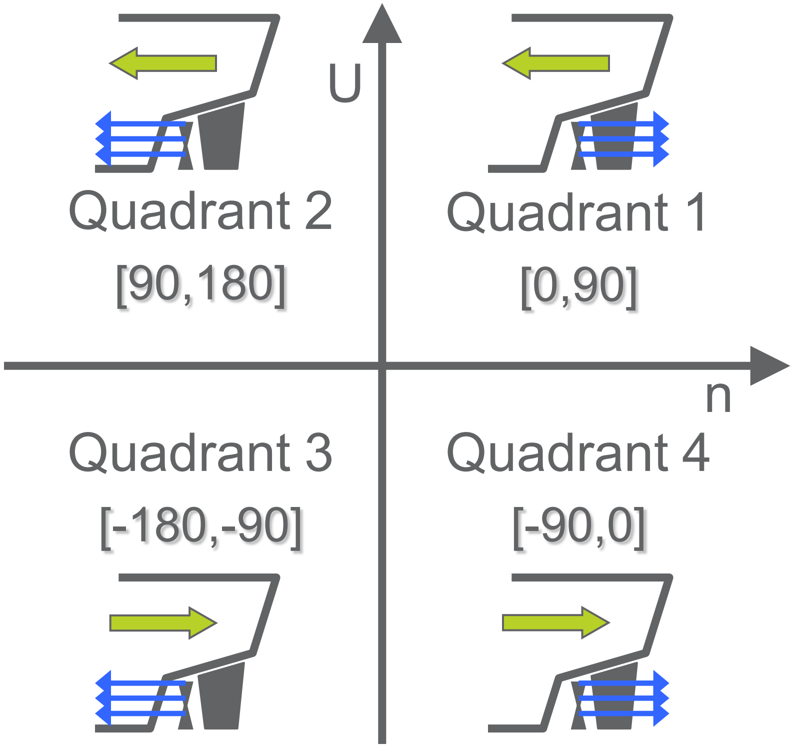


Ship manoeuvring in shallow water

- Literature review: manoeuvring performance
  - **Ankudinov**
  - **Japan Towing Tank Committee**
  - **Oltmann & Sharma, HSVA:**

    four quadrant concept

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n

Quadrant 2
[90,180]

Quadrant 1
[0,90]

Quadrant 3
[-180,-90]

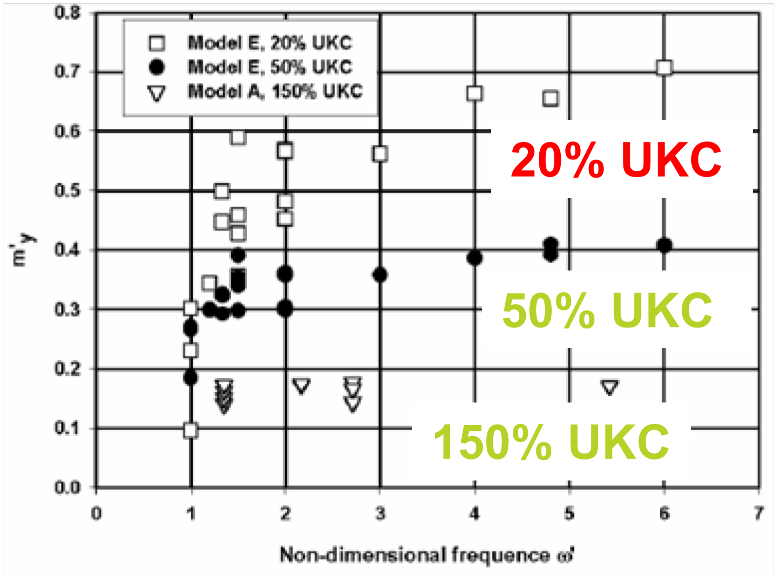
Quadrant 4
[-90,0]

Ship manoeuvring in shallow water

- Literature review: manoeuvring performance
    - **Ankudinov**
    - **Japan Towing Tank Committee**
    - **Oltmann & Sharma, HSVA**
    - **Hydronautics Research:** low speed manoeuvring models
    - **Force Technology (DMI):** look-up tables
    - **Flanders Hydraulics Research:** modular and tabular manoeuvring models (3 or 4 DOF) based on captive model tests and validated using free-running model tests and full scale measurements

Ship manoeuvring in shallow water

- Model tests
  - **Flanders Hydraulics Research:** *increasing influence of chosen test parameters during captive model tests on the derived mathematical model when UKC is decreasing*

