Bilaga 2.

SHALLOW WATER EFFECTS DURING THE COLLISION OF M/V GARDEN AND M/V VINGAREN 2nd of October 2002

1. Vessel Waterway and Vessel to Vessel interactions

The collision of M/V Garden and M/V Vingaren took place in Drogden channel, which has a dredged breadth of 300 m and depth of 8 m. Maximum allowable draft is 7,7 m. Water depth just outside the channel in the collision area is about 7 m. So, this channel is a restricted waterway especially relative to the depth.

Navigation in shallow waterways affects the movements and control of ships. In order to make right decisions for maneuvering one should be familiar with these effects. Additional knowledge is needed when two vessels meet in restricted waters.

Ideally, one should be able to evaluate the behavior of two passing or overtaking ships and calculate safe separation and speed and give instructions for maneuvering. However, a general method is lacking. This situation includes too many parameters to be analyzed by today's methods. However, a lot of theoretical studies, experimental work with ship models and some full-scale measurements have been carried out. In the following applicable results of these activities are used in quite a simple way in order to get a qualitative and partly quantitative picture about one possible course of events.

1.1 Shallow water effects

When a ship is moving in shallow water, the following phenomena will realize

1. draft will increase, which is called squat. It consists of vertical sinkage and change of trim.
2. manoeuvring characteristics will change: manoeuvring (turning) characteristics will deteriorate, coursekeeping (steering) characteristics might worsen or improve depending on ship characteristics and water depth/draft ratio - h/T
3. resistance will increase

Water is deemed to be shallow, which means that the ship will feel the bottom of the fairway when:

1. water depth/draft - ratio (h/T) < 3 ... 4. The depth h corresponds to the normal water level.
2. Froude depth number F_{nh} = ship speed/squareroot(g x h) = $V/(gh)^{1/2}$. Froude depth numbers bigger than 0,1 have already some theoretical effect (squat). In practice squat will be noticeable when $F_{nh} > 0,3$. Resistance increase will be noticeable for $F_{nh} > 0,7$.

In shallow water underkeel clearance is small. Therefore the water flow speed increases under the shipbottom which means that the pressure will decrease according to Bernoulli law. The result is squat.

1.2 Vessel to Vessel interactions

When two vessels move near each other their water flow fields will interact resulting in forces and moments on both ships. Depending on their relative longitudinal position, longitudinal forces will be directed forward or backward, lateral forces may be attractive or repulsive, turning moments try to turn vessels' bows towards each other or away from each other. Also sinkage and trim (squat) will depend on the relative longitudinal position. The maximum of these forces and moments depend strongly on speed of the vessels, separation (transverse distance between them) and their sizes, other ship parameters, water depth, possible stream, wind and waves and channel properties. When the ships are very near each other their own wave systems may have an impact on their movements.

1.3 Parameters of Garden and Vingaren

For this case we will get the following results if the water depth h is taken equal to 8 m, 9 m and 10 m. At the place of the collision the water depth was 8 m, provided that the water level was normal.

	Garden			Vingaren			
Loa/Lpp	151/137,5			81,5			
B	19,3			13,4			
T mean	6,1 (abt during overtaking)			5,0 (abt during overtaking)			
V, knots	14,5			11,5			
CB	abt 0,75			0,69			block coefficient
Δ	abt 12500			3838			deplacement
Fn	0,19			0,20			Froude number
s	80	60	40	80	60	40	separation
s/B	4,15	3,11	2,07	5,97	4,48	2,99	
s/L	0,53	0,40	0,26	0,98	0,74	0,49	
h	**8 (min)**	9	10	8	9	10	water depth
Fnh	**0,84**	0,79	0,75	0,67	0,63	0,60	Froude depth number
squat	**1,05**	0,99	0,92	0,61	0,55	0,52	
h/T	**1,31**	1,48	1,64	1,60	1,80	2,00	

Squat has been evaluated based on reference 10.
As seen, speeds of vessels are quite high for these water depths, especially for Garden. Underkeel clearance of Garden has been about 1 m and of Vingaren about 2,3 m.

