# Investigation report

C1/2006M

# MS ESTRADEN and MT WOLGASTERN, collision in the Kiel-Canal on 2.2.2006

Translation of the original Finnish report

## SUMMARY

The WOLGASTERN left the Holtenau lock of the Kiel-Canal at 23.32 on 1st February 2006. Due to the 9-meter draught of the vessel, her highest allowed speed was 12 km/h (6.5 knots). The vessel approached the siding area of Audorf-Rade slowing down to let three ships (TURCHESE, ANTJE and ESTRADEN) behind it pass her. The ESTRADEN left the Holtenau lock of the Kiel-Canal at 00.35 on 2nd February with a draught of 5.9 m. Three vessels were sailing one behind the other with the ESTRADEN as the last one. Their speed limit was 15 km/h (8.1 knots).

According to the joint plan worked out in the bridge of the WOLGASTERN, the purpose was, at the straight of Audorf-Rade also to encounter the two smaller vessels, the LENA and the RIROIL 5. The ESTRADEN started to pass the WOLGASTERN from her portside while meeting the LENA. The WOLGASTERN started to turn starboard, but the correction succeeded with manoeuvring measures. At that time, the speed of the ESTRADEN was about 8.9 knots and that of the WOLGASTERN about 4.6 knots.

When the ESTRADEN was about half her length ahead of the WOLGASTERN, they encountered the RIROIL 5. At that point, the speeds of the two vessels were about the same: the ESTRADEN 6.0 knots, the WOLGASTERN 6.5 knots and the RIROIL 5 6.5 knots. After the meeting, the manoeuvrability of the ESTRADEN weakened, and she started turning to port. The ESTRADEN increased the speed of the vessel. At the same time it was notified from the bridge of the WOLGASTERN that the WOLGASTERN was turning portside and it was suggested that the ESTRADEN further increases her speed. The WOLGASTERN also increased her speed to improve her manoeuvrability as it was noticed that the vessel was restless. At that moment preceding the accident there were three vessels side by side in a part of the canal with a width of 100–110 m (for that width depth of water was at least 10.5 m).

The bow of the WOLGASTERN hit the ESTRADEN midships at about 02.36, whereupon the stern of the WOLGASTERN turned portside and collided with the aft part of the ESTRADEN. At the time of the collision the speeds of the vessels were about 8 knots. Due to the strength of the impact, the ESTRADEN started to turn to starboard and her aft part approached the portside bank. The Master of the ESTRADEN immediately took charge of the steering. Portside engine was reversed while the starboard engine was in ahead-position to prevent the aft from drifting portside towards the bank of the canal. This measure dropped the speed of the ESTRADEN so that the WOLGASTERN started to slide along the starboard side of the ESTRADEN. The portside wing of the bridge of the WOLGASTERN hit the starboard deckhouse, mess and Master's cabin of the ESTRADEN. There were no people in these premises so personal damage was avoided. The WOLGASTERN slid past the ESTRADEN and drifted to the portside bank of the canal bow first.

The investigation commission considers the reason of the accident the lengthy stay of the colliding vessels too close to each other at too high a speed due to meeting two encountering vessels one after the other. During the overtaking, the WOLGASTERN had to sail close to the right-hand side of the canal, which made its manoeuvrability more difficult. When the manoeuvring of the vessels became more difficult, their speeds were increased, which increased further the interaction forces due to the closeness of the vessels.

The investigation commission addresses safety recommendations to the Wasser- Und Shifffahrtsdirection Nord to specify rules concerning overtaking situations in the canal. Safety recommendations are also addressed to the owners operating in the canals and to other bodies in connection with the canal navigation to estimate additional education needs of their personnel concerning the effects of restricted waters. In addition the committee recommends that maritime training institutes should complete their training concerning the effect of confined waters in ship navigation.

## THE ABBREVIATIONS USED

| | |
|---|---|
| AIS | Automatic Identification System |
| ARPA | Automatic Radar Plotting Aid |
| BSU | Bundesstelle für Seeunfalluntersuchung |
| DGPS | Differential Global Positioning System |
| Dwt | Dead weight tonnage |
| GL | Germanischer Lloyd |
| GPS | Global Positioning System |
| GT | Gross tonnage |
| ECDIS | Electronic Chart Display and Information System |
| IMDG | International Maritime Dangerous Goods (Code) |
| IMO | International Maritime Organization |
| ISM | International Safety Management (Code) |
| kn | Knot |
| kVA | kiloVoltAmperes |
| kW | Kilowatt |
| LR | Lloyds Register |
| OOW | Officer on Watch |
| RPM | Revolutions per minute |
| SMG | Speed Made Good |
| SOG | Speed Over Ground |
| VHF | Very High Frequency |
| VTS | Vessel Traffic Service |
| UTC | Universal Time Coordinated |

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## FOREWORD

The Accident Investigation Board was notified of the collision of the ESTRADEN and the WOLGASTERN on 2nd February 2006. The Accident Investigation Board was in touch with the German maritime authority and received immediate information about the accident.

On 10th February 2006 the Accident Investigation Board appointed an Investigation Commission to investigate the accident. Per their consent, experts of the Accident Investigation Board were appointed as investigators, Captain Juha **Sjölund** as Investigator in Charge and Captain Heikki **Koivisto** as member. Naval Architect Olavi **Huuska** was appointed as an expert. The Finnish investigation authorities have acted as the party in charge of the investigation in accordance with Resolution A.849(20) of the International Maritime Organisation (IMO).

The investigators heard the Master and mate of the ESTRADEN on 23rd February 2006 onboard the ESTRADEN. The investigators did not have a chance to hear the Master and mate of the WOLGASTERN but investigators had the possibility to study their confidential written statements on the events. The Master of the ESTRADEN submitted a recording of the electronic chart of the ESTRADEN to the investigators for the investigation purposes. From the authorities of the Kiel-Canal the investigators obtained the depth information of the site. The investigators had access to the confidential investigation material of German accident investigators (BSU).

An investigator was following the maritime declaration of the ESTRADEN given in Turku on 17th February 2006. The investigators had the possiblity to study the confidential document of maritime declaration record with appendices.

**Statements on the Investigation Report.** The final draft of the Investigation Report was sent for a statement under section 24 of the Decree on Accident Investigation (79/1996): to Waterways and Shipping Directorate North, Kiel, pilot association NOK II/Kiel, shipping companies, Navigation colleges, for comments to the Masters and pilots of the ships, for information to the Finnish Maritime administration and Isle of Man Maritime administration. Statement was received from the owner of the WOLGASTERN and it’s attached in the end of the investigation report.

The investigation report 315/03 by the German Federal Bureau of Maritime Casualty Investigation “Collision between MV GERMA and MV ESTECLIPPER in the Kiel Canal siding area Schwartenbek on 13th October 2003 at 05:33 h CEST” has been helpful during the preparation of this report.

The accident report uses the local time UTC + 1.

# 1 EVENTS AND INVESTIGATIONS

## 1.1 The MS ESTRADEN


*Figure 1. MS ESTRADEN.* *(© Source: Company brochure)*

### 1.1.1 General information

| | |
|---|---|
| Name of the vessel | M/S ESTRADEN |
| Type | Ro-ro cargo vessel |
| Nationality | Finnish |
| Owner | Rederi Ab Engship |
| Home port | Nagu |
| Call sign | OJIL |
| IMO No. | 9181077 |
| Year and place of construction | 1999 Rauma |
| Classification society | Lloyds Register of Shipping |
| Class | LR +100 A1, Roll On-Roll Off Cargo ship L1 |
| Gross tonnage | 18205 |
| Net weight | 5462 |
| DWT | 9,700 t |
| Length, max | 162.7 m |
| Length, B.P.P. | 149.4 m |
| Width | 25.2 m |
| Draught | 6.60 m |
| Engine power | 2 x 7240 kW |
| Bow propellers | 2 x 1100 kW |
| Speed | 19 knots |
| Traffic group[1] | 5 |

[1] For certain navigation restrictions in Kiel Canal ships are divided in traffic groups 1–6 based on their main dimensions.

### 1.1.2 The manning of the MS ESTRADEN

The ESTRADEN had a Finnish crew of 14. The Master had gone to sea in 1971, acted as master since 1989 and as master of the MS ESTRADEN since her construction in 1999. He had passed the Kiel-Canal hundreds of times. The first mate on watch had graduated from the Seamen's School in 1991 and as mate in 1997. Thereafter he had served as mate in the Engship shipping company. He had served on the ESTRADEN in 1999–2003 and from 2004 onwards. The Kiel-Canal had become familiar to him in the traffic of the North Sea and the Baltic. The vessel had three mates, who run a 4–8 watch with a work period of 4 hours and a free period of 8 hours.

Before the accident, the OOW, a German pilot and a German helmsman were on the bridge.

### 1.1.3 The bridge and its equipment

| | |
|---|---|
| Radars; | 1 DECCA ARPA 10cm (bridge master E) |
| | 1 DECCA ARPA 3cm (bridge master II) |
| | 1 FURUNO FR-1932 |
| | 1 EMRI SEM-200 |
| Steering equipment; | 1 ULSTEIN TENFJORD STEERING PANEL |
| | 1 AUTOPILOT ELECTRIC UNIT |
| | 1 change-over switch GPS/GYRO 2 AUTOPILOT |
| | 1 change-over switch GYRO 1/GYRO 2 AUTOPILOT |
| | 1 ULSTEIN OVERRIDE CONTROL |
| | 4 ULSTEIN TENFJORD RUDDER ANGLE INDICATORS |
| | 2 PANORAMA RUDDER ANGLE INDICATORS |
| | 1 EMRI ROT INDICATOR |
| Depth finder, the log; | 1 SKIPPER GDS101 |
| | 1 CONSILIUM SAL IMCOR2 |
| | 2 CETREK Multifunction DEPTH displays |
| | 1 DEIF MALLING WINDDISPLAY INSTRUMENT |
| | 1 DEIF MALLING WINDSENSOR |
| Compasses; | 2 TOKIMEC TG6000 gyrocompasses |
| | 2 gyro compass control units |
| | 1 gyrorepeater (analog) |
| | 2 gyrorepeaters |
| | 5 gyrorepeaters (digital) |
| | 1 BROENDBERG§TANDRUP A/S magnetic compass |
| | 1 repeater (analog) |
| | 1 repeater (digital) |

### 1.1.4 Machinery

Main engines; 2 x Wärtsilä Vasa 8L46A-14480 kW/ 500 rpm

Speed 19 knot in design depth 2 x 6516 kW (shaft generator 400 kW)

Reduction gear; 2 x Valmet MIHBC-950+5600 RATIO 3.32:1

Propellers; 2 KaMeWa 121 XF5/4 4300 mm-156 rpm

Auxiliary engines; 2 x Caterpillar 3508B 1712 kW/ 1500 rpm

Shaft generator; 2 x Leroy Somer LSA 52 S5/4p 1500 kVA

Bow thruster 1100 kW

### 1.1.5 Cargo of the ESTRADEN

The cargo of the vessel consisted of containers, mafi-wagons and trailers, totally 4833 tons of which 45 tons were IMDG cargo. She carried 257 tons of heavy fuel oil and 52.1 tons of diesel oil. Her draught at bow was 5.9 m and at stern, 5.8 m.

## 1.2 The MT WOLGASTERN

*Figure 2. MT WOLGASTERN.* *(©Seafoto Hannu Laakso.)*

### 1.2.1 General information

| | |
|---|---|
| Name of the vessel | M/T WOLGASTERN |
| Type | Chemical-product container ship |
| Nationality | The Isle of Man |
| Owner | Wolgastern |
| Operator | RIGEL SHIFFAHRTS GMBH&Co.KG |
| Home port | Douglas |
| Call sign | MZBO7 |
| IMO No. | 9183817 |
| Year and place of construction | 1999 Poland |
| Classification society | Germanischer Lloyd |
| Class | GL + 100 A5 E3 Chemical Tanker Type 2/Oil Tanker, ESP *MC AUT E3 INTER |
| Gross tonnage | 14400 |

| | |
|---|---|
| Net weight | 6937 |
| DWT | 20,660 t |
| Length, max | 162.16 m |
| Length, B.P.P. | 155.0 m |
| Width | 27.0 m |
| Draught | 9.00 m |
| Engine power | 7860 kW |
| Bow thruster | 590 kW |
| Speed | 15.0 kn |
| Traffic group | 5 |

### 1.2.2 The crew of the MT WOLGASTERN

The Master of the vessel had set out to sea in 1981 and sailed on several different vessels. Since November 2005, he had worked as master of the WOLGASTERN. The mate on watch had set out to sea in 1975 and served mainly onboard tankers. In 1977 he had received qualifications as 3rd mate and in 1982 qualifications as 2nd mate still serving mainly onboard tankers. Since 2003 he had been employed by the Rigel shipping company and since November 2005 onboard the WOLGASTGERN. He had passed the Kiel-Canal about 20–30 times. The vessel had a crew of 18.

The Master, the OOW, a German pilot and a German helmsman were on the bridge.

### 1.2.3 The bridge and its equipment

Atlas Elektronik NACOS 34-3

1 Leica Geosystem Satellite MX 400B DGPS

1 Atlas Elektronik 9600 ARPA x-band

1 Atlas Elektronik 9600 ARPA x-band

### 1.2.4 Machinery

Main engine 1 H. Cegielski/ MAN B&W, type 6S46MC-C

MCR 7860 kW, rpm 129

1 variable-pitch propeller

1 shaft generator 900 kVA

3 diesel H.Cegielski/MAN B&W 7L16/24, 830 kVA

1 bow thruster 590 kW

### 1.2.5 Cargo of the WOLGASTERN

The vessel was carrying 20545 tons of gas oil and her draught at bow was 8.99 m and at stern 9.00 m.

### 1.2.6 Other vessels

Some other vessels affected in various ways the navigation of the WOLGASTERN and the ESTRADEN. First, the TURCHESE and the ANTJE passed the WOLGASTERN. Soon after the ANTJE the LENA encountered the ESTRADEN and the WOLGASTERN and a little bit later the RIROIL 5 encountered them. Two vessels, the TAVASTLAND and the CROWN BREEZE, were approaching the Audorf-Rade siding area from west. Main data of these vessels are shown in table 1. More details of the most significant vessels having some influence on the accident are shown in table 1 in appendix.

*Table 1. Main data of the vessels, (TG means traffic group, length is $L_{OA}$).*

| Name of the vessel | GT | Length, m | Breadth, m | Draught, m | TG |
|---|---|---|---|---|---|
| LENA | 8388 | 151.6 | 20.6 | 6.3 | 4 |
| RIROIL 5 | 4606 | 129.3 | 16.5 | 5.02 | 3 |
| TURCHESE | | 136 | 20 | 6.2 | 5 |
| ANTJE | | 117.9 | 18.15 | 4.5 | 3 |
| TAVASTLAND | | 137.5 | 21.3 | 9.36 | 5 |
| CROWN BREEZE | | 87.8 | 12.5 | 5.42 | 3 |

## 1.3 The accident event

The description of the accident event is based on hearing the Master and mate of the ESTRADEN as well as on the records of the electronic maritime chart of the ESTRADEN and the maritime declaration record. The Master and the mate of the WOLGASTERN gave written statements on the events, but the pilot of the vessel refused to comment the events. The printouts of the engine telegram of the ESTRADEN and the WOLGASTERN were not available to the investigation.[2] The investigators had access to the investigation material of the German accident investigators material which consisted of pilots and wheelmen statements and interviews of various vessels, VHF – protocol of VTS (Channel 3) in written form and the GPS information of the WOLGASTERN in printout version.