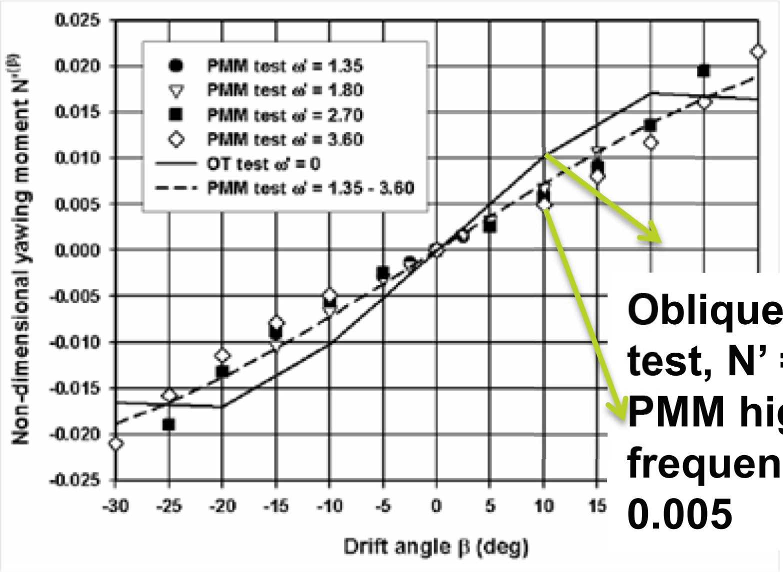


20% UKC

50% UKC

150% UKC

Test frequency

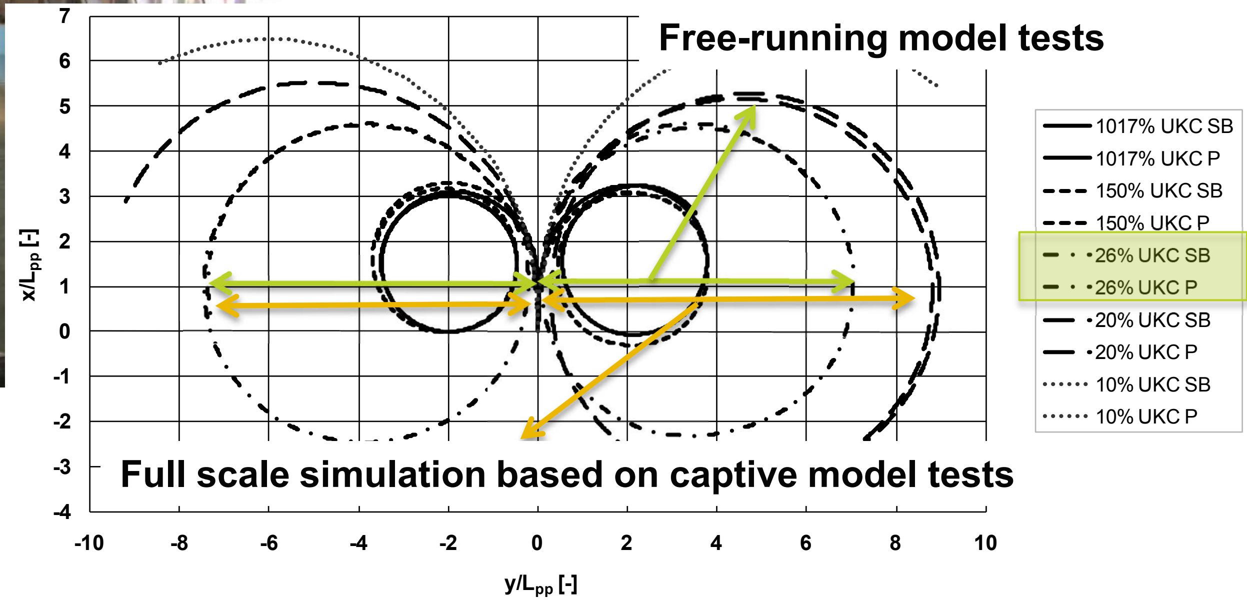


Oblique towing test, N' = 0.010
PMM highest frequency, N' = 0.005

Test type

Ship manoeuvring in shallow water

- Simulation model
  - **Flanders Hydraulics Research:** *increasing influence of chosen test parameters during captive model tests on the derived mathematical model when UKC is decreasing*



Free-running model tests

Full scale simulation based on captive model tests

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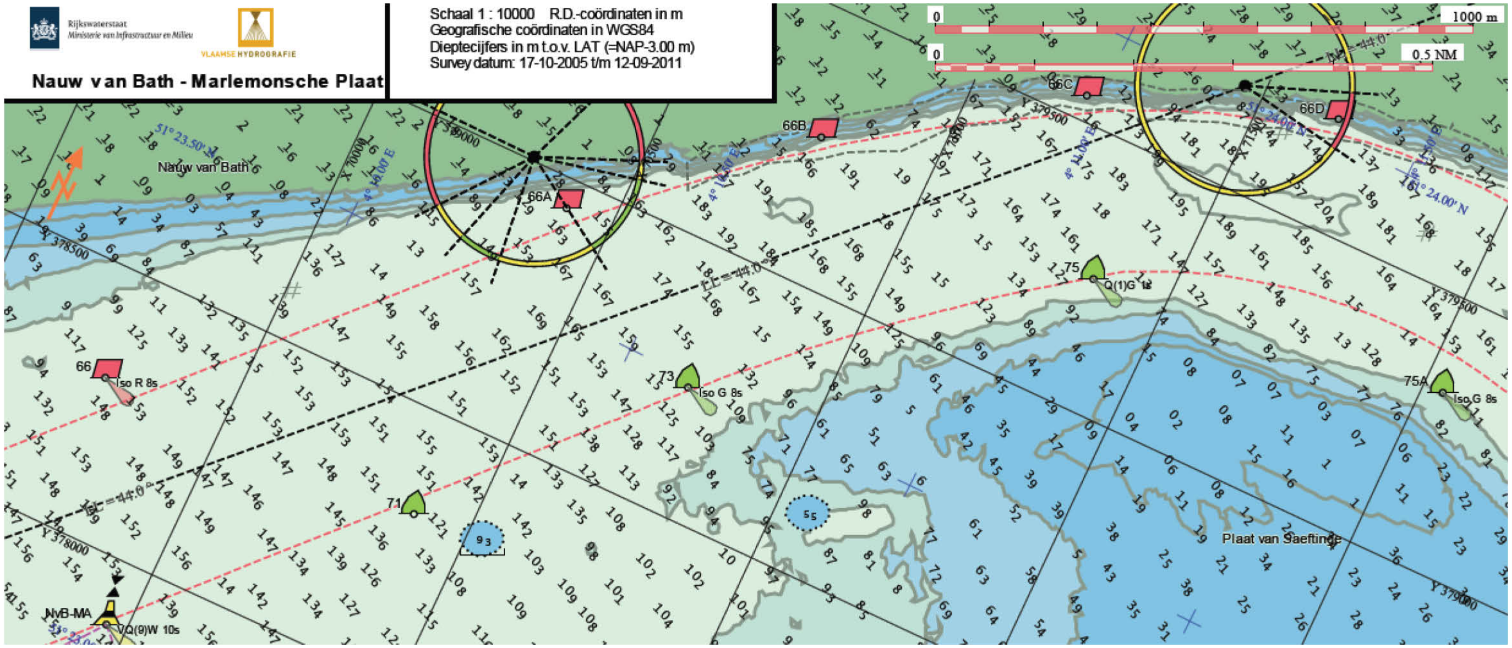
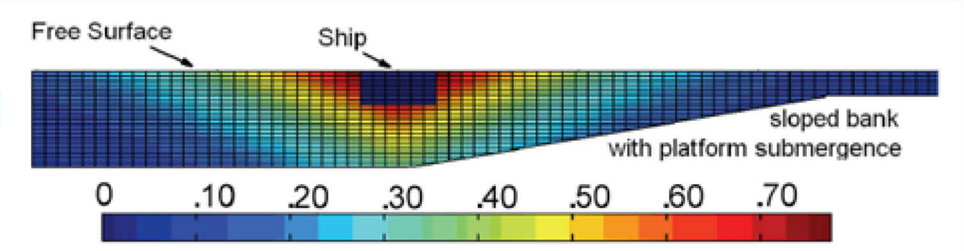
Ship behaviour due to bank effects