2. Results from literature

From literature study the following helpful references has been found. None approximately similar case has been found; however combining nondimensionalized results from many sources it is possible to do an evaluation.

1. **Dand** (NMI R6), **Hydrodynamic Aspects of Shallow Water Collisions**, November 1976.
2. **Dand** (NMI R7), **Some aspects of Tug-Ship Interaction**, January 1977.
3. **Dand** (NMI R8), **Ship-Ship Interaction in Shallow Water**, March 1977
4. **Dand** (NMI R38), **The Physical Causes of Interaction and its Effects**, April 1978
5. **Dand** (NMI R108), **Some measurements of interaction between ship models passing on parallel courses**, August 1981. These reports present results of many model experiments with variable speeds, separation and water depth/draft-ratio. Reports include propeller bias, ships of dissimilar size. A special case of greatly dissimilar ships is the case of an assisting tug (in our case the ships are greatly different in size). The source NMI R38 includes a good overview of the physical basis of this situation. (NMI = National Maritime Institute, Great Britain).
6. **PNA, Principles of Naval Architecture, SNAME 1989, Part III, pp. 287,288.** (This is based on a work by Newton, R.N in 1960) Two models were towed in deep water on parallel straight courses at different longitudinal positions relative to each other over a range of full-scale speeds from 10 to 20 knots. The transverse separation was varied, too. So, the speeds of both vessels are equal, and the water is not shallow. The size - ratio is about the right.

7. **Müller, E, Manövrieren bei Fahrwasserbeschränkung.** Here are put together all effects of restricted waterways on one or two ships. Some results interesting for us are shown: two equal vessels in an overtaking situation, h/T = 2,0 and two separations.
8. **P.Kaplan and K. Sankaranarayanan, Hydrodynamic interaction of ships in shallow channels, including effects of asymmetry.** Here are reported theoretical work and calculated results with comparison of some experimental work. Two tankers were passing each other with a speed of 7 knots or passing a moored ship. So, the situation is too far from ours to be applied. But it confirms the general picture.
9. **Katsuro Kijima, Manoeuvrability of ship in confined water.** This study reports of theoretical work with a calculated example. A bigger vessel (L = 160 m) is overtaking a smaller one (L = 100 m) in a channel of width 200 m. Speeds are 4 and 5 knots, h/T = 1,2 and 1,92. Separation between vessels was varied. This corresponds to our case except the restricted channel width and the speeds. References 8 and 9 are from International Conference on Ship Manoeuvrability - Prediction and Achievement, 29 - 30 April and 1 May 1987, London, RINA
10. **O. Huuska, On the evaluation of Underkeel Clearances in Finnish Waterways,** Helsinki University of Technology, Ship Hydrodynamics Laboratory, Otaniemi, Finland Report No 9, 1976. This is used for squat evaluation.

3. Application to the collision of Garden and Vingaren

3.1 Ship waves

Ship generating waves will be inside a triangle with an angle in the bow of 2 x 19,5 grades. The collision happened when the distance between the ships was decreasing from about 40 m. Then M/V Vingaren will hit the first waves of M/V Garden when the distance from the bow of Garden to the bow of Vingaren is about 70 m. According to the reports this distance was about 125 m. So, Vingaren was inside the wave field of Garden.

3.2 Effect of stream

According to the reports a stream towards NNE had a speed of 1-1,5 knots. The component eastward was then 0,5 - 0,75 kn. Vingaren was already on the east boundary of the channel and it maneuvered so that not going too much eastwards. If Garden only held its course it approached Vingaren with a sideward velocity of 0,26 - 0,39 m/s. The time from the moment when Garden began to overtake Vingaren to the collision was about two minutes. During that time the stream could move Garden 31 ... 47 m towards Vingaren. (The same end result will be achieved by correcting the course of Garden towards north by about 2 grades). Maybe, Vingaren moved about 10 m closer to the boundary of the channel due to the stream and Garden tried to hold the distance. In any case, the stream moved garden somewhat towards Vingaren.