Moreover, a short description concerning the general traffic situation was received from the Wasser- und Schifffahrtsamt Kiel-Holtenau. [3]

### 1.3.1 The accident voyage

The WOLGASTERN was on her way from Vysotsk to Dunkirk. The vessel left the Holtenau lock of the Kiel-Canal at 23.32 on 1st February 2006. Due to the 9-meter draught of the vessel, her highest allowed speed was 12 km/h (6.5 knots). During the voyage, those primarily on the bridge were a German pilot and a German helmsman as well as the OOW. During the voyage, the Master was at times away from the bridge. The vessel

2 The memory of the engine telegram of the ESTRADEN was so small that it had been set to record only alarms and the printer was not in use.

3 Wasser. und Schifffahrtssamt Kiel-Holtenau 4-331.5 SU 02/06, 23rd August 2007.

approached the siding area of Audorf-Rade slowing down to let the three vessels behind her overtake her. The Master of the WOLGASTERN had come to the bridge 8–10 minutes before the collision.

The ESTRADEN was on her way from Turku to Bremerhaven. The vessel stayed at the Holtenau lock of the Kiel-Canal from 00.20 to 00.35, after which she started sailing down the Canal towards Brunsbüttel with a draught of 5.9 m. It was told to the Master, that there were no stop signals coming and after this the Master went to his cabin to rest. The OOW, a German pilot and a German helmsman remained on the bridge. Three vessels were sailing one behind the other with the ESTRADEN as the last one. The first vessel was the TURCHESE and the second was the ANTJE. The vessels approached the siding area of Audorf-Rade intending to overtake the slower WOLGASTERN. According to the record of the electronic chart of the ESTRADEN, the vessel had to, before the overtaking, raise her speed, which momentarily reached a maximum of 22.8 km/h (12.3 knots) to reach the WOLGASTERN.

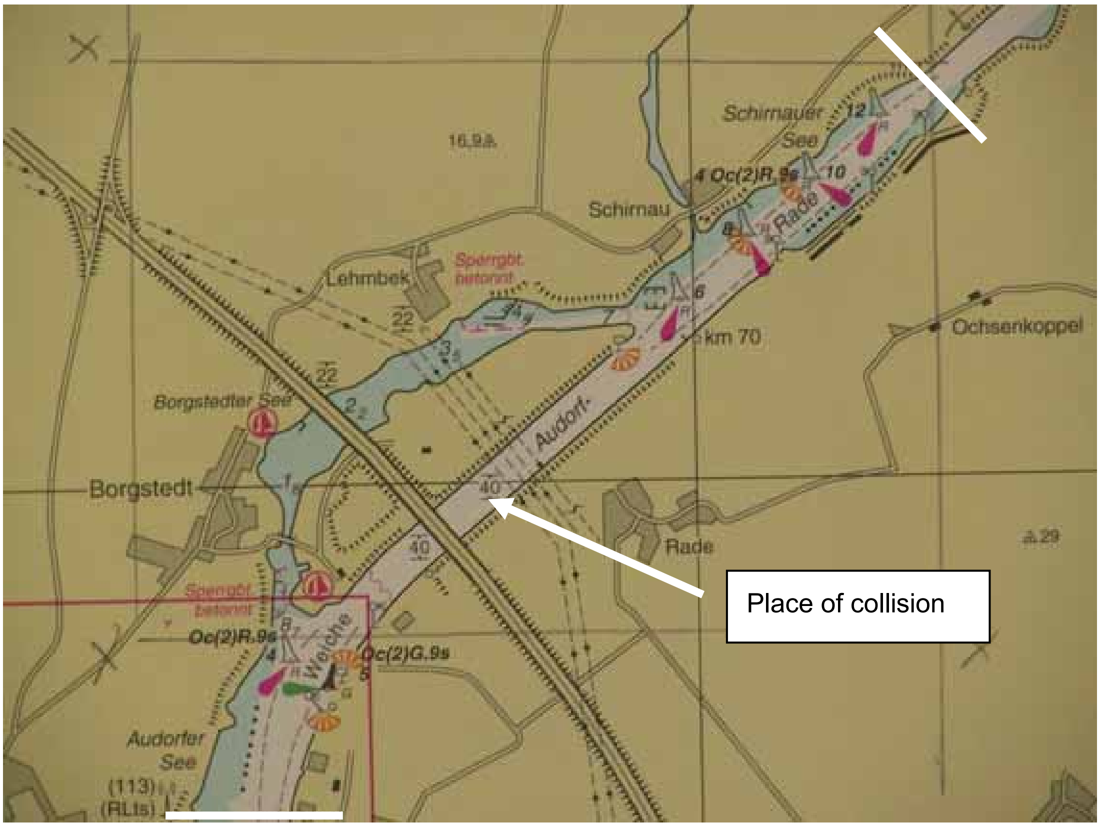


*Figure 3* *A map of the accident area. The limits of the siding area are shown with a white line (length 5.7km, endpoints at km 66,093 and 71,749). (© Bundesamt für Seeschifffahrt und Hydrographie, Hamburg-Rostock).*

Communication in the Kiel-Canal between traffic control and other vessels took place only in German. The officer on watch of the ESTRADEN did not know German, so he could not exactly follow the discussion between the pilots and the traffic control. The map of the accident area is presented in Figure 3.

### 1.3.2 The event

**General traffic situation.** All westbound vessels were shown an extended stop signal in Audorf-Rade at 1.25 ("one red interrupted light", which means, that the exit of the siding area in Audorf-Rade was prohibited for vessels of traffic group 3 and above, because there were ships coming from the west). This traffic situation and the future intentions of VTS NOK II were announced on VHF to all vessels in Kiel Canal at 01.50. The continuation of the voyage was anticipated for 03.10, as one had to wait for the TAVASTLAND and the CROWN BREEZE to enter this siding area. This stop signal was due to the regulations SeeSchStrO[4], which states that, the maximum sum of the traffic group numbers between the sidings of Audorf-Rade and Schülp[5] of any two vessels in a head-on situation is six[6].

**The accident.** It was known on the bridge of WOLGSTERN that a stop signal was to be expected at Audorf-Rade siding area. WOLGASTERN was still at the east end of the siding area, when the convoy closed up on her. TURCHESE asked WOLGASTERN on VHF 73 for permission to overtake. WOLGASTERN confirmed and requested ANTJE and ESTRADEN to pass as well. According to the owner of WOLGASTERN it was a Master's consent to an overtaking and not a request. When reaching the siding area of Audorf-Rade, the purpose was also to meet the two smaller vessels, the LENA and the RIROIL 5. The vessels were in contact with each other during these operations through VHF. At 02.28 the ANTJE was overtaking the WOLGASTERN and the ESTRADEN was already approaching, Figure 4. The WOLGASTERN had to steer near the right bank of the canal.

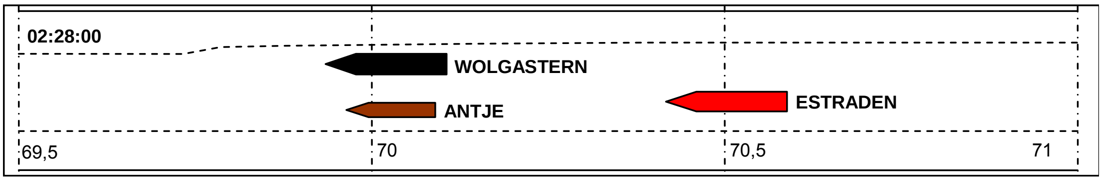


*Figure 4. The ANTJE is overtaking the WOLGASTERN.*

The remark of the LENA about her size on VHF channel 73 that even the LENA was not a very small vessel was not replied to. The LENA slowed down heavily and steered as far starboard as possible switching on the bow thrusters for safety reasons. The ANTJE turned starboard, and came in front of the WOLGASTERN, Figure 5.

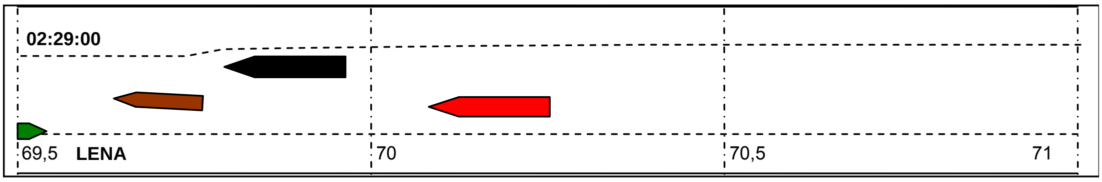


*Figure 5. The ANTJE has overtaken the WOLGASTERN and the LENA is nearing.*

4 Seeschifffahrtstrassenordnung, German Traffic Regulations for Navigable Maritime Waterways, Wassser- und Schifffahrtsverwaltung des Bundes.

5 Schülp is the next siding area westwards, at kilometers about 57-58.

6 SeeSchStrO, § 24, 11. To prevent any head-on situations which are not allowed, the traffic control centre (VTS NOK II) set signals at the end of the sidings. These signals show the ships for which category numbers the exit of a siding area is prohibited or allowed.

It was known on the bridge of the ANTJE that there was a stop signal for them at Audorf-Rade. The TURCHESE had already earlier overtaken the WOLGASTERN. There was a stop signal for TURCHESE and therefore she slowed down the ship's speed under the big bridge at Rade. The positions of some vessels in the fairway at 02.30 are shown in Figures 6 and 7. One can also see that the starboard of the WOLGASTERN is in water that is 1.5–2 m shallower that at her portside. At the same time, the WOLGASTERN was coming to the point in the Canal where the navigable water area for her became narrower.

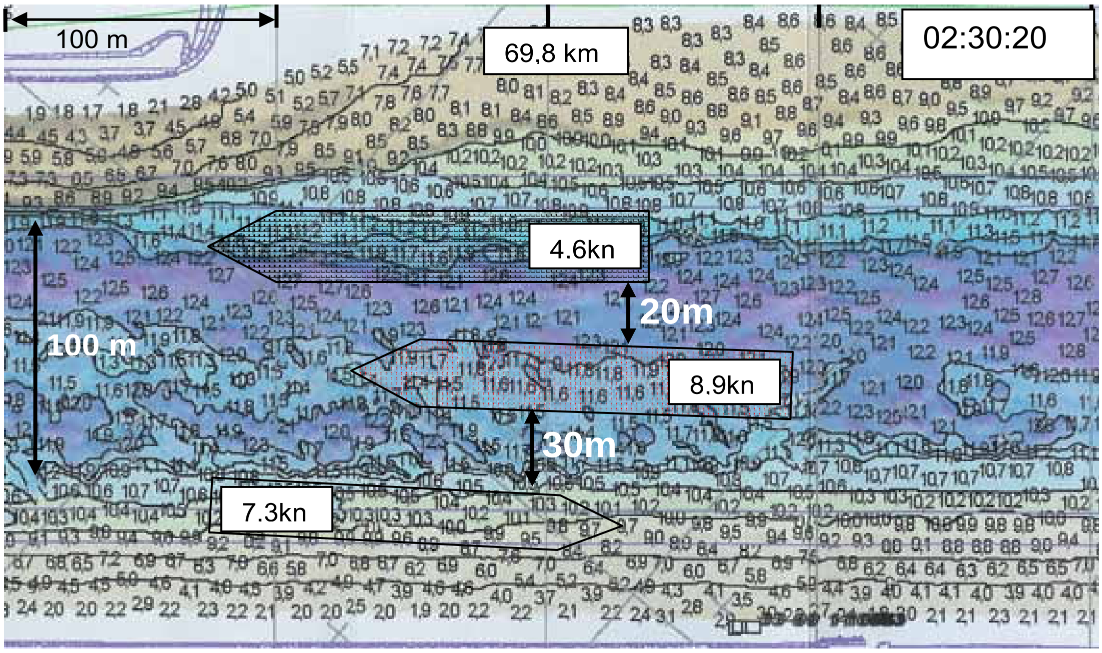


*Figure 6. The LENA is encountering the ESTRADEN and the WOLGASTERN. The vessels were positioned by the investigators so that their sides were as far as possible from each other (exact positions were not known). The widths of the vessels are: the WOLGASTERN 27m, the ESTRADEN 27.7m and the LENA 20.6m.*

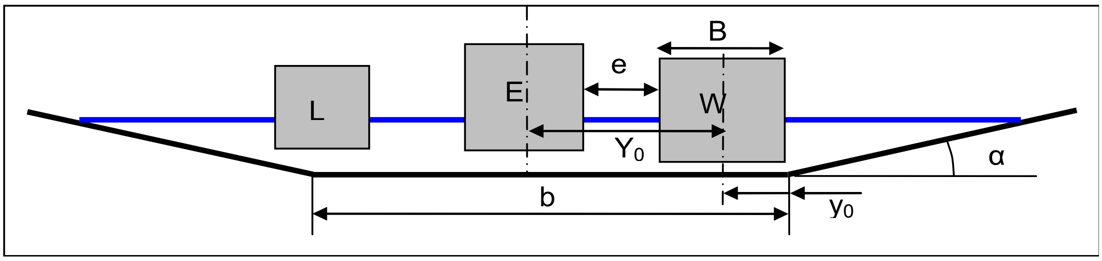


*Figure 7. The view of the investigators on the positioning of the vessels in the fairway at 02.30.00: W (WOLGASTERN), E (ESTRADEN) and L (LENA). The figure also shows certain related parameters. The distance between the sides of the vessels is e, the distance between the centerlines is $Y_0$, the distance $y_0$ from the bank bottom of the Canal has been determined as shown in the figure. The parameters are found in the calculations of Appendix 1. The width b of the bottom of the Canal varies between 100 and 150 m depending on the longitudinal position. The slope angle α of the banks is about 13 degrees. The depth of the fairway varies between 10.5–13 m.*

For a moment the speed of the ESTRADEN was about 14 km/h (7.6 knots) and that of the WOLGASTERN about 7.4 km/h (4.6 knots). At that instant the vessels were at point 70 km in the Canal. The ESTRADEN started to overtake the WOLGASTERN while encountering the LENA coming from the opposite direction. The WOLGASTERN started to turn starboard, which was successfully compensated with the helm command over to port while using the engine to support the turn. As the ESTRADEN continued to overtake the WOLGASTERN, the vessels simultaneously encountered the RIROIL 5, which stayed on the portside of the ESTRADEN, Figures 8 and 9.