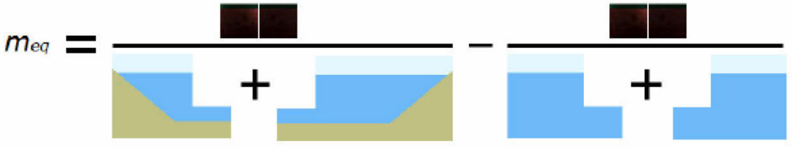
- Video

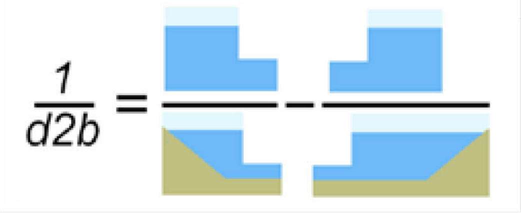


Ship behaviour due to bank effects

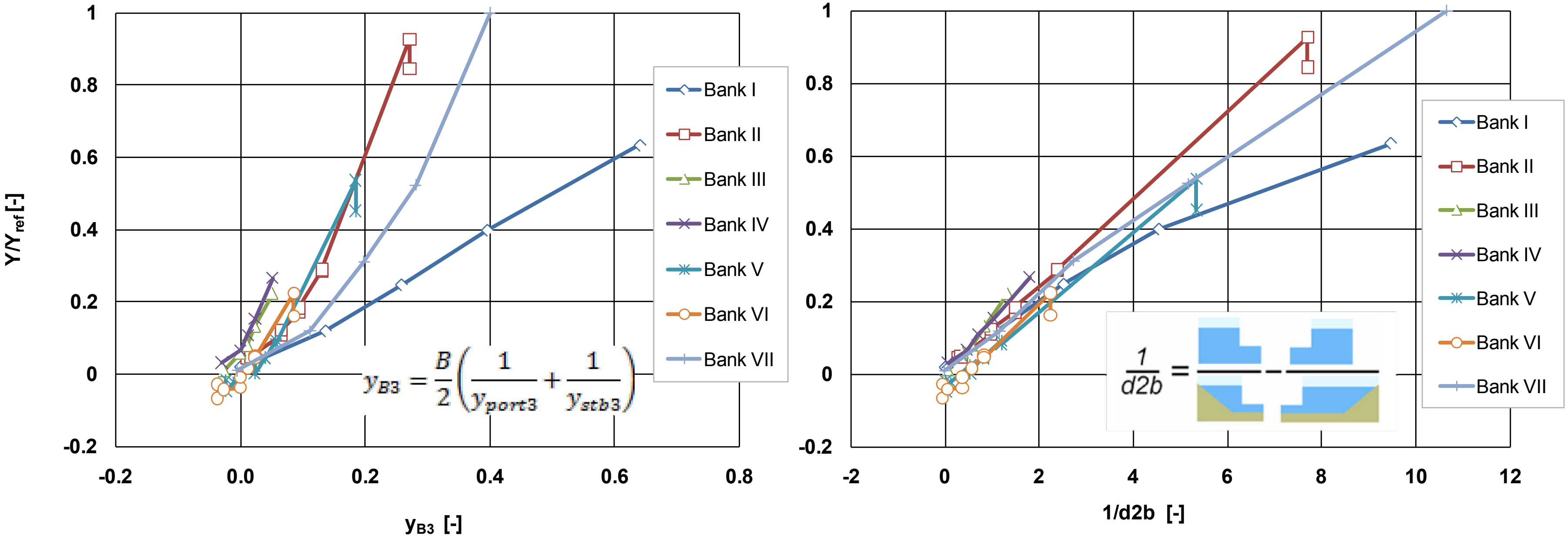
- Norrbin: “*if the channel banks are not vertical walls but sloping beaches the definition of the bank distance parameter is less obvious.*”, work extended by Ch’ng, Doctors and Renilson
  - Which vertical reference height to measure the distance between a ship and a bank?
  - Other formulations for the hydrodynamic changes in the water flow due to the vicinity of banks
- FHR and UGent: d_{2b} and m_{eq}
  - Weight distribution $e^{-a|y|-b|z|}$