3.3 Effect of ship size

The mass of Garden is more than three times that of Vingaren. According to crude estimations in the middle of overtaking the attractive force on Vingaren could be about 50 kN and on Garden about 100 kN. Therefore, accelerations are higher for Vingaren.

3.4 Effect of ship speed

As a first approximation, the forces and moments are directly proportional to the square of the ship speed. The effect of relative speed is a little bit unclear.

3.5 Effect of water depth

As a first approximation, the forces and moments are inversely proportional to ratio h/T in power 0,7. For example, if this ratio decreases from 1,5 to 1,3 (water gets shallower or draft increases), increase of forces and moments is about 10 %.

3.6 Effect of separation

As a first approximation, the forces and moments are inversely proportional to ratio s/L. For example, if the separation is halved, forces and moments are doubled.

3.7 Effect of steering

Both vessels steered in order to keep the course. In addition, Vingaren had to avoid the channel boundary. In principle, they should act together as shown in the following figure 1 based on ref. 6. In the references, the need of steering with the right rudder angles is discussed. According to the reports, the vessels did not try to counteract the stream by active steering.

4. Evaluation of Garden - Vingaren case

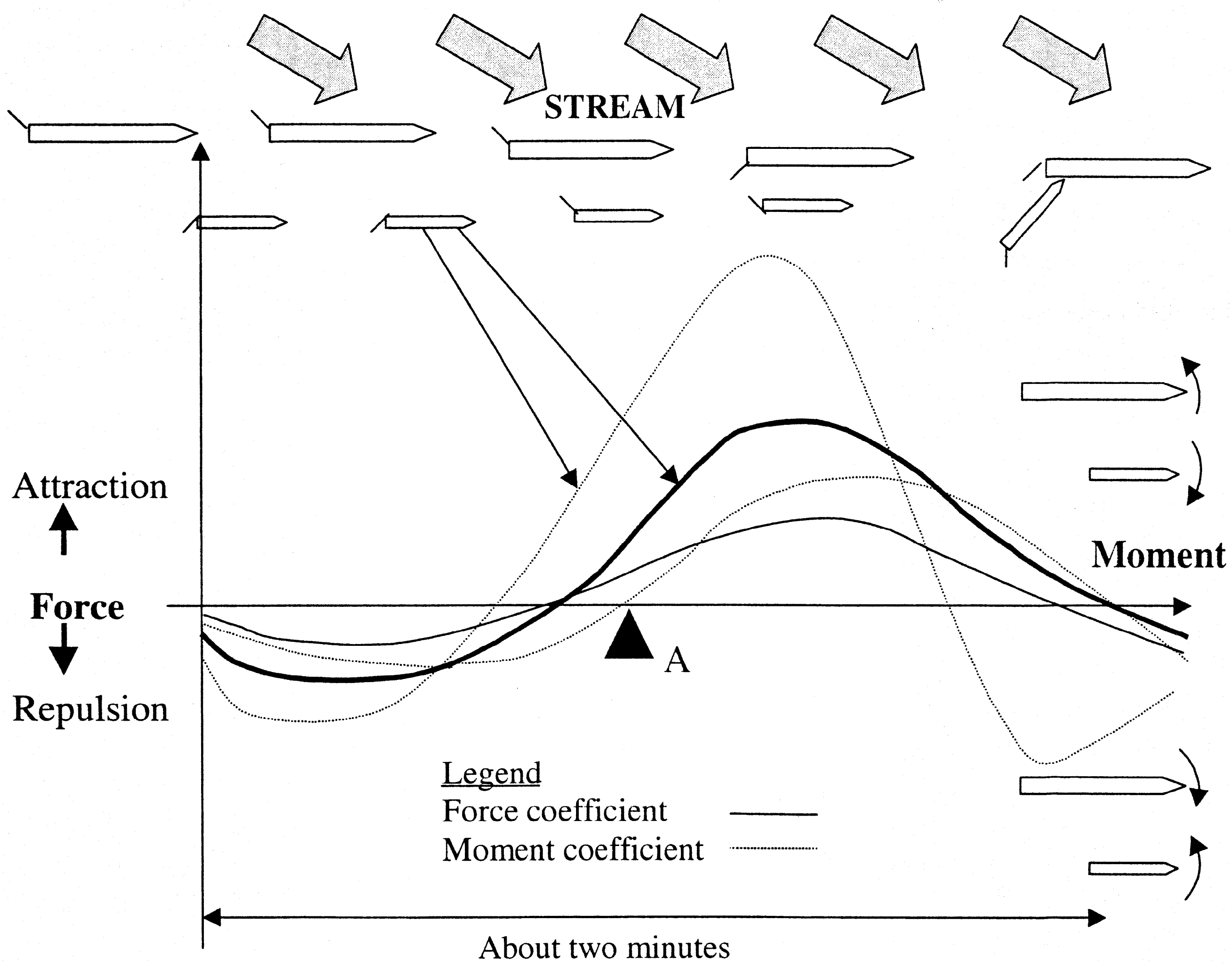
The relative speed was 3 knots when the ships were side by side and had same course. During the approaching stage the relative speed was 4,2 knots, see figure 2. The time from the start of the overtaking (Gardens bow at the stern of Vingaren) to the moment of collision (Vingaren's bow at 10 meters from the stern of Garden) took about two minutes. During that time Garden advanced about 900 m with a speed of 14,5 knots.