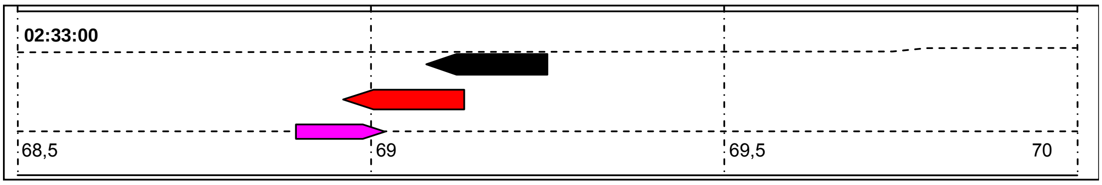


*Figure 8. The RIROIL 5 is encountering the ESTRADEN and the WOLGASTERN.*

At the moment preceding the accident there were three vessels side by side in a part of the Canal with a nominal width of 100 m, Figure 9. Onboard the RIROIL 5 it was noticed that at the time of the overtaking, the bow of the RIROIL 5 was alongside the sterns of the ESTRADEN and the WOLGASTERN and the overtaking distance between these vessels was smaller than the distance between the ESTRADEN and the RIROIL 5.

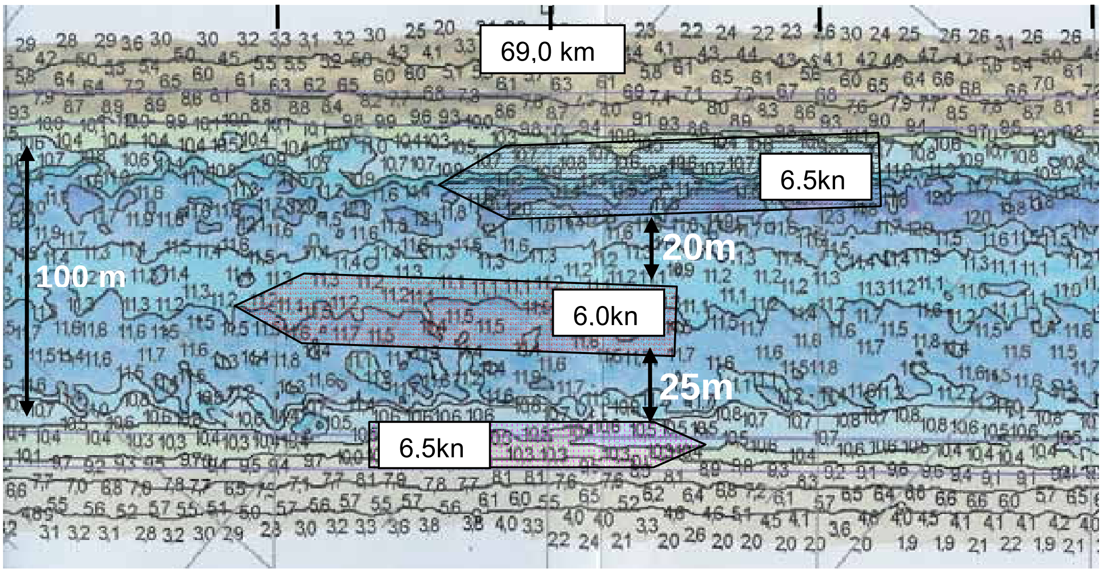


*Figure 9. Investigators' view on the positions of the vessels in the Canal at 02.33.20.*

At 02.35 the ESTRADEN was still only about halfway past the bow of the WOLGASTERN, Figure 10. It was noticed on the bridge of the ESTRADEN that the manoeuvring capability of the vessel weakened. Simultaneously, the ESTRADEN tended to turn portside. The ESTRADEN increased her speed so that, according to the recording of the electronic chart, it was 8.1 knots (Figures 19 and 20). At the same time the WOLGASTERN notified on channel 73 that she was turning portside and suggested that the ESTRADEN further increase her speed. The WOLGASTERN also increased her speed to 8 knots (Figures 19 and 20) to improve her manoeuvrability as it was noticed that the vessel was restless.

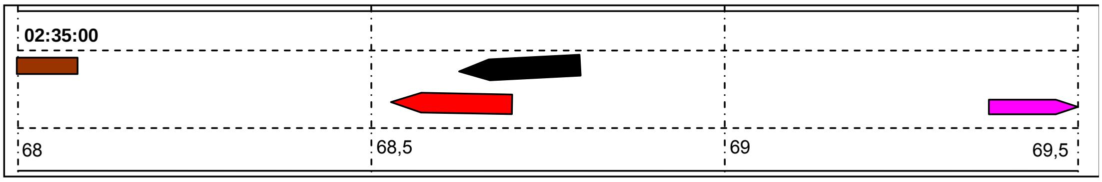


*Figure 10. The positions of the vessels a moment before the collision. On the right, the RIROIL 5, on the left, still the ANTJE.*

The OOW of the ESTRADEN alerted the Master to the bridge, because he considered that the changing situation required it. In spite of the manoeuvring measures, the WOLGASTERN kept turning further portside. As the Master of the ESTRADEN hurried to the bridge, he felt the first collision as the bow of the WOLGASTERN hit the ESTRADEN amidships at about 02.36, Figure 11.

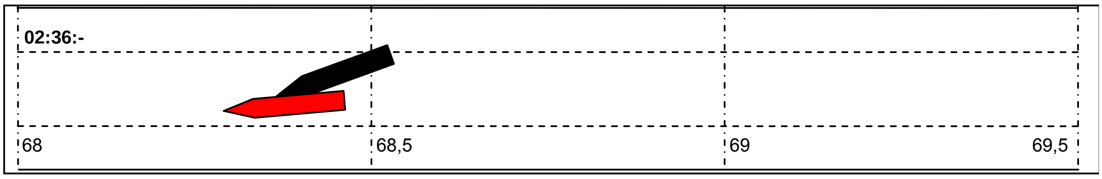


*Figure 11. The vessels at the first stage of the collision.*

After that the stern of the WOLGASTERN turned portside and the ship hit the aft part of the ESTRADEN. Due to the strength of the impact, the ESTRADEN started to turn to starboard and her aft part approached the portside bank. The Master of the ESTRADEN immediately took control of the steering. The Master took the steering to the portside wing and set the engines to go crosswise so that the portside engine was astern at 60–70 % and the starboard engine was ahead at 40 % while the right rudder was to portside. By this measure it was avoided the stern from drifting to the bank. This measure dropped the speed of the ESTRADEN so that the WOLGASTERN started to slide along the starboard side of the ESTRADEN, Figure 12a.

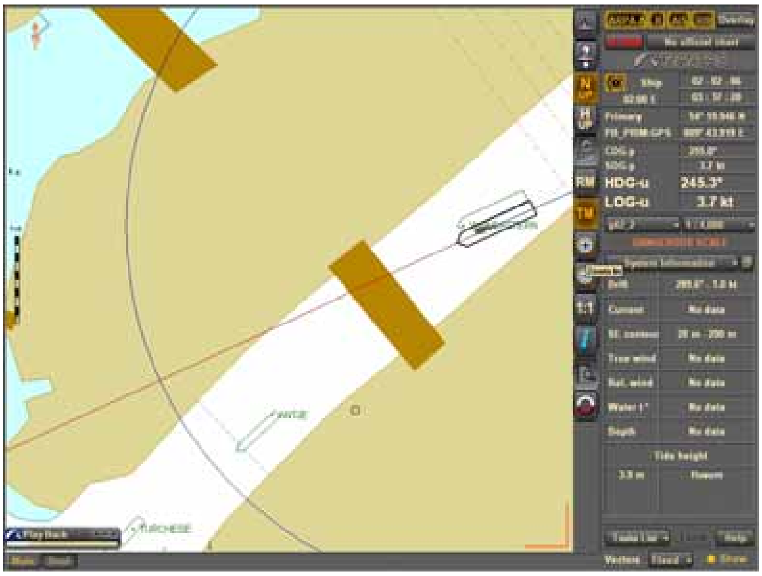


*Figure 12a. The WOLGASTERN is sliding along the side of the ESTRADEN on the electronic chart display. (Time on the chart is Finnish time).*

The portside wing of the bridge of the WOLGASTERN hit the starboard deckhouse, mess and master's cabin of the ESTRADEN, Figure 12b. There were no people in either of these premises so personal damage was avoided.

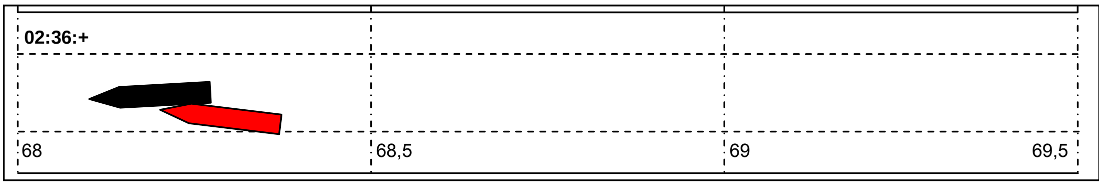


*Figure 12b. The deckhouse of the WOLGASTERN is hitting the wing of the ESTRADEN.*

The WOLGASTERN was then sliding past the ESTRADEN and drifted to the portside bank of the Canal, bow first.

### 1.3.3 The scene of the accident

At the site of the accident (Audorf-Rade siding area) the width of the Canal bottom having the depth at least 10.5 m varies between 100–110 m outside the Schirnauer See (Figure 3) and inside it between 110–150 m. The widest area is between kilometres 70 and 71. At the nominal depth of 11 m the width is 10–40 m narrower than at depth of 10.5m[7]. The water depth varied both lengthwise and sidewise between 10.5 and 13.5 m, Figures 6 and 9. Figure 7 shows a cross-section of the point where there were three vessels side by side as the LENA was encountered. The map of the area is presented in Figure 3. The ESTRADEN and WOLGASTERN collided just before the end of the straight part of the Audorf-Rade siding area, near the bridge.

The Kiel-Canal (Nord-Ostsee-Kanal) is 98.6 km in length; it goes through the Jylland Peninsula and connects the Baltic Sea to the North Sea. It is one of the busiest water routes in the world. In 2006, the most important traffic figures were: number of vessels 41,472, amount of cargo 95.8 Mt and registered tonnage 149.9 million[8]. In 24 hours, the number of vessels is thus, on the average, about 114, i.e., 4–5 vessels every hour. The number of Canal pilots (in 2006) is 135[9]

In 2005, 65 accidents were reported and 96 in 2006; of these, vessel collisions amounted to 23 and touches of the embankment without damage, 34[8]. For a more comprehensive statistics, see appendix 2[10].

### 1.3.4 Weather conditions

At the time of the accident wind speed varied between 3–4 m/s. It was dark and the lights of the vessels and the Canal were ordinary. The weather caused no impediments to sight. According to the view of the investigators weather conditions had no effect on the accident.

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7 Wasser-und Schifffahrtsdirektion Nord, Nordostseekanal, Verkehrssicherungspeilung, KM 68,94 bis KM 73,10, Stralsund, den 28th July 2005.
8 Jahreskurzbericht 2006 der Wasser- und Schifffahrtsämter Brunsbüttel und Kiel-Holtenau
9 Lotsenbrüderschaft Nord-Ostsee-Kanal I, home page
10 Email 30th May 2007 from Wasser- und Schifffahrsamt Kiel-Holtenau

## 1.3.5 Damage to the vessels

### The ESTRADEN

The vessel received numerous dents as well as 4 minor cracks in the upper starboard bulkhead of the main deck. Starboard from the living quarters, the wall of the mess and the master's cabin was ripped open and the interior was damaged. The starboard wing of the bridge was partly bent and its lid was bent open.


*Figure 13. Damages of the ESTRADEN's SB-side. (the picture on behalf of BSU)*

*Figures 14 and 15. The outer bulkhead of the master's cabin and the mess (Figure 14, left). The mess from the inside (Figure 15, right). (the pictures on behalf of BSU)*

**WOLGASTERN**

The portside bulkhead of the forecastle of the vessel was bent and the portside planking got several dents. The portside wing of the bridge and the steering console there were badly damaged.

*Figures 16 and 17. The portside wing of the vessel (Figure 16, left). The portside steering equipment console (Figure 17, right). (the pictures on behalf of BSU)*

*Figure 18. Damages on the side of the WOLGASTERN. (the picture on behalf of BSU)*

### 1.3.6 Registration equipment

Both vessels had electronic chart systems, which record information of the position, direction and speed of the vessel. The investigators received from the ESTRADEN a recording relating to the time before and after the accident for investigation purposes. The investigators had the possibility to study the paper printout of the recording of the WOLGASTERNs electronic chart.

### 1.3.7 The operation of the supervision and VTS systems

The VTS does not record traffic-related information but the radio traffic record was available to the investigators. The Kiel-Canal VTS supervises the traffic by means of radar but this is not recorded.[11]

### 1.3.8 Measures after the event

The ESTRADEN and the WOLGASTERN continued their voyage towards Brunnsbüttel. The ESTRADEN was fastened in the dolphins at 09.40 for inspections by the authorities and the classification society. The ESTRADEN shifted to Elbehaven in the morning of 3rd February, where the temporary repairs required by the classification society were done. The repairs were completed in the evening of 3rd February and the vessel was able to continue her voyage.

## 1.4 Rescue operations

On the basis of the investigations made by the crews of the vessels, no rescue operations were necessary.

### 1.4.1 Alerting activities

The ESTRADEN immediately gave on Kiel-Canal VHF-channel 3 a notification of the accident and VTS further informed other traffic that there was no transit trough the Canal at the time.

The crew of the WOLGASTERN reported a small fire and asked, because of her position, to call the fire brigade so the fire brigade was alerted. It turned out that the “fire” came from the smoke signal device, which was activated in the bridge wing due to the collision. Onboard the ESTRADEN, the investigation of the damage took place accordingly and the situation was quickly under control. The vessels were in contact with each other and the traffic control by the VHF. When the situation was under control, they continued with their voyage at 03.50.

[11] VTS centers commonly utilize the benefit of AIS system such as ships name, speed, course, position, rate of turn.

## 1.5 Investigations conducted

### 1.5.1 Investigations onboard the vessel and at the scene

The investigators visited the ESTRADEN at the Naantali docks twice to familiarise themselves with the damage and to hear the crew of the vessel. The investigators did not receive permission of the shipping company to familiarise themselves with the WOLGASTERN and to hear her crew.

### 1.5.2 Effects of a restricted water area

The collision of the ESTRADEN and the WOLGASTERN took place in the Kiel-Canal on 2nd February 2006. This is a water area where restrictions in the width and depth significantly affect the movements of the vessel. The restrictions set by the fairway have to be taken into account even when navigating one vessel. The task becomes more demanding when there are two or more vessels close to each other in the fairway. In situations of overtaking and encountering, changes in the flow state of the water caused by the vessels affect the movements of the vessels. Continuous traffic in both directions causes waves and changing currents, which make manoeuvring more difficult.