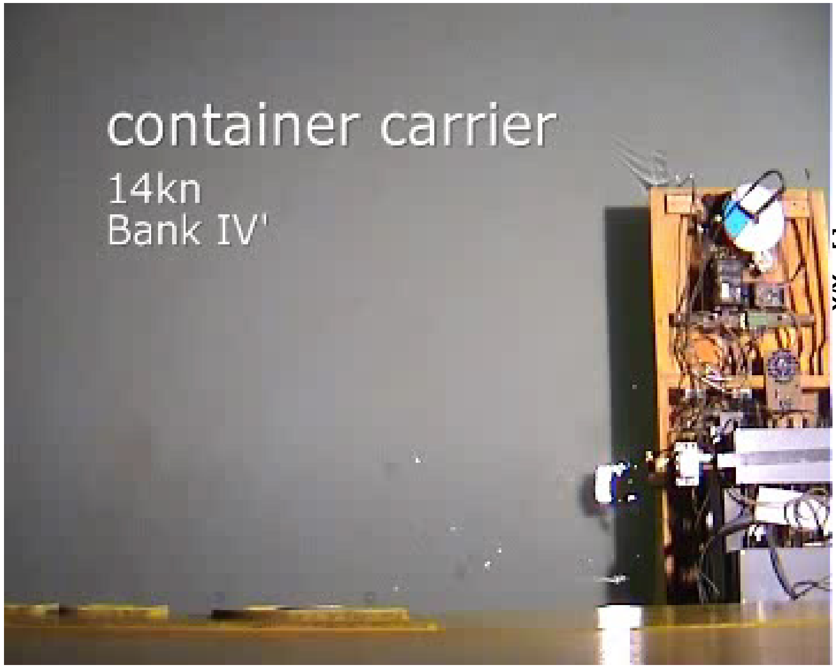


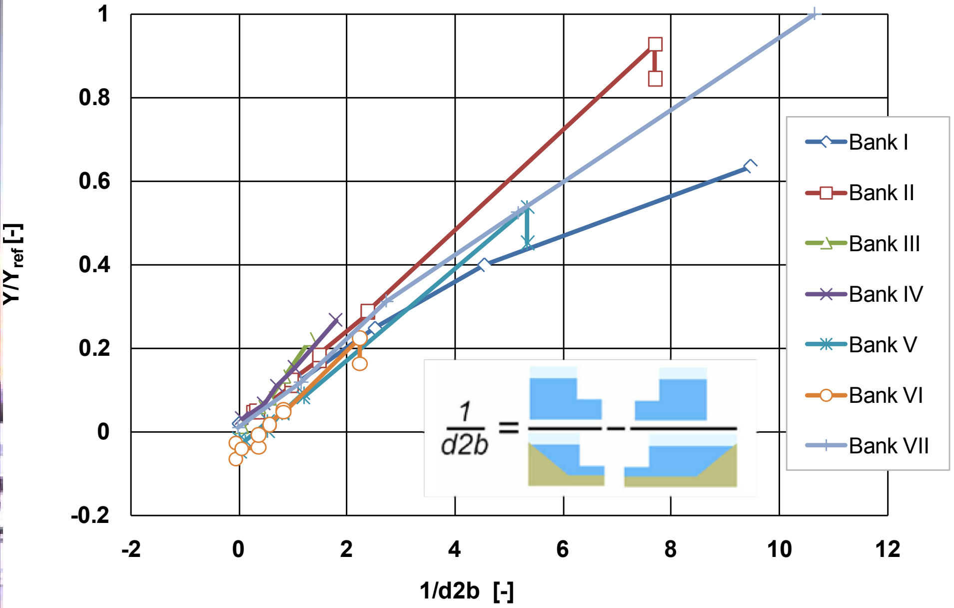
Ship behaviour due to bank effects



Container carrier at 10 knots and 100% UKC, no propeller

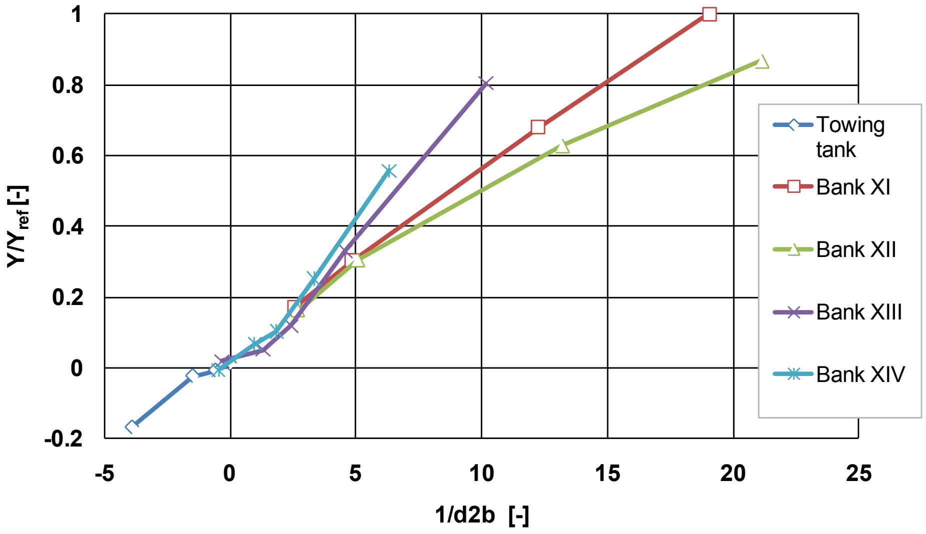
Ship behaviour due to bank effects





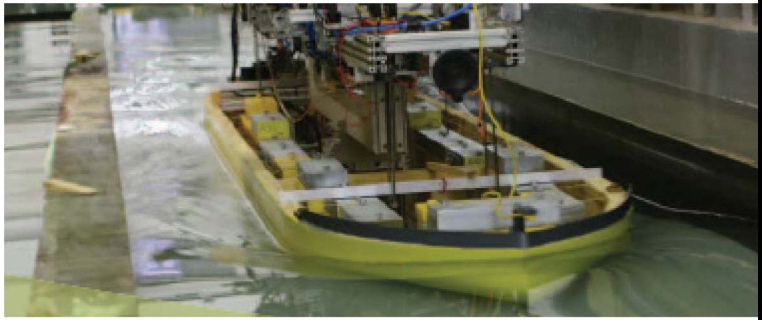
Ship behaviour due to bank effects

- KVLCC2 (10 knots, 50% UKC)



Ship behaviour due to bank effects

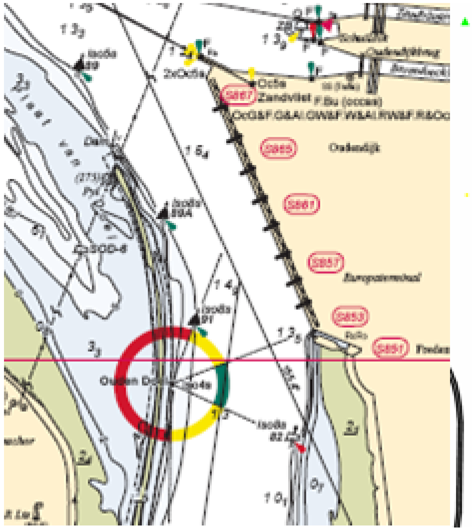
- KVLCC2

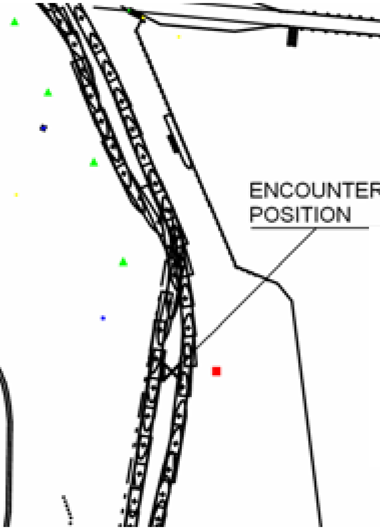


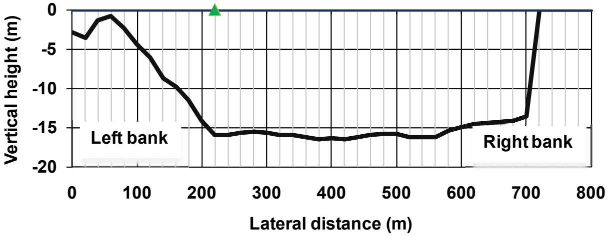
Ship behaviour due to bank effects

Real-time simulation study: meeting of two ULCS

- Length 350 to 400 m
- Beam 42.8 to 56.4 m







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  used for

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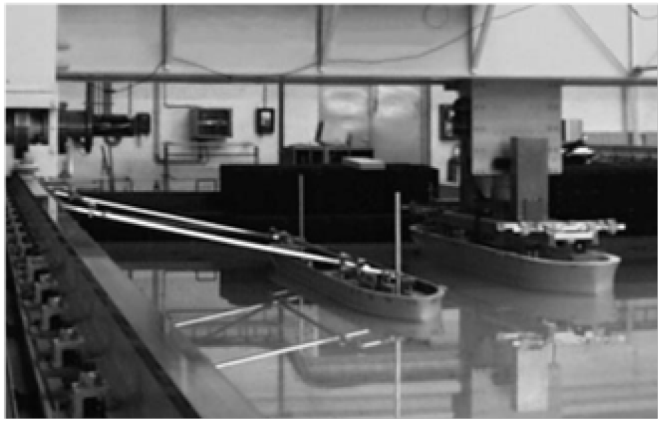
Ship behaviour during ship-to-ship interaction

Knowledge Centre Manoeuvring in Shallow and Confined Water, Conference May 2011 hosted by NTNU and MARINTEK

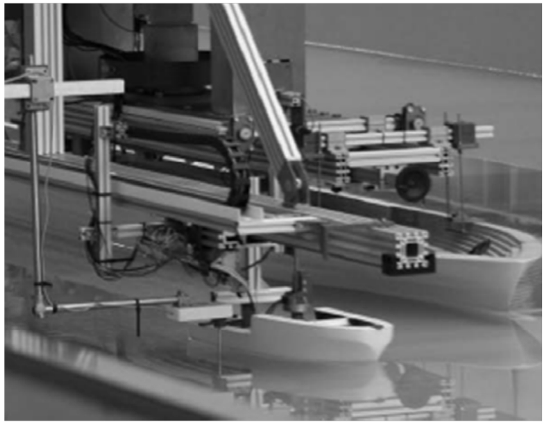
- **moored ships alongside quays;**
- **ships anchored or moored to buoys;**
- **ships meeting / passing on parallel / oblique / curved / steered paths;**
- **interaction with more than one ship or marine structure;**
- **ship-to-ship interaction during lightering operations;**
- **ship-to-ship interaction during tug assistance.**

Ship behaviour during ship-to-ship interaction



Meeting and overtaking

Lightering



Tug – ship interaction

Ship		C	D	E	H
L_{pp}	m	3.984	3.864	3.824	2.210
B	m	0.504	0.550	0.624	0.296
T_{ref}	m	0.180	0.180	0.207	0.178
C_B (at T_{ref})	-	0.843	0.588	0.816	0.830
T	m	0.155 – 0.200	0.155 – 0.200	0.136 – 0.256	0.125 – 0.178

Ship behaviour during ship-to-ship interaction

Project: KMB Investigating hydrodynamic aspect and control systems fot ship-to-ship operations, co-ordinated by MARINTEK and financially supported by the Research Council of Norway

- **Zero longitudinal speed difference**
- **Special case of overtaking and overtaken**
- **Steady state and dynamic tests**
- **Open STS data**