In the figure 1 are shown general tendencies of dimensionless coefficients of lateral force and turning moment for Garden and Vingaren. It may be noticed that in the course of one minute before the collision there was an attraction force between these vessels. If we guess that the distance in the early stage of attraction was 70 m (point A), we get the following approximate attractive forces: Garden 30 kN and Vingaren 15 kN. When the vessels were side by side the attraction force was at its maximum (distance between vessels about 60 m): Garden 100 kN and Vingaren 50 kN.

We can now evaluate the maximum sideways speed from the equation of resistance force $F = \frac{1}{2}\rho ACU^2$, where ρ is the density of water, A is the projected under-water area, C is a constant (about 1,2) and U is sideways speed. The result is 0,3 - 0,34 m/s. Further, the force increased due to decreasing distance between ships. In one minute a decrease in separation may well be 15 ... 30 m.

As seen from the figure, the **bow** of Vingaren tries to turn towards Garden. Just before that, Vingaren had a strong tendency of turning towards the boundary of the channel, which was supposedly compensated by steering. Moreover, the change from outward moment to inward was very quick. At the same time, Garden had a decreasing tendency of turning its **stern** towards Vingaren. At the same time there exists yet a decreasing attractive force between these vessels. So, all these effects were in favor of collision. Because of the mass differences and differences in turning moments, turning realized mainly for Vingaren.

The separation between ships was initially about 300 m, but they had courses which brought them closer to each other, see figure 2. The interaction started when the separation was about 100 m. During the overtaking just before collision the separation could have decreased due to the stream and attraction down to the reported 40 m. Then the turning tendencies of Vingaren and Garden effectively turned the bow of Vingaren very quickly towards the after part of Garden.



Coefficients have been nondimensionalized by dividing force with $(\rho/2)v^2L^2$ and moment with $(\rho/2)v^2L^3$.