IMO has requirements on the steering of vessels in deep-water trial conditions[12]. No corresponding requirements or instructions exist for restricted water areas even though navigation there is more demanding and accident risks are higher. Meeting the IMO criteria do not guarantee good manoeuvrability in restricted water areas; instead, special manoeuvring requirements should be developed for these areas[13]. There are fairway-specific instructions and practices. What is important is the experience gained by ships' Masters, mates and pilots. So far there is no standard calculation method to determine the movements of vessels in canals. The situation involves too many variables. Advanced hydrodynamic software (CFD, computational fluid dynamics) has already been used to calculate certain cases. Many theoretical studies and model experiments but only a few full-scale measurements have been conducted. Especially fairway-specifically numerous model experiment results are available. Appendix 1 discusses in more detail the effects of a restricted water area on the movements of vessels and presents the related parameters and the literature used in the investigation as well as the results best suited for this case. They give a qualitative overall picture of the cause of events and, for parts, also numerical values.

**A restricted water area** affects the movements of vessels as follows. 1) The draught increases, which is referred to as squat. It consists of vertical sinkage and a change in trim. 2) The manoeuvring characteristics change. The turning of the vessel takes more room, the directional stability changes for the better or the worse. 3) The resistance of the vessel increases. 4) The propeller slip stream changes. 5) Near the canal walls, a bank effect appears. 6) When several vessels are side by side in the canal, the above phenomena are more pronounced. 7) Wave generation changes in shallow water. Waves reflected from the canal walls may interfere with manoeuvrability.

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12 IMO Resolution MSC.137 (76), Standards for Ship Manoeuvrability, adopted on 4th December 2002.

13 Dand, I.W. Low Speed Manoeuvring Criteria: Some Considerations, International Conference on Marine Simulation and Ship Manoeuvrability, MARSIM '03, 25th-28th August 2003, Kanazawa, Japan.

When **two vessels** move close to each other, their flow fields meet and affect each other. The effect manifests itself as forces trying to move the vessels or as a moment trying to turn them. Depending on the mutual positions of the vessels and their relative speeds, longitudinal forces affect the direction of the movement and against it, while the transverse forces try to push the vessels closer to each other or farther away from each other. The turning moment tries to turn the bows of the vessels either towards each other or away from each other. The maximum values of the forces and moments strongly depend on the absolute and relative speeds of the vessels, their mutual longitudinal positions, the distance between their sides, the dimensions of the vessels, the depth of the water, currents, the wind and the waves. Also the distance of the other sides of the vessels from the canal walls has a significant effect.

So, when the mutual positions of the vessels change, the magnitude and the direction of the forces and moments may change very quickly.

**The meetings of the vessels on 2nd February 2006**

The investigation has made use of the recording of the electronic chart of the ESTRADEN. The numerical recording shows the canal banks, the scale, the time, vessel speed and the location of the other vessels. The electronic chart is inexact with regard to the mutual positions of the vessels and the fairway. The investigation has assumed that the longitudinal positions of the vessels are sufficiently reliable and match the hearings and statements of the crew members. The GPS recordings gave the speeds and courses of the vessels at ten second intervals, except ESTRADEN, of which the before mentioned recordings was picked up. The recordings of ESTRADEN were received in one minute intervals.

The investigation calculations have used a knot as the speed unit and, at times, m/s, even though the practice of the Kiel-Canal is to use km/h.

**Speeds and positions.** Figures 19 and 20 present the view of the investigators on the speeds and mutual longitudinal positions of the vessels before and during the accident. The mutual longitudinal positions of the vessels are indicated as the distances between their bows. When three vessels met each other, the encountering vessel had reduced its speed. The ESTRADEN and the WOLGASTERN had about the same speed about 4 minutes before the collision and both were increasing their speed. The allowed speeds were at times exceeded.

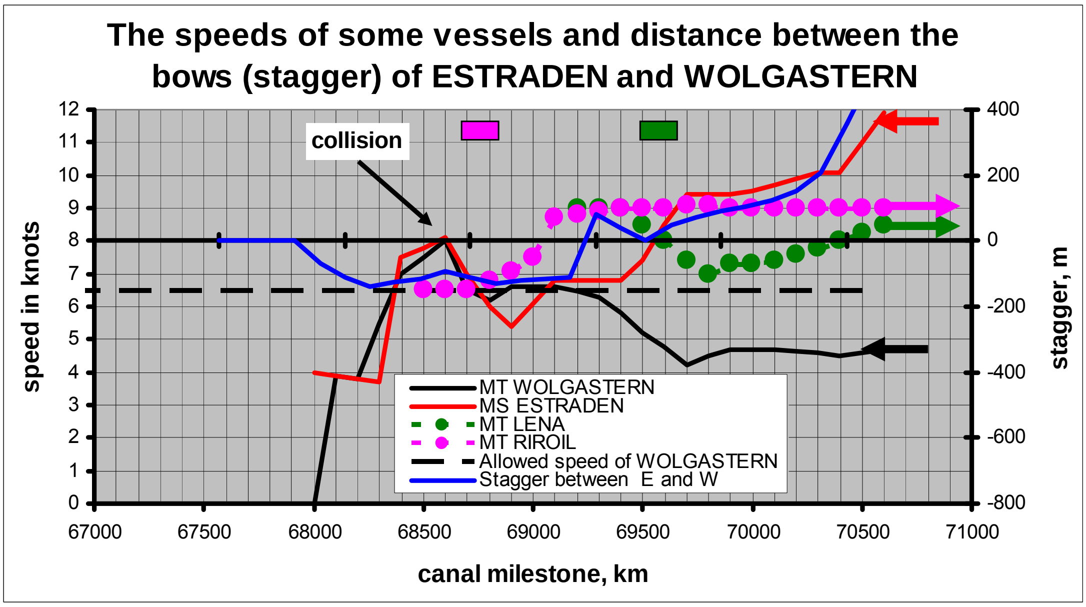


*Figure 19. The speeds of the vessels and the longitudinal distance between the ESTRADEN and the WOLGASTERN. The encountering situations are indicated with small rectangulars.*

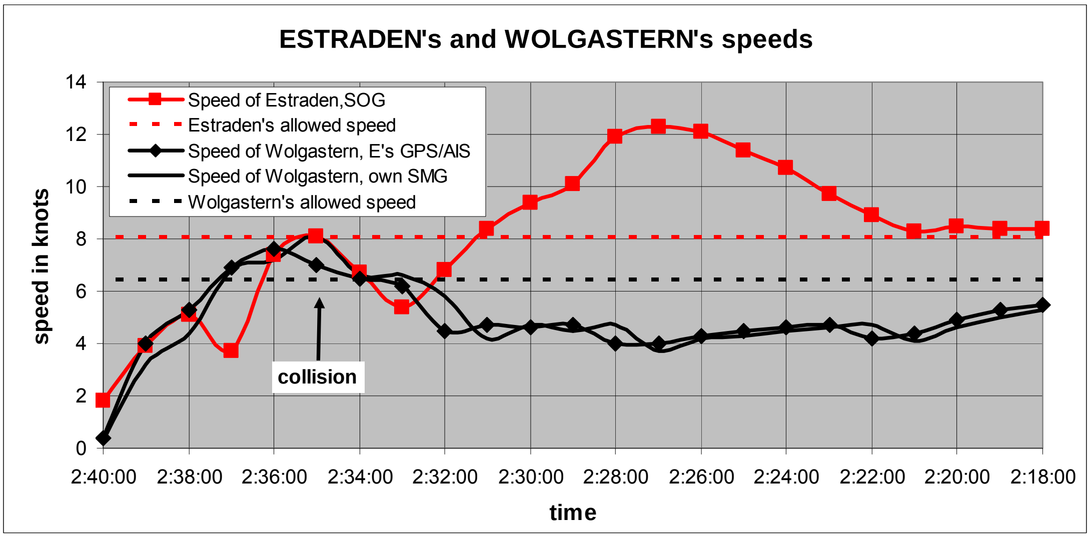


*Figure 20. The speeds of the ESTRADEN and the WOLGASTERN.*

**The heading of the vessels.** Figure 21 presents the headings of the ESTRADEN and the WOLGASTERN before and after the collision. The effects of the steering measures onboard and the mutual interaction are difficult to distinguish. However, it can be seen that, especially after encountering the RIROIL 5, the headings of the vessels started to change more strongly than before it.

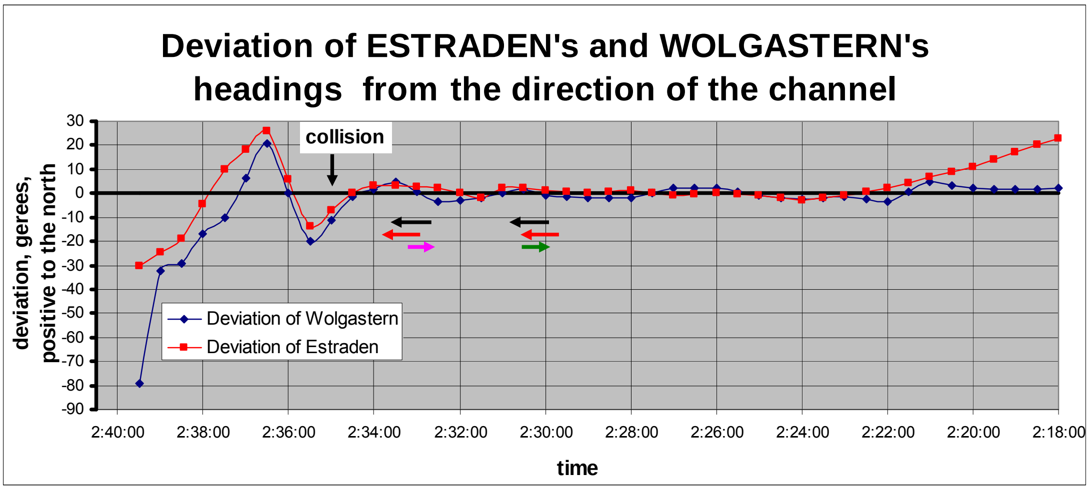


*Figure 21. The headings of the ESTRADEN and the WOLGASTERN. The encounters of the LENA and the RIROIL 5 are also shown.*

**The forces and moments**

Figure 22 presents principally the directions of the forces and moments when a vessel slowly passes another as found in literature on model experiments and theoretical calculations. In fact, due to the small difference in speed and the closeness of the vessels, the encountering will not succeed. The changes in the longitudinal forces (resistance) are such that the vessels remain captives of each other. When the ESTRADEN came alongside the WOLGASTERN (position B), her resistance decreased and that of the latter increased. When the ESTRADEN then tried to get ahead (position D), the directions of the forces changed. On the black vessel (the WOLGASTERN), the h/T ratio is 1.2, on the red one (the ESTRADEN) 2.0, and therefore the effect is stronger on the black vessel. An increase in speed increases this "captivity". The plus sign indicates an increase in the resistance and the minus sign its decrease. Additionally, the manoeuvrability of the WOLGASTERN was affected by the bank effect.

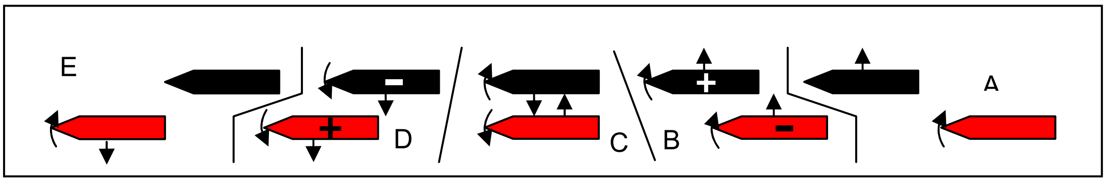


*Figure 22. The principal directions of forces and moments when the vessels have about the same speeds.*

## 1.5.3 The activities of the crew onboard the ESTRADEN

Right after the collision, the chief officer deckhands were sent to investigate any leaks and damages. The chief engineer and engine room crew inspected the engine room. Chief officer notified that there were smaller holes above the main deck. No leaks were detected in the lower cargo hold or other compartments. The Chief engineer reported at 02:45 that there were no leaks in the engine room and the engine room functions were normal. The soundings of the ballast tanks were unchanged and no leaks were detected in the cofferdams.

## 1.6 Provisions and regulations guiding the operations

### 1.6.1 National rules

In the Kiel-Canal, which is one of the federal German waterways, traffic is regulated by the German Traffic Regulations for Navigable Marine Waterways (Seeschifffahrtsstraßen-Ordnung, known by the German acronym SeeSchStrO), in addition to the International Maritime Regulations. The SeeSchStrO includes the following text in § 23[14]:

*(1) As a rule, an overtaking vessel shall pass the vessel being overtaken on the latter vessel's port side. If the circumstances of the case so require, the overtaking vessel may pass the vessel being overtaken on the latter vessel's starboard side.*

*(2) The overtaking vessel, acting in compliance with the provisions of Rule 9(e) and Rule 13 of the International Regulations for Preventing Collisions at Sea, 1972, as amended, shall slacken her speed so much, respectively, shall give the vessel being overtaken such a wide berth that no dangerous suction or wash can develop and that no vessel proceeding in the opposite direction will be put at any risk for the entire duration of the overtaking process. The vessel being overtaken shall facilitate the overtaking vessel's action to the greatest possible extent.*

These instructions contain instructions for overtaking at the siding areas of the Kiel Canal, but SeeSchStrO do not mention the maximum size categories of the overtaking vessel or the vessel to be overtaken nor how big a vessel may be encountered during the overtaking. A maximum amount of vessels side by side inside siding areas is not regulated nor do the SeeSchStrO specify when the vessel to be overtaken has to be fastened to the dolphins for the duration of the overtaking. What to do depends on individual situations. The Master of a ship as the responsible person has to decide together with the pilot if overtaking is practicable, necessary or useful. If he wants to overtake in a difficult situation, he has to pay attention to ensure the safety of shipping traffic and to avoid any other ships to be exposed to any damage or detriment. (Section 3 of the SeeSchStrO).

For the minimum distance between the vessels passing side by side, the Masters have to think about how to take the hydrodynamic effects into consideration. This is not manifested in the SeeSchStrO otherwise than as an act of good seamanship.

On the other hand, restrictions are given for overtaking or meeting outside the siding areas[15].

According to the SeeSchStrO, the ESTRADEN belonged to traffic group 5 and so did the WOLGASTERN[16]. The maximum speed of the ESTRADEN in the Canal was 15

[14] English text issued by the German authorities.
[15] SeeSchStrO, § 23, 9

km/h (8.1kn). The maximum speed of the WOLGASTERN was, due to the draught of the vessel (over 8.5 m), 12 km/h (6.5 kn)[17]. These maximum speeds are not allowed to be exceeded neither during steaming alone nor during overtaking. The end points of Audorf-Rade siding place are situated at kilometers 66.093 and 71.749[18].

Under the SeeSchStrO (§ 3), the Master has to follow the VTS notifications, which are given in German and, upon request, in English.