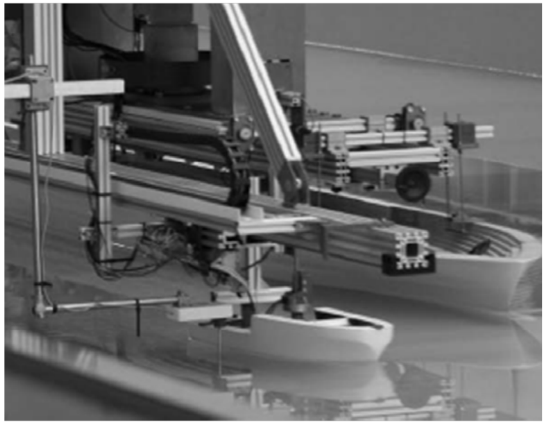
Lightering

h	T_{STBL}	n_{STBL}	V	T_{SS}	ψ_{SS}	n_{SS}	δy	δx
[m]	[m]	[-]	[kts]	[m]	[deg]	[-]	[m]	[m]
h_{max}	20.8	selfprop	2.0	7.5	180	Slow	4	0
1.35 T_{STBL}	12.8		4.0	15	179	Half	10	L/2
			5.0		178	selfprop	25	-L/2
			6.0		177		50	
					175		100	

Ship behaviour during ship-to-ship interaction

Lightering

Ship behaviour during ship-to-ship interaction



Tug – ship interaction

Forward speed [knots], full scale	5, 6, 7, 8, 9
Longitudinal separation x'_{rel} [-], from amidships of container vessel to centre of gravity of tug (non-dimensional value based on length of tug)	0.73, 1.25, 1.77, 2.29, 2.82, 3.33, 3.88, 4.41, 4.93
Transverse separation y'_{rel} [-], from centreline to centreline (non-dimensional value based on breadth of tug)	2.6, 3.3, 4.0, 4.4, 5.3
Drift angle [°], negative angle bow-in since tug model is situated on starboard in the towing tank	-10, -5, 0, 5, 10

Ship behaviour during ship-to-ship interaction

- Dedicated interaction models – complex pressure field change
- Different methodic combinations as EFD, CFD or other numerical codes
- JIP – ROPES, lead partner MARIN, Research on Passing Effects on Ships

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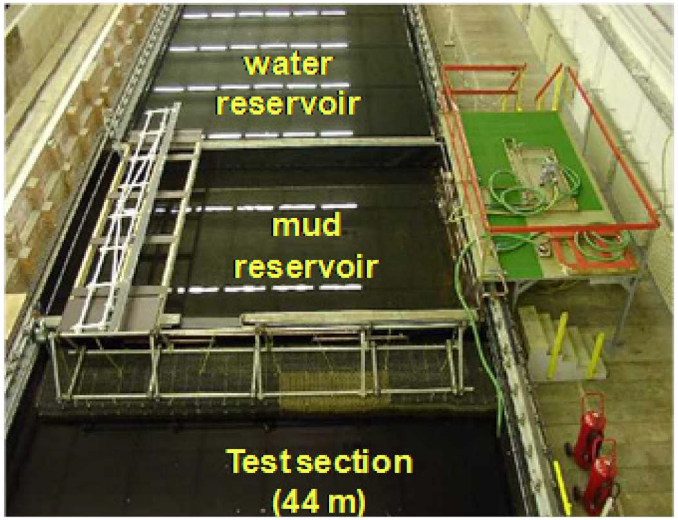
Nautical bottom

- PIANC: “*nautical bottom as the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and manoeuvrability*”
  - **Multidisciplinary approach: measuring/survey techniques, dredging techniques, physical mud characteristics, effect of mud layers on the behaviour of ships**
  - **EFD and nautical bottom research = how incorporate viscous effects if Reynold’s law is not fulfilled? Mud layer is a homogeneous layer with constant density and rheological properties.**

Nautical bottom

- Model tests at FHR
  - **Layer thickness**
  - **Mud density**
  - **Mud viscosity**
  - **Under keel clearance**

→ **78 parameter combinations**



Nautical bottom

- Results for the port of Zeebrugge
  - **Density criterion is 1.2 ton/m³ instead of 1.15 ton/m³**
  - **Navigation through the mud (negative UKC's water-mud interface)**
  - **300 m length container ship -7% UKC assisted by two 45 ton tugs**
- Main causes for the effect of mud layers on ship manoeuvrability:
  - **Internal wave pattern in the water-mud interface greatly depended on mud density**
  - **Rheological characteristics of the mud: (non –) Newtonian fluid**
- Development of in situ survey techniques

STT sediment test tank

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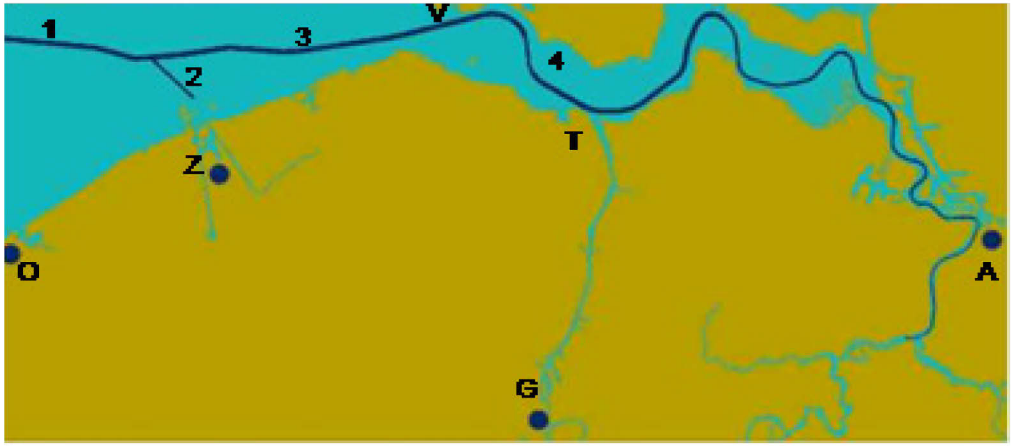
Example 1: admittance policy

Admittance policy based on a certain window

- **Tidal water level (min. gross UKC, % ship's draft):**
  - 15% coastal channels 1, 3
  - 12.5% for 2 and 4 (Dutch part)
  - 10% for 4 (Belgian part) and Z outer harbour
  - 1 m for Sea Canal Terneuzen – Ghent
- **Current (Z: 2 kn – 1.5 kn)**
- **Penetration in fluid mud (Z: 7%)**



Example 1: admittance policy

Admittance policy based on a gross UKC

Improved by a decision supporting tool ProToel:

- **Deterministic:** *gross UKC (nautical bottom and top of fluid mud layers, lateral current component)*
- **Probabilistic:** *probability of bottom touch (due to squat and response to waves) < selected maximum value*

Used for long term and short term decisions for the maximum allowable draft

Evaluation phase by the Flemish Pilotage and Shipping Assistance Devision for the port of Zeebrugge