Figure 1. General tendencies of forces and moments for overtaking ships

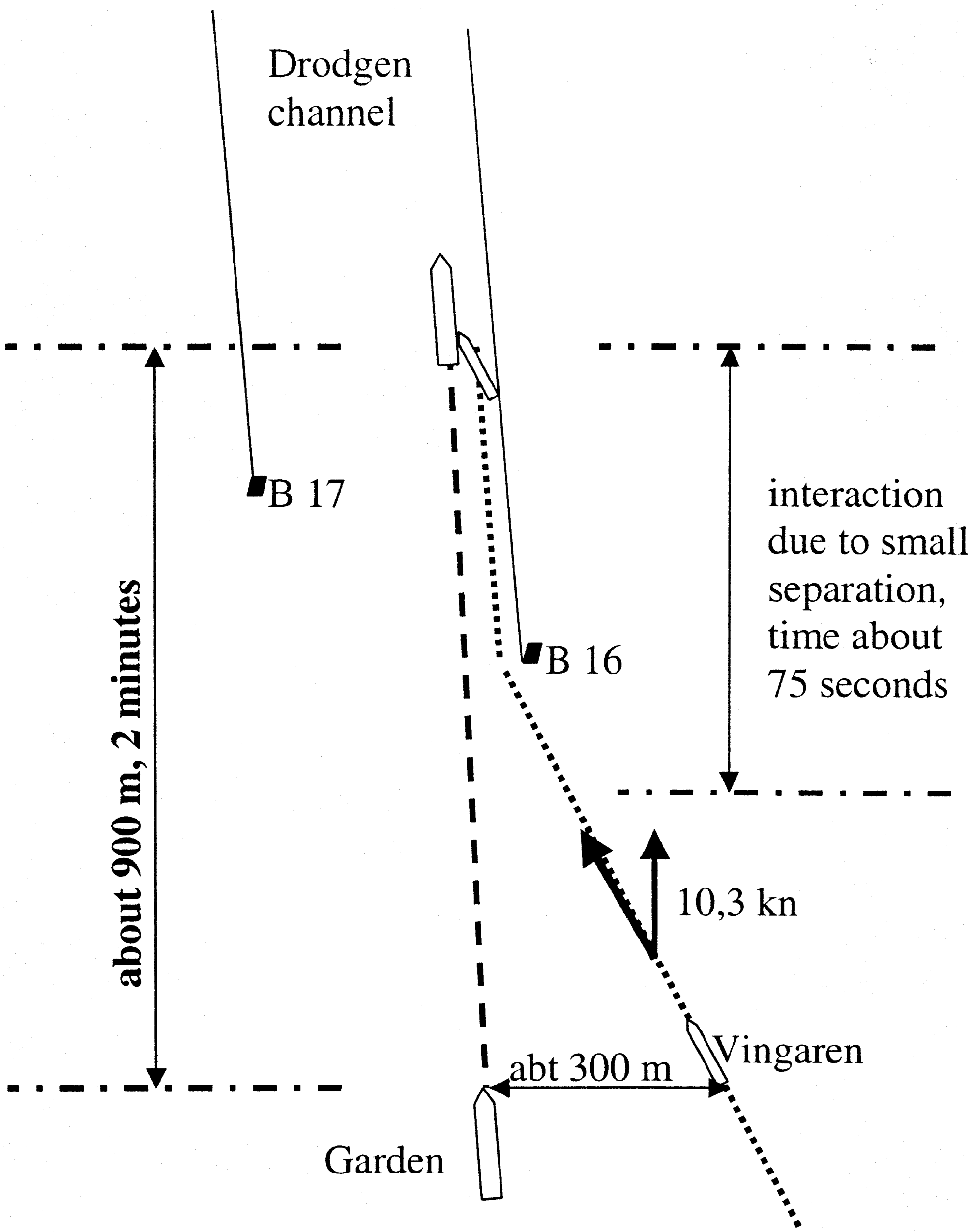


Figure 2. Approximate tracks of Garden and Vingaren based on reporting. The realized course of Garden has been corrected by taking into account the stream, and we get 357.

5. Recommendations

- The speed of vessels in Drogden channel should be restricted depending on the draft. The main reason is to avoid grounding. For a water depth of 8 m we get the following table in calm water for "normal" ships. A more accurate table requires deeper analysis. Moreover, every ship should have its own table. If the ship is moving in waves, maximum allowable draft should be decreased at least by the significant wave amplitude as a first approximation.

draft [m]	6,0	6,5	7,0	7,5
max. speed [kn]	16,5	13,5	10,5	7,5

- Relative (overtaking speed) should be about 5 knots in order to shorten the overtaking time.

- Separation of vessels should be held at more than 0,8 x the length of the bigger vessel, for example in our case about 120 m.

- The two vessels should plan the procedure of overtaking together.

- Vessels using restricted waterways should have instructions for navigating and meeting other ships including squat tables.