### 1.6.2 Instructions of the shipping company

**The ESTRADEN**

In the Rederi AB Engship Safety Management, sea watch in a narrow fairway, point 29.4.2 describes the instructions when the pilot is onboard. *If a manual helm is used, the pilot issues the helm commands, which are repeated and complied with by the helmsman. The Master/OOW supervises that the helmsman carries out the commands correctly. If automatic steering is used, the steering is done by the pilot/OOW. The OOW supervises the operations of the pilot and interferes or assists when needed. Contacts with the local traffic control are carried out in accordance with the local practice. The OOW makes the entries in the log and chart. If the Master is not on the bridge, he has to be in immediate readiness to come there.*

The instructions of the shipping company do not contain a separate instruction on navigation in the Kiel-Canal.

**WOLGASTERN**

No instructions of the RIGEL shipping company were received.

### 1.6.3 International Conventions and Recommendations

Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) as amended, Rule 9 handles narrow fairways. Point e) 1) of the Rule states that *if in a narrow passage, overtaking can only take place after the vessel to be overtaken has taken steps to ensure safe overtaking, the vessel intending to overtake shall indicate its intent by giving a sound signal determined in Rule 34, paragraph c, point 1. If the vessel to be overtaken consents to the overtaking, it has to give a sound signal determined in Rule 34, paragraph c, point 2 and take steps to ensure safe overtaking. If it hesitates, it can give the sound signal determined in Rule 34, paragraph d. 2) This Rule does not discharge the overtaking vessel from the obligation laid down in Rule 13.*

Rule 13 handles overtaking. Part a) of the Rule states that *every vessel overtaking another has to yield the way to the vessel being overtaken.* Point d) of the Rule states that *no later change in the heading of these two vessels will make the overtaking vessel into a vessel that, in for the purpose of these Rules, cuts the direction of the other vessel nor*

[16] SeeSchStrO, § 2, 5.7
[17] SeeSchStrO, § 26, 12.13.1
[18] Wasser-und Schifffahrtsamt Kiel-Holtenau, Sachbereich 4-Schifffahrtwesen, letter 4-331.5 SU 02/06 (30th May 2007 )

*will it discharge it from the obligation to remain clear of the vessel it has overtaken until it has totally overtaken it and succeeded therein.*

The overtaking was agreed upon on the VHF telephone between the vessels in question and also with the VTS NOK II in German. This is allowed according to the SeeSchStrO, § 23, (4) if conditions listed therein are fulfilled.

# 2 ANALYSIS

## 2.1 General traffic situation

All westbound vessels were shown an extended stop signal in Audorf-Rade at 01:25. This signal meant that the exit of the siding area of Audorf-Rade was prohibited for vessels of traffic group 3 and above. This traffic situation and the future intentions of VTS NOK II were announced on VHF to all vessels in Kiel Canal at 01.50. So all involved west going vessels had knowledge of the expected delay in the siding area of Audorf-Rade for approximately 30 minutes.

The continuation of the voyage was anticipated for 03.10, as one had to wait for the TAVASTLAND and the CROWN BREEZE. Therefore, after passing RIROIL 5 at 02.33 the ESTRADEN might have overtaken WOLGASTERN relatively safe for more than half an hour, without any need to overtake with concurrent oncoming traffic. So, the ESTRADEN had the possibility to follow the WOLGASTERN until the LENA and the RIROIL 5 had been encountered. Then the WOLGASTERN would not have to sail too close to the bank and the distance between the sides the ESTRADEN and the WOLGASTERN would have been safe.

## 2.2 Bridge co-operation

There was no possibility for smooth bridge resource management in the bridge of ESTRADEN because the pilot and the helmsman of the ESTRADEN communicated mutually and with the WOLGASTERN in German, and the OOW of the ESTRADEN did not fully understand it. Also the communication with the Canal traffic control took place in German in accordance with the local practice. When the OOW started to suspect that something out of the ordinary was going on, he asked the pilot about this in English. All information could have been asked in English according to the SeeSchStrO but this was utilized neither on the ESTRADEN nor on the WOLGASTERN.

The Master of the vessel is in a difficult position in this kind of situation. On the one hand, he is responsible for his vessel, but on the other hand, the pilot and the helmsman appointed onboard by the Canal administration steer the vessel in practice quite independently. During the passage through the Canal, normally the OOW is on the bridge. The Master comes there by OOW’s invitation and he may then interfere in the steering if he sees that necessary. At that point, it may already be too late.

In the beginning of the canal pilotage, the Master should agree with the pilot, what kind of information has to be informed to him in English. This kind of information are amomg other things forthcoming overtaking situations.

## 2.3 The overtaking situation

The ESTRADEN could not fully meet its obligations as the overtaking vessel, because during the overtaking of the WOLGASTERN, it encountered first the LENA and then the RIROIL 5 and they were encountered at the same time as the ESTRADEN with port side to port side. The LENA is relatively wide (20.6 m) and so it also requires its own space for encountering. The Lena made a remark about her size, but the encountering was carried out in spite of that. When continuing the overtaking, the ESTRADEN could not move to the left enough due to the encountering RIROIL 5.

In the understanding of the investigators, there should be a possibility for the overtaking of a vessel of the size of the WOLGASTERN by a vessel of the size of the ESTRADEN without encountering large vessels. This would have been the case if the WOLGASTERN had started to decrease her speed earlier or if the LENA or/and RIROIL 5 had been ordered to wait or slow down early enough. The overtaking operation of the ESTRADEN could have been interrupted until the encountering vessels had been passed. This could have been achieved with more efficient VTS traffic control.

The WOLGASTERN increased her speed in order to improve her manoeuvrability. In principle, this is the right type of measure, but in this situation it prolonged the time needed for the attempt of the ESTRADEN to overtake it. That is why the vessels sailed a long time (six minutes) side by side, and four minutes of that time at almost the same and increasing speed. This resulted in the development of strong mutual interactions.

The fact that the ESTRADEN dropped her speed after the first collision resulted in the WOLGASTERN sliding along the side of the ESTRADEN, and this caused further damage to both vessels. On the other hand, this was how the drifting of the ESTRADEN to the channel wall was prevented, which could have resulted in damage to the rudders and propellers.

## 2.4 Effects of a restricted water area

The effects of a restricted water area on the movements and steering of vessels are handled in Appendix 1. In the Appendix, the literature review has resulted in the following opinions.

Already the overtakings by the TURCHESE and the ANTJE had forced the WOLGASTERN to move to the right-hand side of the fairway. At that point, the passageway was still wide even though the WOLGASTERN could not, due to her deep draught, make full use of it. It was forced to remain close to the starboard side of the fairway, because the encountering vessels were allowed to pass it and the ESTRANDEN, which was already at her side. The starboard side of the WOLGASTERN was in water that was 1.5–2m shallower than on her port side, which possibly increased the manoeuvring difficulties, which were already present due to the closeness of the bank. Right after encountering the LENA, the WOLGASTERN proceeded to the narrower part of the channel, where it had no room to move to starboard. Moving to a narrower channel was likely to make the steering more difficult.

The underkeel clearance (the distance between the vessel and the bottom of the channel) varied also due to the unevenness of the bottom of the Canal. For this reason, the squat of the WOLGASTERN varied. The increased speed further increased the squat. The squat estimated in the investigation is shown in Figure 5 of Appendix 1. These facts in part resulted in unexpected changes in the manoeuvring characteristics of the vessels. Due to the encountering LENA, the ANTJE had to quite quickly move in front of the WOLGASTERN, which might have increased the steering difficulties already noticed. The h/T ratio of the WOLGASTERN varied at such a range (about 1.2–1.4) so that sudden changes in manoeuvrability were possible. They could be partly due also to changes in the operation conditions of the propeller in shallower water.

The encountering vessels, the LENA and the RIROIL 5, were allowed to meet the ESTRADEN and the WOLGASTERN, which were already side by side, and therefore the ESTRADEN had to be too close to the WOLGASTERN, which could not move at all starboard. As a result of this, the interactive forces and moments of the vessels became so strong that the steering forces could no longer overcome them. In addition, the vessels became captives of each other in the longitudinal direction. The directions of the forces and moments changed in an unpredictable way as the mutual longitudinal positions of the vessels changed and the steering forces did not have time to affect due to the inertia relating to the turning of the vessel. The attempts to increase speed, even above that allowed, in order to increase the steering forces, were not sufficient, because the interactive forces increased at a rate closely proportional to the square of the speed.

After encountering the latter of the vessels, the RIROIL 5, the ESTRADEN still remained close to the WOLGASTERN, even though she would have had room to move farther away. On the other hand, at that time the vessels were affected by a force pushing them to port and a moment turning them to port, which would have made a move farther away more difficult.

In the opinion of the investigators, the personnel on the bridge might not have been able to evaluate the risks of the situation. The vessels were allowed to sail too close to each other at too high speeds. The LENA, however, wondered about the three vessels being side by side at the same time. "Even the LENA is no a small vessel." However, this did not result in a re-evaluation of the situation. Within quite a short time, there were several encounters and overtakings, which took the attention of the bridge personnel to such an extent that it was not possible for any of them to make an overall evaluation of the development of the situation and any risks connected thereto. The bridge personnel of each vessel examined the situation from their own viewpoint. It is likely that already the overtaking of the WOLGASTERN by the ANTJE and the encounter of the LENA right after that resulted in instability in the manoeuvrability of the ESTRADEN and the WOLGASTERN, and a need for active steering. The situation worsened further as the vessels kept sailing side by side at an increasing speed.

The German Traffic Regulations for Navigable Maritime Waterways (SeeSchStrO) restrict the encountering and overtaking of vessels both on the basis of the place and size (traffic group). Outside the siding area, it was not allowed to overtake the WOLGASTERN. All the overtakings and encounters investigated in connection with this accident took place in the siding area. The SeeSchStrO contain only general instructions for the situation when several ships meet inside the siding areas. In the opinion of the investigators, the fact that the three vessels were side by side contained a risk factor due to the sizes of the vessels involved. The blockage[19] of the fairway was about 3.3, which is clearly below 15, a figure below which the Canal starts to feel narrow for vessels.

### 2.5 Other observations

**The speed.** The investigation revealed that the speed limits of the Kiel Canal were broken. The ESTRADEN had sailed at times at least at 22.8 km/h (12.3 kn) against the maximum allowed 15 km/h (8.1 kn). The WOLGASTERN had exceeded her maximum allowed speed of 12 km/h (6.5 kn) by increasing her speed just before collision up to 14.8 km/h (8 kn). The investigators do not know if there are any consequences to the ship Masters or ship owners concerning over speed or how the canal traffic control is observing and regulating the speeds of the vessels.

The primary **speed unit** in the Kiel-Canal is km/h. However, in maritime traffic the knot (kn) is a more common unit. Most often navigation equipment displays the speed in knots. This parallel use of two speed units results in an extra need for conversion when estimating the speed, which may, in certain cases, result in false estimates. In the opinion of the investigators, the use of two units or one unit unfamiliar in navigation is unnecessary and an extra factor causing risks.

[19] See Appendix 1, page 3.

# 3 CONCLUSIONS

At times there were too many vessels side by side, so that their distances developed too small and they became captives of each other. The overtaken vessel, the WOLGASTERN, had to steer a long period too close to the bank of the canal due to several overtakings and encounters. The possibilities due to the general traffic situation, which might have made the encounters of the LENA and the RIROIL 5 unnecessary at the same time when the ESTRADEN was overtaking the WOLGASTERN, went unnoticed. Due to increases in speeds, the vessels were attracted by each other. The pilots were likely not to have a sufficiently clear idea of the effects of hydrodynamic forces in this particular situation (several vessels passing and overtaking in a short interval, three vessel for a while side by side), nor are they emphasised in SeeSchStrO as strongly as they should.

The Canal Rules contain no exact instructions for overtaking in a siding area, such as for example what size of vessels or how many ships may be side by side. The final responsibility lies on the Masters. The speeds of the vessels exceeded their maximum allowed speeds at times. This may make one conclude that the overtaking had not been planned in time. It seems that the Canal Administration allows excessive speeds in order to guarantee flexible traffic. Because of this accident, the WOLGASTERN's owner has decided, that they will not in general pass the Kiel Canal when the draft of the vessel is 8.5 m or more.

The decision on the steering of the vessels is mainly on the shoulders of the pilot and the helmsman. However, it is the Master of the vessel who is responsible for his vessel. How well the Master can follow the events depends on his language skills, because the Canal personnel use German. The use of English would give the crew of the vessel better opportunities to interfere in matters in good time. Traffic notifications are also obtained in English upon request, but the ships crew did not ask for them. According to the German authorities, they are not willing at the moment to have English as the bridge language. Vessel-specifically, the pilot and helmsman can answer questions in English.

Traffic control did not interfere in these overtaking situations. No vessel was ordered to stop and wait. A situation arose where three vessels were side by side twice. Managing the situations was left to the pilots.

In navigation, the most common speed unit is the knot. Navigation equipment, such as the log and electronic map, indicate the speed in knots but in the Kiel Canal km/h is applied. This fact tends to confuse the monitoring of speed and any decisions based thereon.

# 4 RECOMMENDATIONS

The investigation revealed that the practices relating to the overtaking of vessels inside the siding areas are fairly free. The rules SeeSchStrO give only general instructions without any specific restrictions for the navigation inside the siding area. In the overtaking situation, traffic from the other direction was encountered, the size of which has not been restricted in the SeeSchStrO nor did the Traffic Control in this case restrict it. The maximum allowed speeds were exceeded. Forces and moments affecting ships are proportional to the square of the speed, and consequently observing the speed limits improves the navigation safety. Therefore the Investigation Commission recommends to the Wasser- und Shifffahrtsdirection Nord that:

1. *The relevant rules should be specified so that overtaking situations can be implemented safely without traffic from the opposite direction endangering it. The speed limits should be controlled more effectively.*

Knowledge on the effects of restricted waters on the ship navigation seems to be fairly poor among the seafarers and pilots, so the Investigation Commission recommends that:

2. S*hipping companies operating in channels and other bodies in connection with the canal navigation should estimate the need of additional education of their personnel concerning the effects of restricted waters and increase training as needed*.

3. *Maritime training institutes should complete their curriculum concerning the influence of confined waters in ship handling theory and practice. This subject area should not be ignored when renewing curriculum.*

There is in Germany advanced training for ship owners and pilots provided by the Kiel Canal Training Centre and the Maritime Education and Training Centre at Hochschule Wismar. For example fully interactive training of complex traffic situations based on Kiel-Canal experience.

Helsinki 15th October 2007

Juha Sjölund Heikki Koivisto Olavi Huuska

# Appendix 1. ESTRADEN and WOLGASTERN in the canal

## 1 General notes about ship-ship and ship-bank interactions in channels

MS ESTRADEN and MT WOLGASTERN collided in Kiel Canal 2nd of February 2006. This canal is an example of restricted waterways where the limited water depth and canal's sides have a marked influence on the maneuvering of the ship(s). Already during the passage of one vessel through the channel the effects of restricted waters on the maneuvering must be considered. The situations become more challenging when two or more ships are in close proximity to each other. Overtaking and meeting develop complicated changes in the water flow around the ships which in turn generates forces affecting the maneuvering of the vessels. Continuous traffic flow to both directions generates waves and unsteady flow conditions having disturbing effect on the maneuvering operations.