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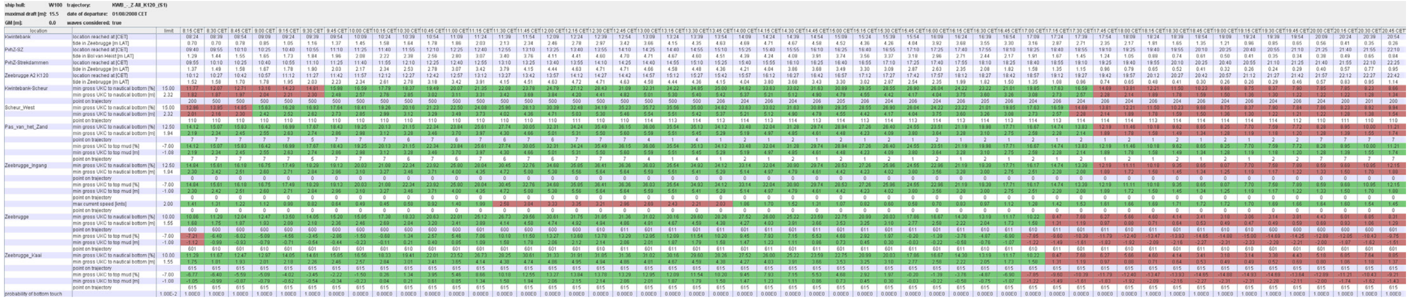
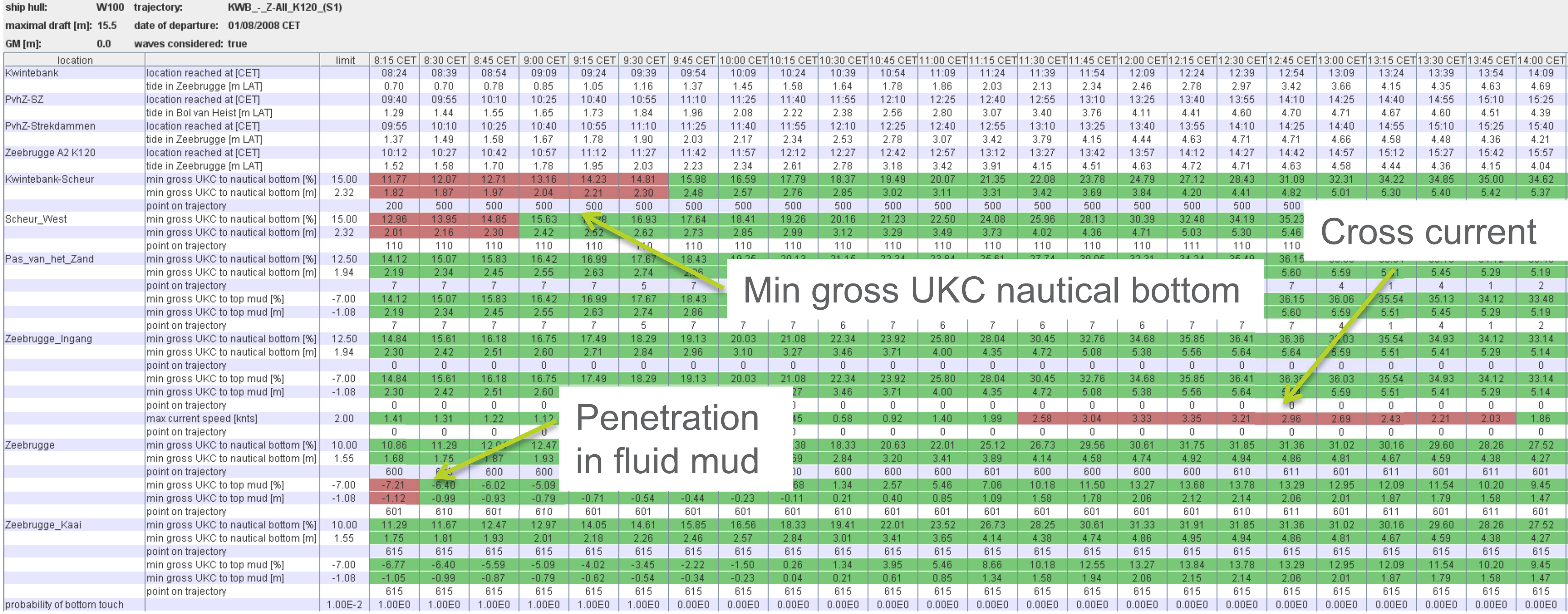




ship hull: W100 **trajectory:** KWB_-_Z-All_K120_(S1)
maximal draft [m]: 15.5 **date of departure:** 01/08/2008 CET
GM [m]: 0.0 **waves considered:** true