For deep water trial conditions IMO has issued requirements for maneuvering[20]. Similar requirements for restricted water conditions are lacking in spite of the fact that navigation in the latter conditions is more difficult and risky. The fulfillment of the deep water requirements does not guarantee that the ship is safely navigable in restricted waterways. For these situations one should develop new requirements[21]. All waterways have own rules and practices. Significant for the safe navigation in restricted waterways is the acquired experience of Masters, officers and pilots. As one example of this experience serves the practice called ”Texas Chicken”, which uses shallow water effect during the encounter of two big ships[22].

The aim of the research in the field of ship navigation in confined waters is to determine safe speeds, distances and separations between ships and channel's walls and bottom for different situations. However, the knowledge in this field is not sufficient for developing corresponding requirements for low speed in confined waters. Reason for this is the considerably bigger amount of parameters connected with navigation in restricted waters than in unrestricted waters. Methods in computational fluid dynamics (CFD) are developing quite quickly, but their verification is lacking because of the scarcity of full-scale and standardized model-scale results. However, quite good correlation between model test results and calculations has been achieved already in many cases, see references. Based on these results, simple simulation models have been developed, but they need yet considerable improvements. Especially, the complicated interaction of ship's stern, propellers(s) and rudder(s) needs additional studies (see references 14, 18, 19 and 22). The aim is to develop PC-programs for use onboard ships in order to determine the risks of next channel passage and to plan corresponding maneuvering operations.

CFD-calculations and model tests have most often forced the ship(s) to move on a parallel course with channel walls. Turning and moving sideways were not possible. As a result, the forces and moments do not correspond to the real situation where by maneuvering the ship is held on needed course. However, in real life active steering turns and shifts the ship a

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20 IMO Resolution MSC.137(76), Standards for Ship Manoeuvrability, adopted on 4th December 2002

21 Dand, I.W. Low Speed Manoeuvring Criteria: Some Considerations, International Conference on Marine Simulation and Ship Maneuverability, MARSIM '03, 25th-28th August 2003, Kanazawa, Japan.

22 Pilots are using this practice in Houston Ship Channel. When two big ships are going to encounter, the ships are steaming on head on courses until about half a mile before collision the pilots agree upon moving aside. (Pilots see long life for Texas Chicken, August 22, 2002, Reporter News.Com, Texas).

little bit from planned course which means that the calculated or model test results are not correct. The human effect of steering is not included in the results. Moreover, the maneuvering characteristics of the vessel are neglected. Some calculations include a set of steering constants, but e.g. the mutual feedback of two helmsmen in case of two meeting ships has not been included in any mathematical model so far. According to the reference 22, model tests should be carried out with self-propelled models, which has been uncommon so far. In addition to these shortcomings the scale effect is not fully clear[23]. On the other hand, it might be possible that through the acquired experience the real safety margins in practice are smaller than calculated or based on model tests.

Consequently, the results of model tests and calculations must be applied with care; they show most often only general trends. In connection with the investigation of this accident a short literature study was carried out. Based on its results, only most suitable references for this case have been selected. The opinion of the accident investigators is that a general qualitative picture has been reached and some quantitative results, too. Each selected reference has a comment explaining how useful it has been in this case.

### 1.1 Effect of restricted waters on the maneuvering of ships

In shallow water the underkeel clearance[24] is small. According to the Bernoulli-law, the flow speed increases and the pressure decreases between the hull and the channel bottom. Consequently, the water level sinks around the vessel and the underkeel clearance decreases. This phenomenon is called squat. Bernoulli-law works also between the hulls of two ships and between the ship and channel walls.

**A ship navigating in the channel meets following phenomena:**

i. The ship sinks with the lowering water level, which actually means an increase of the draft. The phenomenon is called squat and it consists of a vertical sinkage and change of trim.
ii. Maneuvering characteristics will change. To turn the ship requires more space. Tactical diameter may increase considerably when the ship moves from deep to shallow water (for some ships with very high breadth to draft-ratio turning abilities may improve). Coursekeeping (steering) characteristics might worsen or improve (in very shallow water).
iii. Resistance will increase.
iv. The propeller slip stream will change (the propeller load will change depending on the depth to draft-ratio).
v. Near the walls of the channel a bank effect is felt. The configuration of the bank and the material and construction of the surface have a strong influence on the developing forces and moments. The configuration of the banks could be as follows:
    1. Vertical, surface piercing. Here the reflected waves play also a role. Normally the bow turns out. At the same time the ship feels a strong attractive

[23] Reviews of the state of the art in research of maneuvering in restricted waters are:
- ITTC2002, 23rd International Towing Tank Conference 2002, Venice, Appendix A
- ITTC2005, 24th International Towing Tank Conference 2005, Edinburg, the Manoeuvring Committee. Conference reports may be found at http://ittc.sname.org/proceedings.htm.
- Gray, W.O., Waters, J.K., Blume, A.L., Landsburg, A.C, "Channel Design and Vessel Maneuverability: Next Steps", Marine Technology, vol. 40, No 2, April, p. 93-105, (2003).

[24] Distance between the bottoms of the ship and the fairway.

force. There is a risk to collide with the bank if the outturning trend is compensated by the rudder. The results of model tests and computations handle most often this channel configuration.
2. Sloped bank as in this case. Therefore, other configurations have been considered in this accident investigation only for comparison.
3. Flooded bank, in fact an underwater channel.

Forces and moments affecting the ship are smaller in these two latest configurations.

vi. Blockage, described later on.
vii. Waves generated by the ship will differ from the deep water waves.

**Water is defined shallow** in various ways. Water is shallow when the bottom of the fairway affects the maneuvering of the ship.

i. Relative depth of the fairway which is measured by the ratio h/T (water depth draft-ratio), which has e.g. following limits:[25]
   - h/T > 3, deep water
   - 1,5 < h/T < 3, medium deep water
   - 1,2 < h/T < 1.5 shallow water
   - h/T < 1.2, extremely shallow water

   Water depth is defined at the undisturbed water level[26]. Also the ratio (h-T)/T is used (underkeel clearance divided by draft).
ii. Relative speed in shallow water is measured by the Froude depth number $F_{nh}=V/(gh)^{½}$ , where g = 9.81 $m/s^2$ and V is the speed of the vessel in m/s. When this number is over 0.1, a small squat is already noticed. More noticeable it becomes when the number is over 0.3. The resistance increases clearly when the number is over 0.7. The flow is subcritical when the number is under 1 and supercritical when it is bigger than 1.This case was subcritical, Froude depth number was below 0.6.

**Relative size of the ship** compared to the dimensions of the channel is measured with the following parameters.

i. The ratio of the channel breadth to the length of the ship, b/L If this ratio is below 0.35, the ship waves possibly reflected from the bank hit back to the ship. The slope of the bank and the surface construction will influence on the reflection.
ii. The ratio of the channel breadth to the breadth of the ship, b/B. This ratio gives some idea about how good space the ship has in the channel. For normal vessels this ratio tells also about the reflection of the waves, because the ratio L/B does not alternate considerably.
iii. Blockage, which is measured by the ratio cross section area of the channel divided by the cross section area of the ship(s), $A_{CH}/A_S$ = n. When this is below 15, the ship(s) feel(s) the channel narrow.
iv. Transverse position of the ship in the channel, measured by the ratio the distance of the centerline of the vessel from the channel wall divided by the breadth of the ship, $y_0/B$. The minimum of this ratio is normally a little bit below 0,5 depending on the ratio h/T and slope of the bank. In the case of sloped bank, $y_0$ is measured to the beginning of the slope. Another method is shown in the reference 23.

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[25] ITTC2002, 23rd International Towing Tank Conference 2002, Venice, Appendix A.
[26] One has to agree about the method of determining the water depth to be used in calculations, because the bottom profile is seldom flat, see reference 23.

### 1.2 Ship-ship interactions in the channel

When two ships are moving close to each other, their flow fields (pressure fields) meet and interact. The ships feel forces and moments which try to move and turn them. Depending on the mutual position and directions of steaming, longitudinal forces are accelerating or decelerating the speed, transverse forces are repulsive or attractive and turning moments (which depend on point of impact of the force) try to turn bows in or out. Maximum values of these forces and moments depend strongly on the mutual relative speed, absolute individual speed, longitudinal stagger (distance between the bows), distance between the sides, dimensions and lines of the ships, water depth, stream, wind, waves and maneuvering operations (propeller revolutions, rudder and steering characteristics). In addition, the distances of the other sides of the ships from the channel walls are important. Forces and moments of this case are shown in figure 9a[27]. The investigators have used mainly the following nomenclature of references 1–5.

i. The relative transverse distance between the centerlines of the ships, $Y_0$ divided by the breadth of the ship, $Y_0/B$ or by the length, $Y_0/L$. As a reference ship the overtaken is normally used. Also the distance between sides, e, is used.
ii. Longitudinal relative position, called stagger, $X_0$, is measured here by the longitudinal distance between the bows of the ships divided by the length of the overtaken ship, $X_0/L$. Also quite commonly the distance between the centers is used. (For head on encounters, the ratio $X_0/L$ is zero when the bows are crossing, but this ratio calculated with the help of centers is 1). The distance $X_0$ is positive in direction of the travel and is calculated by subtracting the x-coordinate of the overtaken vessel's bow from the x-coordinate of the overtaking vessel's bow.
iii. Mutual relative speed, measured as the difference in knots, or in m/s or as a ratio of the speeds or as the difference in Froude depth numbers $F_{nhR}$. During the head on encounter the relative speed is quite high and the interactions have only a short time to realize. In this case, ship length 160m, overtaking with 7kn speed a ship steaming with a speed of 4kn, takes about 3½ minutes. Head on encounter with these speeds lasts about one minute.

The parameters are defined in various ways in the references cited in this investigation. The investigators have tried to harmonize the results according to the definitions used in references 1–5. Some parameters are shown in figure 1, which correspond to the situation when LENA was encountering ESTRADEN and WOLGASTERN. During the literature study it has been noted that comparisons between calculated and model test results are sometimes problematic; tests are sometimes old and not all information for the comparison was possible to reach. Moreover, the test methods and facilities differ. Shallow water test conditions might have some unknown scale effect, too[28].

[27] Reference 4, figure 3.
[28] ITTC2005, 24th International Towing Tank Conference 2005, Edinburg, The Maneuvering Committee, § 6.6.

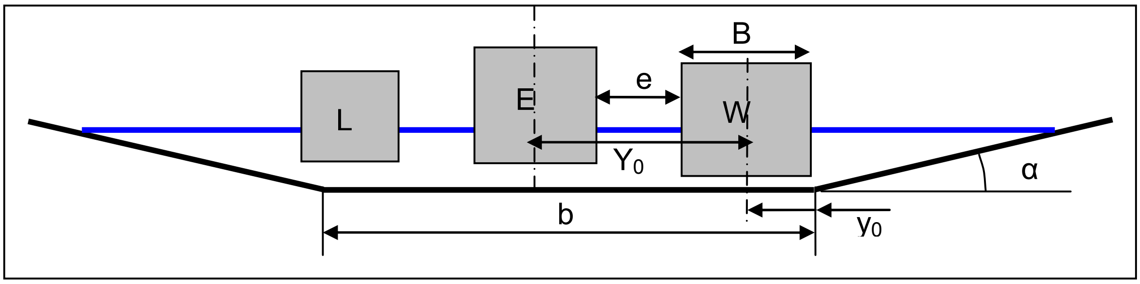


*Figure 1. Some parameters connected to the positions of the ships in the channel.*

### 1.3 Vessel and canal data

Four ships are considered to take the main roles: WOLGASTERN, ESTRADEN; LENA and RIROIL 5. ESTRADEN tried to overtake WOLGASTERN from the left side. During the early stage of this overtaking ESTRADEN was encountered from the left side first by LENA and later by RIROIL 5. A little bit earlier WOLGASTERN were overtaken by TURCHESE and ANTJE. In tables 1 and 2 relevant data and parameters of these vessels are shown.

*Table 1 Main data of the vessels. After the name the traffic group number is shown.*

| | WOLGASTERN/5 | ESTRADEN/5 | RIROIL 5/3 |
|---|---|---|---|
| $L_{OA}$, m | 162.16 | 162.7 | 129.3 |
| $L_{PP}$, m | 155 | 149.4 | 123.2 |
| B, m | 27 | 25.2 | 16.5 |
| T max, m | 9.0 | 5.9 | 5.0 |
| Power, kW | 7860 | 2x7240 | 1800 |
| Max. speed, kn | 15 | 19 | |
| V,kn | 4.5–8 | 4.5–12.3 | |
| $C_B$ | | 0,68 | |
| Displacement, t | 28710 | 18200 | 9440 |
| $F_n$ | 0.06–0.11 | 0.06–0.17 | |
| $Y_0$, m | 36–46 | 36–46 | |
| $Y_0$/B | 1.3–1.7 | 1.4–1.8 | |
| h, m | 11–12.5 | 12.0 | 7–12 |
| h/T | 1.22–1.39 | 2.03 | 1.4–2.4 |
| $F_{nh}$ | 0.21–0.40 | 0.21–0.58 | |
| | LENA/4 | TURCHESE/5 | ANTJE/3 |
| $L_{OA}$, m | 151.6 | 136 | 117.9 |
| $L_{PP}$, m | about 145 | about 130 | |
| B, m | 20.6 | 20 | 18.15 |
| T max, m | 6.3 | 6.2 | 4.5 |
| Power, kW | | | |
| Max. speed, kn | | | |
| V, kn | 7.3 | 8 | |
| $C_B$ | | | |
| Displacement, t | | about 13500 | |
| $F_n$ | 0.10 | 0.12 | |
| $Y_0$, m | 48–53 | | |
| $Y_0$/B | 2.3–2.6 | | |
| h, m | 8–12 | 12.0 | 11–12.5 |
| h/T | 1.26–1.90 | 1.94 | 2.4–2.8 |
| $F_{nh}$ | 0.35–0.42 | 0.38 | |

*Table 2. Maximum allowable draft in dm in traffic group 5. From SeeSchStrO.*

| Ship's length in m | Ship's breadth in m | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 160 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 94 |
| 163 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 94 | 93 |

The breadth of the canal at the bottom varies along the canal. Outside the Schirnauer See at Audorf-Rade siding area it is 100–110 m, with water depth of at least 10.5 m. At Schirnauer See between kilometers 70 and 71 the breadth varies between 110 and 150 m. The depth varies between 10.5 and 13 m, figure 2, which is the same situation as in figure 1. The slope angle is about 13 degrees. The breadth of the water level is about 200m, and more at the Schirnauer See, on the northern side.

Some restrictions (for e.g. maximum speed and overtaking) are in force in Kiel Canal based on the main data of the vessels. Ships are divided in traffic groups 1–6 in the following way. Group 3: up to 120/19 or 140/17 ($L_{OA}$/B) and draft 6,1m. Group 4: up to 132/23 or 160/20 and draft 9,5m. Group 5 up to 200/28 or 210/27 and draft from table 2.