location		limit	8:15 CET	8:30 CET	8:45 CET	9:00 CET	9:15 CET	9:30 CET	9:45 CET	10:00 CET	10:15 CET	10:30 CET	10:45 CET	11:00 CET	11:15 CET	11:30 CET	11:45 CET	12:00 CET	12:15 CET	12:30 CET	12:45 CET	13:00 CET	13:15 CET	13:30 CET	13:45 CET	14:00 CET
Kwintebank	location reached at [CET]		08:24	08:39	08:54	09:09	09:24	09:39	09:54	10:09	10:24	10:39	10:54	11:09	11:24	11:39	11:54	12:09	12:24	12:39	12:54	13:09	13:24	13:39	13:54	14:09
	tide in Zeebrugge [m LAT]		0.70	0.70	0.78	0.85	1.05	1.16	1.37	1.45	1.58	1.64	1.78	1.86	2.03	2.13	2.34	2.46	2.78	2.97	3.42	3.66	4.15	4.35	4.63	4.69
PvhZ-SZ	location reached at [CET]		09:40	09:55	10:10	10:25	10:40	10:55	11:10	11:25	11:40	11:55	12:10	12:25	12:40	12:55	13:10	13:25	13:40	13:55	14:10	14:25	14:40	14:55	15:10	15:25
	tide in Bol van Heist [m LAT]		1.29	1.44	1.55	1.65	1.73	1.84	1.96	2.08	2.22	2.38	2.56	2.80	3.07	3.40	3.76	4.11	4.41	4.60	4.70	4.71	4.67	4.60	4.51	4.39
PvhZ-Strekdammen	location reached at [CET]		09:55	10:10	10:25	10:40	10:55	11:10	11:25	11:40	11:55	12:10	12:25	12:40	12:55	13:10	13:25	13:40	13:55	14:10	14:25	14:40	14:55	15:10	15:25	15:40
	tide in Zeebrugge [m LAT]		1.37	1.49	1.58	1.67	1.78	1.90	2.03	2.17	2.34	2.53	2.78	3.07	3.42	3.79	4.15	4.44	4.63	4.71	4.71	4.66	4.58	4.48	4.36	4.21
Zeebrugge A2 K120	location reached at [CET]		10:12	10:27	10:42	10:57	11:12	11:27	11:42	11:57	12:12	12:27	12:42	12:57	13:12	13:27	13:42	13:57	14:12	14:27	14:42	14:57	15:12	15:27	15:42	15:57
	tide in Zeebrugge [m LAT]		1.52	1.58	1.70	1.78	1.95	2.03	2.23	2.34	2.61	2.78	3.18	3.42	3.91	4.15	4.51	4.63	4.72	4.71	4.63	4.58	4.44	4.36	4.15	4.04
Kwintebank-Scheur	min gross UKC to nautical bottom [%]	15.00	11.77	12.07	12.71	13.16	14.23	14.81	15.98	16.59	17.79	18.37	19.49	20.07	21.35	22.08	23.78	24.79	27.12	28.43	31.09	32.31	34.22	34.85	35.00	34.62
	min gross UKC to nautical bottom [m]	2.32	1.82	1.87	1.97	2.04	2.21	2.30	2.48	2.57	2.76	2.85	3.02	3.11	3.31	3.42	3.69	3.84	4.20	4.41	4.82	5.01	5.30	5.40	5.42	5.37
	point on trajectory		200	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scheur_West	min gross UKC to nautical bottom [%]	15.00	12.96	13.95	14.85	15.63	[illegible]	16.93	17.64	18.41	19.26	20.16	21.23	22.50	24.08	25.96	28.13	30.39	32.48	34.19	35.23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	min gross UKC to nautical bottom [m]	2.32	2.01	2.16	2.30	2.42	2.52	2.62	2.73	2.85	2.99	3.12	3.29	3.49	3.73	4.02	4.36	4.71	5.03	5.30	5.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	point on trajectory		110	110	110	110	110	[illegible]	110	110	110	110	110	110	110	110	110	110	111	110	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pas_van_het_Zand	min gross UKC to nautical bottom [%]	12.50	14.12	15.07	15.83	16.42	16.99	17.67	18.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	min gross UKC to nautical bottom [m]	1.94	2.19	2.34	2.45	2.55	2.63	2.74	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.60	5.59	[illegible]	5.45	5.29	5.19
	point on trajectory		7	7	7	7	7	5	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	4	1	4	1	2
	min gross UKC to top mud [%]	-7.00	14.12	15.07	15.83	16.42	16.99	17.67	18.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.15	36.06	35.54	35.13	34.12	33.48
	min gross UKC to top mud [m]	-1.08	2.19	2.34	2.45	2.55	2.63	2.74	2.86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.60	5.59	5.51	5.45	5.29	5.19
	point on trajectory		7	7	7	7	7	5	7	7	7	6	7	6	7	6	7	6	7	7	7	4	1	4	1	2
Zeebrugge_Ingang	min gross UKC to nautical bottom [%]	12.50	14.84	15.61	16.18	16.75	17.49	18.29	19.13	20.03	21.08	22.34	23.92	25.80	28.04	30.45	32.76	34.68	35.85	36.41	36.36	[illegible]	35.54	34.93	34.12	33.14
	min gross UKC to nautical bottom [m]	1.94	2.30	2.42	2.51	2.60	2.71	2.84	2.96	3.10	3.27	3.46	3.71	4.00	4.35	4.72	5.08	5.38	5.56	5.64	5.64	5.59	5.51	5.41	5.29	5.14
	point on trajectory		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	min gross UKC to top mud [%]	-7.00	14.84	15.61	16.18	16.75	17.49	18.29	19.13	20.03	21.08	22.34	23.92	25.80	28.04	30.45	32.76	34.68	35.85	36.41	[illegible]	36.03	35.54	34.93	34.12	33.14
	min gross UKC to top mud [m]	-1.08	2.30	2.42	2.51	2.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.46	3.71	4.00	4.35	4.72	5.08	5.38	5.56	5.64	[illegible]	5.59	5.51	5.41	5.29	5.14
	point on trajectory		0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	max current speed [knts]	2.00	1.41	1.31	1.22	1.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.58	0.92	1.40	1.99	2.58	3.04	3.33	3.35	3.21	2.96	2.69	2.43	2.21	2.03	1.86
	point on trajectory		0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zeebrugge	min gross UKC to nautical bottom [%]	10.00	10.86	11.29	[illegible]	12.47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.33	20.63	22.01	25.12	26.73	29.56	30.61	31.75	31.85	31.36	31.02	30.16	29.60	28.26	27.52
	min gross UKC to nautical bottom [m]	1.55	1.68	1.75	1.87	1.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.84	3.20	3.41	3.89	4.14	4.58	4.74	4.92	4.94	4.86	4.81	4.67	4.59	4.38	4.27
	point on trajectory		600	[illegible]	600	600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	600	600	600	601	600	600	600	600	610	611	601	611	601	611	601
	min gross UKC to top mud [%]	-7.00	-7.21	-6.40	-6.02	-5.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.34	2.57	5.46	7.06	10.18	11.50	13.27	13.68	13.78	13.29	12.95	12.09	11.54	10.20	9.45
	min gross UKC to top mud [m]	-1.08	-1.12	-0.99	-0.93	-0.79	-0.71	-0.54	-0.44	-0.23	-0.11	0.21	0.40	0.85	1.09	1.58	1.78	2.06	2.12	2.14	2.06	2.01	1.87	1.79	1.58	1.47
	point on trajectory		601	610	601	610	601	601	601	601	601	610	601	601	601	601	601	601	601	610	611	601	611	601	611	601
Zeebrugge_Kaai	min gross UKC to nautical bottom [%]	10.00	11.29	11.67	12.47	12.97	14.05	14.61	15.85	16.56	18.33	19.41	22.01	23.52	26.73	28.25	30.61	31.33	31.91	31.85	31.36	31.02	30.16	29.60	28.26	27.52
	min gross UKC to nautical bottom [m]	1.55	1.75	1.81	1.93	2.01	2.18	2.26	2.46	2.57	2.84	3.01	3.41	3.65	4.14	4.38	4.74	4.86	4.95	4.94	4.86	4.81	4.67	4.59	4.38	4.27
	point on trajectory		615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615
	min gross UKC to top mud [%]	-7.00	-6.77	-6.40	-5.59	-5.09	-4.02	-3.45	-2.22	-1.50	0.26	1.34	3.95	5.46	8.66	10.18	12.55	13.27	13.84	13.78	13.29	12.95	12.09	11.54	10.20	9.45
	min gross UKC to top mud [m]	-1.08	-1.05	-0.99	-0.87	-0.79	-0.62	-0.54	-0.34	-0.23	0.04	0.21	0.61	0.85	1.34	1.58	1.94	2.06	2.15	2.14	2.06	2.01	1.87	1.79	1.58	1.47
	point on trajectory		615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615	615
probability of bottom touch		1.00E-2	1.00E0	1.00E0	1.00E0	1.00E0	1.00E0	1.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0	0.00E0

Cross current

Min gross UKC nautical bottom

Penetration in fluid mud

Overview

Ship Behaviour in Shallow and Confined Water

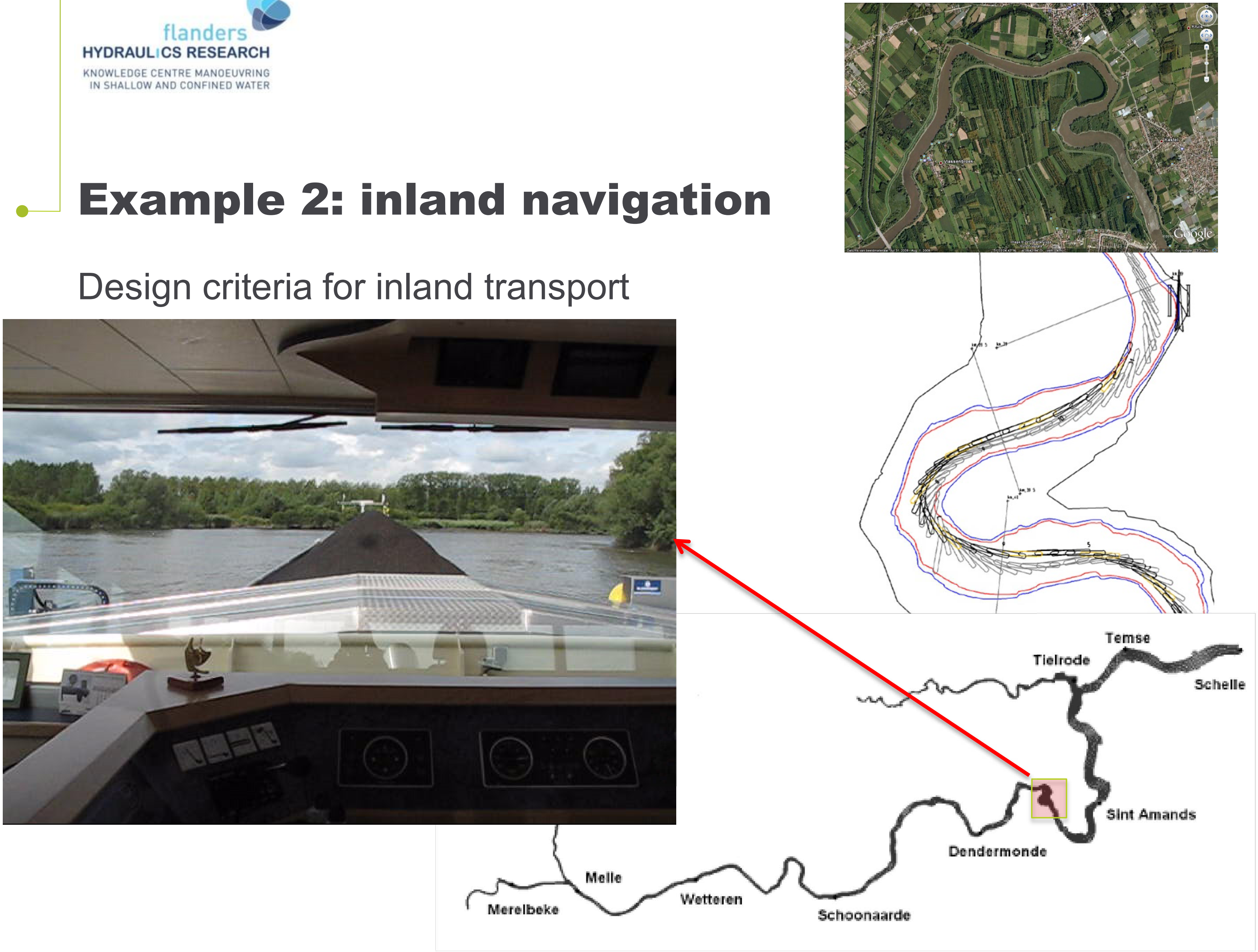
- **Shallow and confined water areas in Flanders**
- **Effect on ship behaviour**
  - ship manoeuvring in open and shallow water
  - bank effects
  - ship-to-ship interaction
  - nautical bottom

  used for

  - admittance policy
  - inland navigation

Example 2: inland navigation

Design criteria for inland transport



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IN SHALLOW AND CONFINED WATER

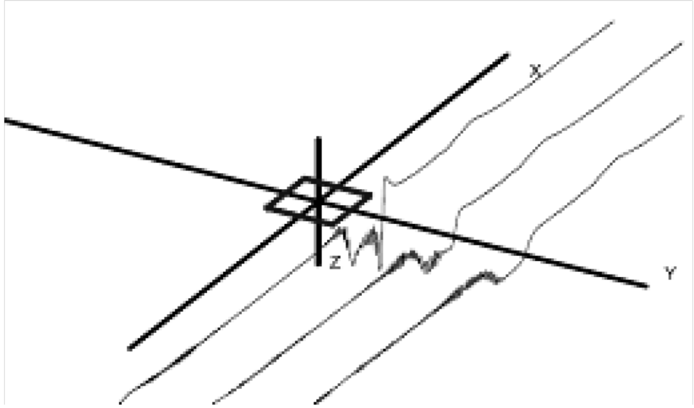
department
Mobility and
Public Works

Example 2: inland navigation

Simulation model based on captive model tests

- **Ship manoeuvring in shallow water**
- **Bank effects**
- **STS interaction module**

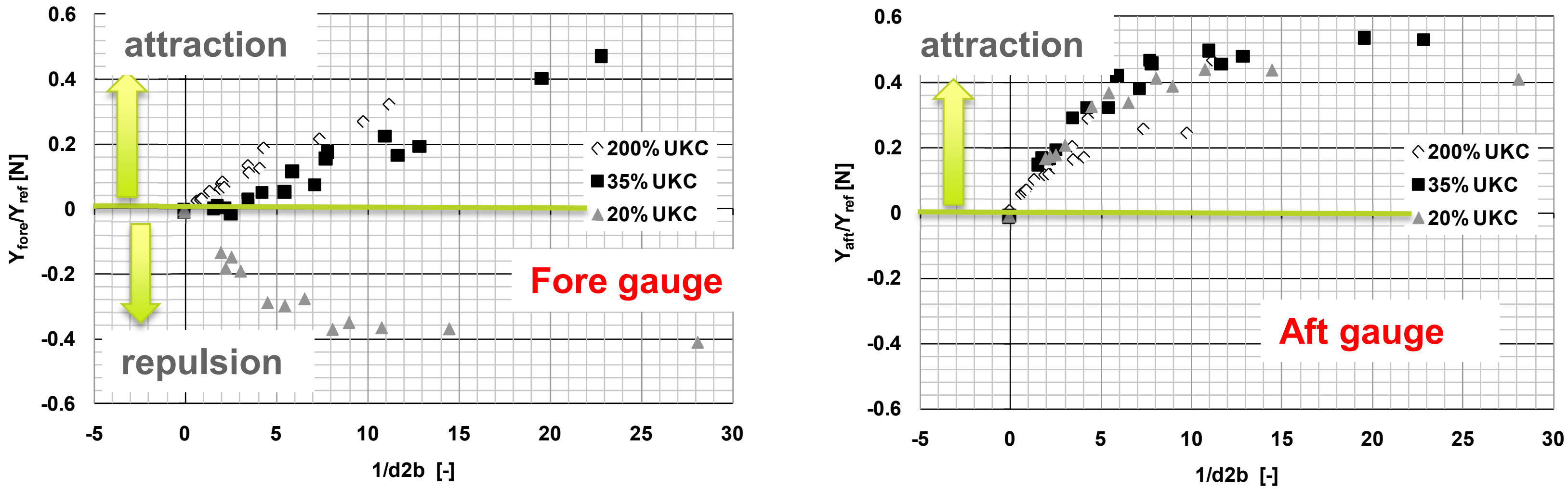
  based on generalised model
  for maritime ships



Example 2: inland navigation

Validation

- **Multimodal captive model tests**
- **Free-running model tests**
- **Full scale measurements during trial voyages**
- **Real-time simulation by a skipper on the inland simulator Lara**



Lateral force due to bank effects at fore and aft gauges

Summary

- Ship manoeuvrability decreases for UKC < 50% draft
- Complex hydrodynamic effects due to horizontal (bank, ship) and vertical (shallow water, nautical bottom) restrictions
- Knowledge based on different methodologies
  - **Experimental fluid dynamics (force – water flow)**
  - **Computational fluid dynamics (pressure – water flow)**
  - **Numerical methods**
- Co-operation