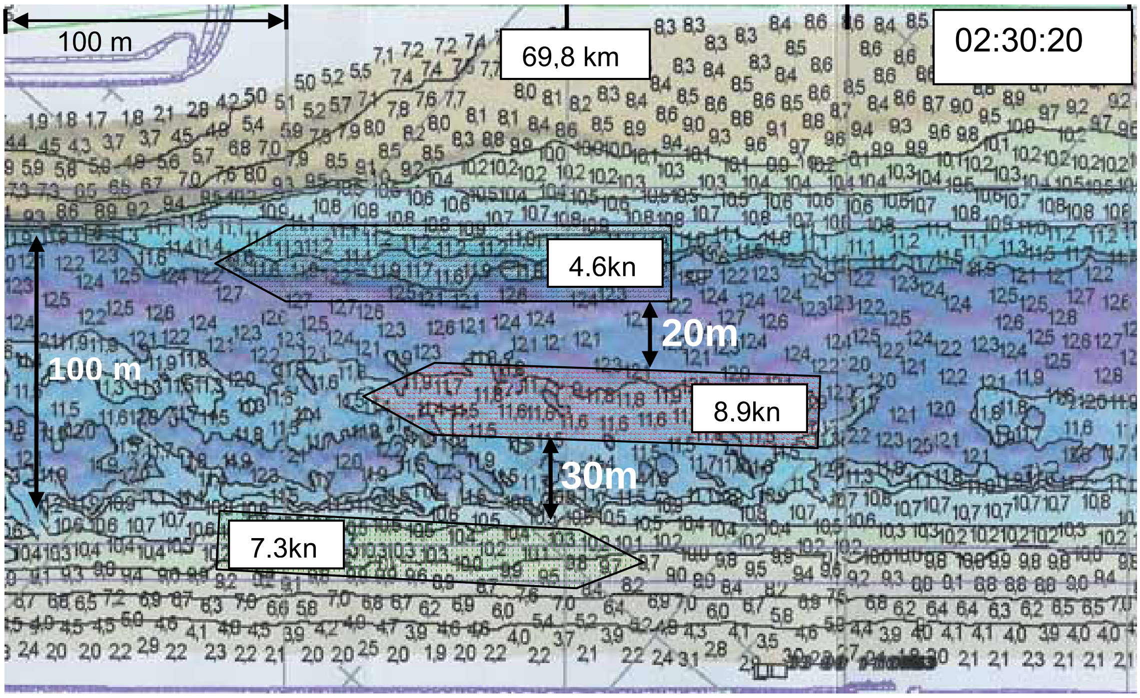


*Figure 2. LENA is encountering ESTRADEN and WOLGASTERN. Vessel positions are according to the evaluation by the investigators. The aim has been to position the ships breadth wise as far as possible from each other. The draft of LENA, 6.3m, allows it to be placed into shallower water, h/T is about 1.6. WOLGASTERN's right side is in about two meters shallower water than the left side, h/T is about 1.25 on the average. For ESTRADEN, draft 5.9m, h/T is about 2.0. The encounter with LENA lasted about 40 seconds.*

## 2. Evaluation of ESTRADEN-WOLGASTERN collision

During the investigation the following interactions have been studied:

1. ESTRADEN trying to overtake WOLGASTERN
2. Encounter of LENA with ESTRADEN and WOLGASTERN
3. Encounter of RIROIL 5:n with ESTRADEN and WOLGASTERN
4. Interaction between WOLGASTERN and the nearest bank wall. Also interactions of WOLGASTERN with LENA and RIROIL 5.
5. Overtaking of WOLGASTERN by TURCHESE
6. Overtaking of WOLGASTERN by ANTJE
7. Encounter of LENA and ANTJE

The first interaction is the main one, the collision. Other interactions have variable impact on the path to this collision.

### 2.1 Waves

Waves in the canal were generated only by the vessels. The ships steamed close to each other and therefore the waves encountered other ships and other waves. The waves were short and low because the water was shallow and speeds quite low. In addition, the banks were sloping. Therefore the impact of the waves on the collision is evaluated marginal. According to the reference 22 the changes of the water level have an effect on the interactions[29]. For the Froude depth numbers of this case, transverse waves behind the ship are dominating.[30].

### 2.2 Stream

Investigators have not received any reports of streams and therefore it has been assumed that they have no impact in this case.

### 2.3 Wind

According to the reports, wind direction was between west and northwest. The direction of the canal was 229, which means that the wind force had strength of 70–100 per cent from its maximum impact. Wind speed was according to various reports 8 knots and 1–2 bf. Investigators have translated these figures into 3–4 m/s, which give only small wind forces on the ships. Biggest impact was against ESTRADEN, because of her great windage. In any case, that small force worked against the collision.

### 2.4 Size of the vessels

TURCHESE, ESTRADEN and WOLGASTERN had nearly the same length and breadth. The two first mentioned had a draft of about 5.9 m, WOLGASTERN about 9 m. LENA was a little bit smaller; ANTJE and RIROIL 5 were clearly smaller. When selecting appropriate results from the references, the sizes of the vessels have been considered. Main data of the vessels are shown in table 1. One should note that this case includes many different h/T ratios at the same time (figure 2 and chapter 2.6).

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[29] See also : Simonsen, C.D., Stern, F., Agdrup, K., CFD with PMM Test Validation for Manoeuvring VLCC2 Tanker in Deep and Shallow Water, MARSIM 2006.

[30] Jiang, T., Henn, R., Sharma, S.D., Wash Waves Generated by Ships Moving on Fairways of Varying Topography, 24th Symposium on Naval Hydrodynamics, Fukuoka, Japan, 8-13 July 2002.

### 2.5 Speeds of the vessels

German authorities have announced speed limits[31]. Forces and moments affecting the maneuvering of a vessel are proportional to the square of the speed. Consequently, speed is a very important safety factor. WOLGASTERN's draft was over 8.5 m, and therefore her maximum speed was 6.5 knots. Maximum speeds of other vessels were 8.1 knots. The speeds of some vessels are shown in figure 3. The speeds of ESTRADEN and WOLGASTERN are also shown in figure 4. At some instants the maximum speeds were exceeded as seen in this figure. Relative Froude depth number $F_{nhR} = F_{nhE}$-$F_{nhW}$ during the overtaking of WOLGASTERN by ESTRADEN was at the beginning about 0.27. The overtaking did not succeed and therefore relative Froude depth number was around zero for some minutes until the collision.

The unit of speed used in Kiel Canal is km/h. In the rules the speed is given in km/h and in knots in parenthesis. In spite of this, using two units during the passage might be confusing because normally the unit knot is used in shipping (pilots and helmsmen use km/h, Master and officers knot). All navigation instruments show normally the speed in knots. Wrong interpretation could lead to over speed. The radar monitor of ESTRADEN used unit kt, which is taken equal to knots. ESTRADEN's maximum allowed speed in Kiel Canal was 15km/h or 8.1 knots. The highest speed found in the investigation was 12.3 knots. At the minimum the speed was about 5.4 knots, during the overtaking attempt. Maximum allowable speed of WOLGASTERN in Kiel Canal was 12 km/h or

6,5 knots. When she accelerated the speed before the collision, her highest speed was about 8 knots. Also LENA and RIROIL 5 exceeded the speed limit at some instants. It may be concluded that the increase of speeds increased also the risk of collision.

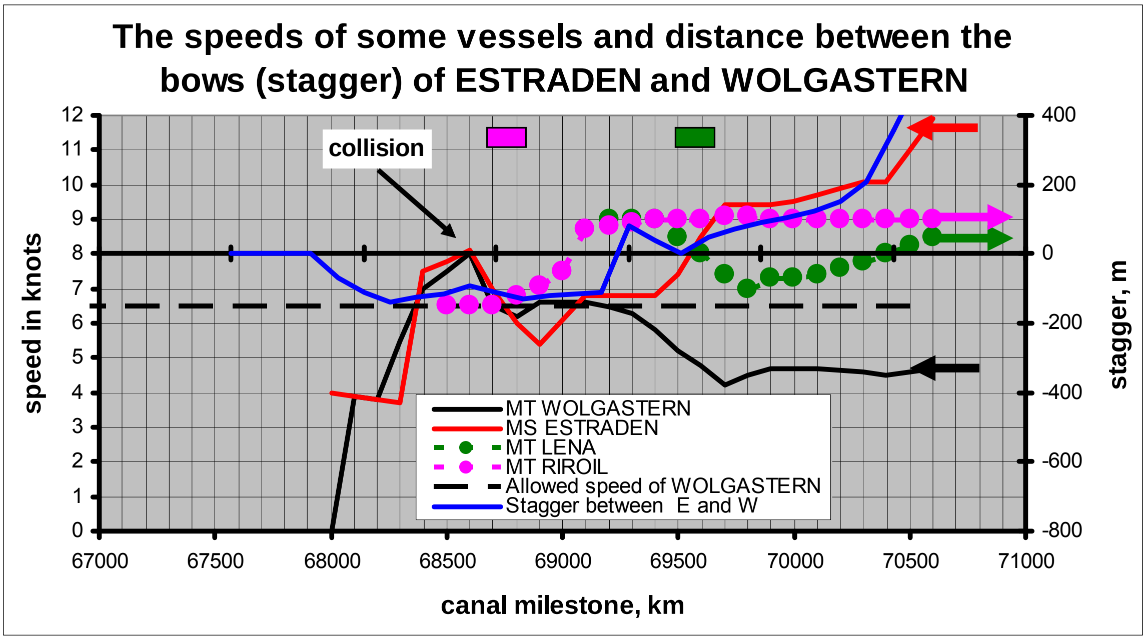



*Figure 3. Speeds of the vessels and stagger between ESTRADEN and WOLGASTERN. The small rectangles show the encounters of three vessels. As seen, the encountering vessels decreased their speed during the meeting.*

[31] SeeSchStrO, § 26, 12.13.1.

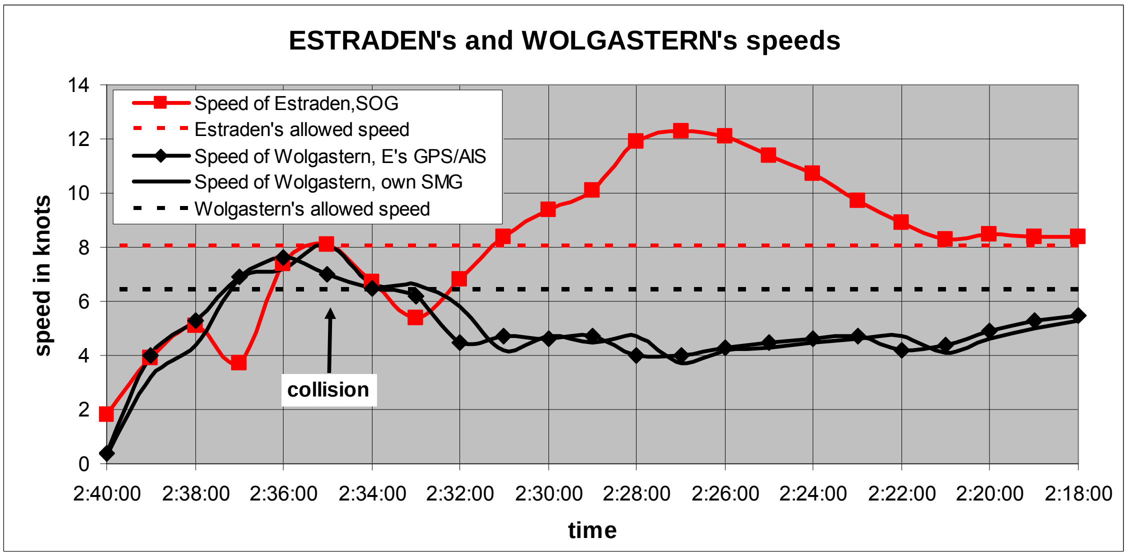



*Figure 4. Speeds of ESTRADEN and WOLGASTERN and allowed speeds. Collision's first stage happened at about 02:35.*

### 2.6 Water depth and squat

Water depth varied both lengthwise and across the channel resulting in variable squat, forces and moments depending on the vessel position. Squat is evaluated according to the principles of reference 10, figure 5. Squat at encounters with LENA and RIROIL 5 might be overestimated, because the meetings lasted only about one minute. Squat of WOLGASTERN increased considerably with the speed increase; from about 0,4 m possibly to nearly one meter. This fact has been one reason for the worsening maneuvering observed.

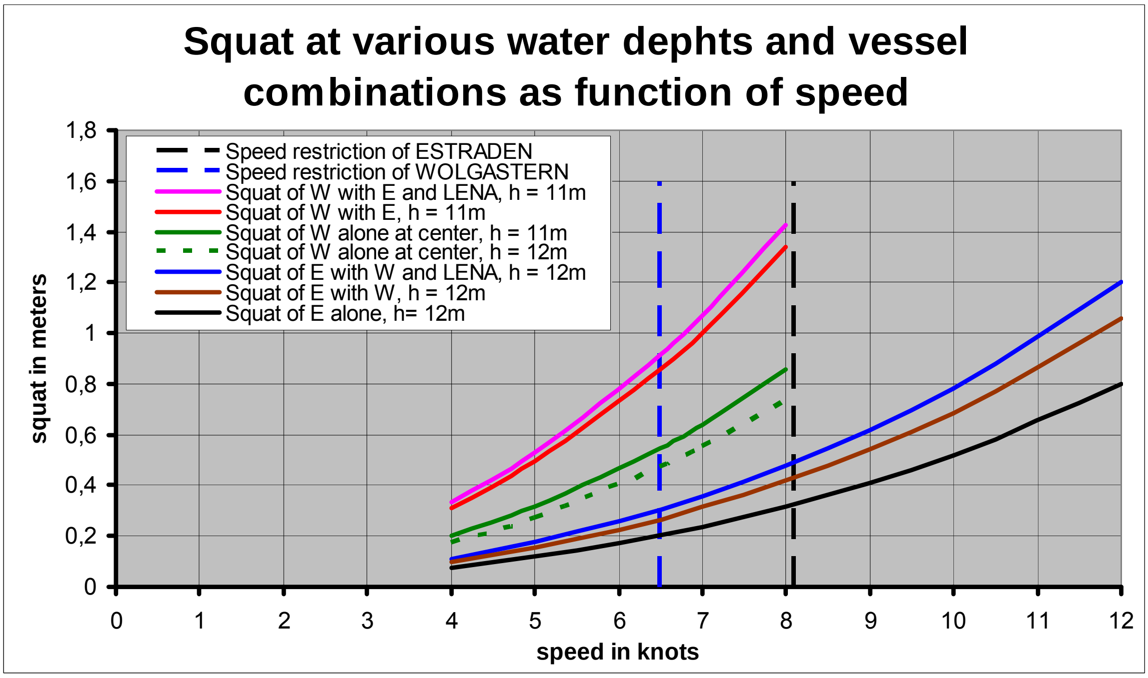



*Figure 5. Estimated squat of various ship meetings.*

As an overtaken vessel, WOLGASTERN was traveling on the north side of the canal. Her right side was in about two meters shallower water than the left side, figures 2 and 6. Also this position might have some adverse effect on the maneuvering, which has been evaluated in chapter 2.9. Ratio h/T varied therefore between 1.17 and 1.39 and was in average about 1.25. LENA and RIROIL 5 had small drafts, and therefore they could give space for ESTRADEN and WOLGASTERN, figures 5 and 7. For LENA the ratio h/T was during the encounter about 1.5, for RIROIL 5 about the same and for ESTRADEN about 2.0.

### 2.7 Distance between centerlines (sides)

ESTRADEN and WOLGASTERN had two encounterings with other ships. Therefore the separation between their sides was at maximum about only 20 meters. During the meetings of three vessels they reserved 50–55 per cent from the useful bottom breadth of about 130 m. The opinion of the investigators is that the separations shown in figures 2 and 6 were all too small. According to the reference 9, the forces and moments acting on WOLGASTERN (4.5 kn) and ESTRADEN (7.5 kn) will be doubled if the separation between sides decreases from 33 m to 9 m. The reported distance between sides was 10–20 m. After the RIROIL 5 encounter this distance could have been increased to about 50 m, and the forces and moments had decreased at least by 50 per cent, if ESTRADEN had moved towards the left bank. Then WOLGASTERN had probably not increased her speed and ESTRADEN had succeeded in her overtaking operation.

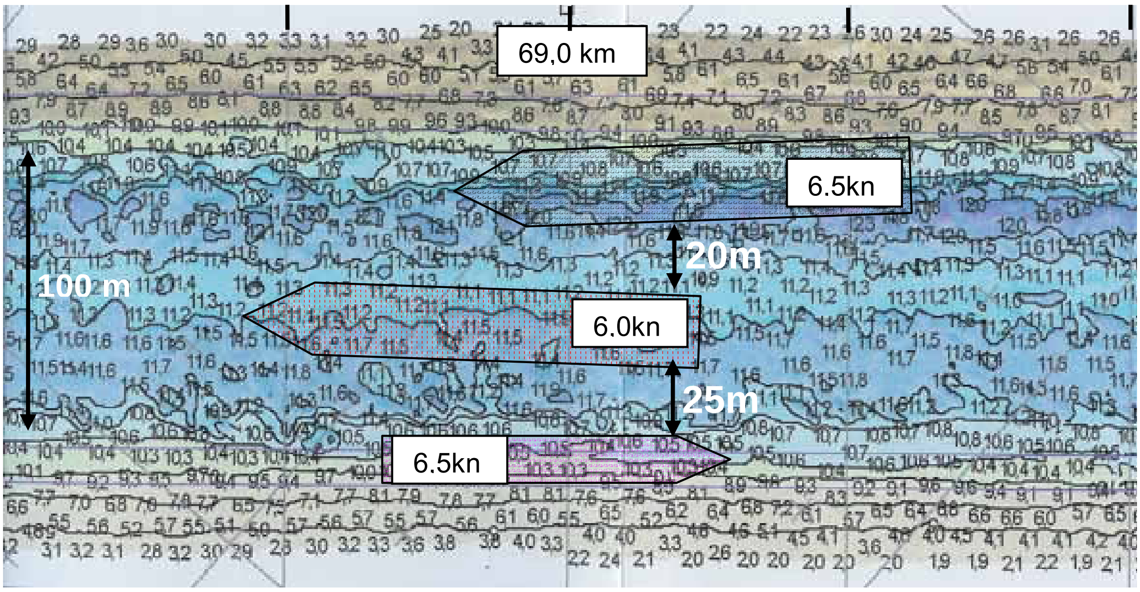



*Figure 6. Second encounter of three vessels. RIROIL 5 is encountering ESTRADEN and WOLGASTERN.*

### 2.8 Analysis of the meetings

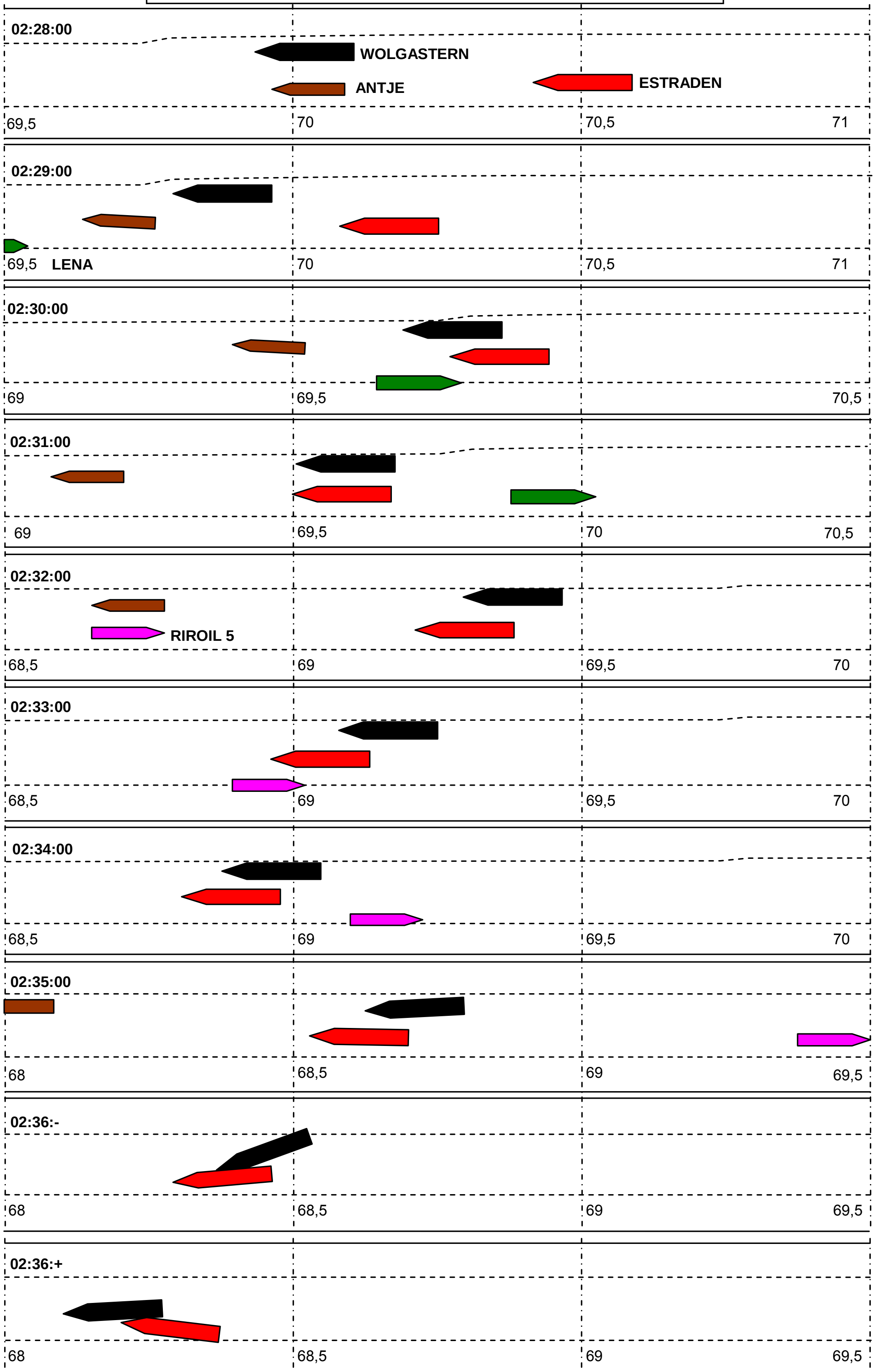
Figure 7 shows the positions of vessels at one minute's intervals up to the moment of collision. The headings of ESTRADEN and WOLGASTERN are shown in figure 8. WOLGASTERN had proceeded with a nearly constant speed of 4.5 knots until to 02:32. At that moment ESTRADEN was already at an overtaking position. Some minutes before the overtaking, ESTRADEN proceeded at maximum allowed speed, about 8 knots. She increased her speed at 02:22 in order to overtake WOLGASTERN inside the boundaries of the siding place. During the overtaking attempt, the speed of ESTRADEN diminished and equaled approximately the speed of WOLGASTERN.

TURCHESE overtook WOLGASTERN at 02:20–02:23, which is seen in the change of the latter's heading: in the beginning WOLGASTERN turned to the right and at the end to the left. The same trend is seen also during ANTJE's overtaking at 02:26–02:29. Probably, during these overtakings some maneuvering operations were realized, too. At 02:28 ANTJE was overtaking WOLGATERN and ESTRADEN was catching them up with her speed of 12 knots. After this overtaking, ANTJE was forced to quickly move to the right, because LENA was approaching. The reported difficulties of the maneuvering by the pilot and helmsman of WOLGASTERN might be caused by the propeller slipstream of ANTJE and the flow changes by approaching ESTRADEN and encountering LENA. This situation is quite complicated one. These difficulties continued because ESTRADEN could not move further to the left caused by encountering RIROIL 5. ESTRADEN tried to increase her speed, which increased the interaction forces and moments with WOLGASTERN. The latter tried to increase steering forces by increasing propeller revolutions, which increased the speed, too. However, the ships were so close to each other that the longitudinal forces had trapped them and ESTRADEN was not able to overtake. As a result, a vicious circle emerged: both vessels increased the speed, which increased the interaction forces and moments. At the end the steering moments were not strong enough and the vessels collided.

The accurate moment of the collision has not been possible to determinate. Therefore, in the two last small figures in Figure 7 seconds have not been shown.

Let's look more closely to the meeting situations.

Figure 7. Positions of ships and canal milestones 02:28–02:36




The next Figure 8 shows the deviation of heading of the vessels from the direction of the channel, which is at the straight part of the Audorf-Rade siding area 229 degrees.

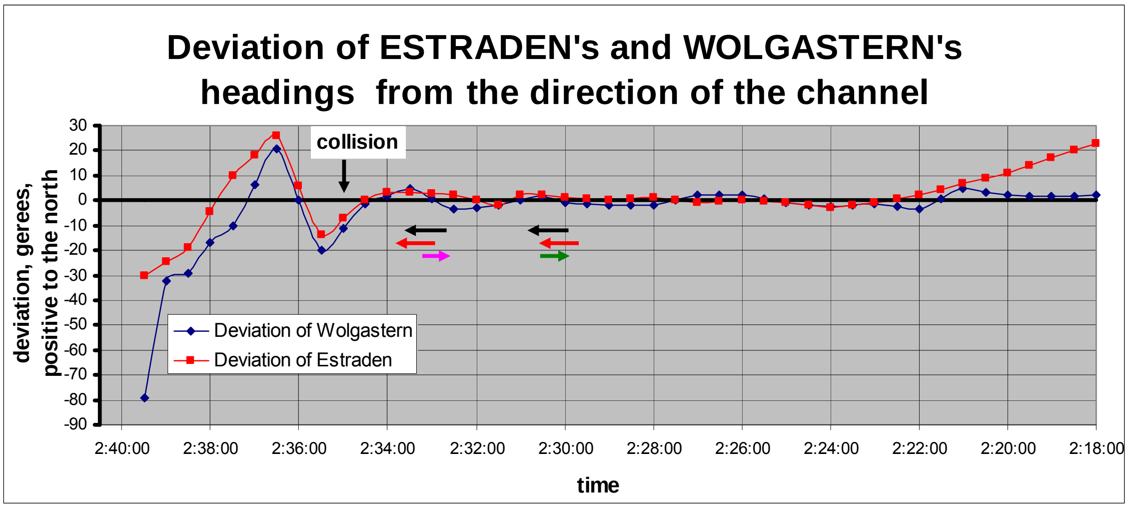



*Figure 8. Deviation of ESTRADEN's and WOLGASTERN's headings from the direction of the channel (229 degrees). Also the instances of encounters with LENA and RIROIL 5 are shown. ESTRADEN proceeded to the straight part of the channel at 02:23.*

### 2.8.1 Overtaking of WOLGASTERN by ESTRADEN

The forces and moments of interactions between two ships are shown in figures 9–11. The collision took place between vessels proceeding in the same direction. At first, ESTRADEN's speed was higher, but during the overtaking the speeds leveled. Therefore, figures show general, approximate trends of forces and moments in two situations: ships proceeding at the same speed (dotted curves) and with different speeds (unbroken curves). When the vessels are heading with different speeds, the mutual interaction forces and moments as a function of the stagger are shown for both vessels. When the vessels are heading with the same speed, the forces and moments affecting the WOLGASTERN are shown. Longitudinal force is either accelerating or decelerating, transverse force is attractive or repulsive. Turning moment tries to turn the bows in or out. These figures are mainly based on references 4, 5, 7 and 8. Results corresponding best with the parameters of this accident have been selected. In general, other model tests and calculated results mentioned in other references support the use of these curves. However, as stated earlier, these results give only a qualitative picture of the interactions. Any numerical results give only an idea about the possible order of magnitude, because none of model test results correspond exactly with this case.

Ship models of the most suitable model tests were nearly of equal size. The overtaken model was a little bit bigger. The length ratio was 1.19 (in this case 1.00 ($L_{OA}$) and 1.04 ($L_{PP}$), breadth ratio 1.07 (in this case also 1.07) and draft ratio 1.28 (in this case 1.53). The separation $Y_0/L_W$ was at equal speed 0.252, which would correspond is this case to 42 m. Then the distance between sides would be in our case 42–0.5x(27+25.2) = 15.9 m. This is quite near to the reported value of 10–20 m. In model tests at different speeds this separation is determined by the ratio $Y_0/B$, which had values of 1.3 and 2.2 corresponding to separation between sides of 9 m and 33.3 m. Based on overtaken vessel, in model tests the ratio h/T was at equal speeds 1.3 (in this case about 1.25) and at different speeds the model test results were shown at three h/T ratios including 1.2, which is same as in our case. Translating the model scale results in full scale as done in reference 4, the forces and moments for ESTRADEN and WOLGASTERN are at the speed of 6 knots as following: resistance change is tens of tons, transverse force some hundred tons and moment in the order of ten thousand ton meters. Results of an investigation, where a tanker (a little bit greater than WOLGASTERN) passed another tanker of similar size with a speed of 7 knots, gave for the values of the forces and moments affecting the overtaken tanker, 50 tons, 200 tons and 12000 ton meters, respectively.[32]

The curves in figures 9–11[33] do not include the bank effect. The right side of WOLGASTERN was near the north bank of the channel. During the encounter of LENA the breadth of the channel was greater than a little bit later, see figure 2. At the time of the collision ESTRADEN and WOLGASTERN were in channel having the bottom breadth of 100m and a variable depth of 10.5–12.5 m. The banks had a slope of about 13 degrees. References 4, 20, 21 and 23 include some information for corrections affected by similar bank. The effect of sloped banks is handled in chapter 2.9.

**The case of equal speeds.** ESTRADEN's attempt of overtaking proceeded quite quickly up to position D, figure 9a. This figure shows longitudinal forces acting on the respective vessel. If the speeds are too close and the separation is too small, overtaking will not succeed. ESTRADEN's resistance increased and WOLGASTERN's decreased.

Figure 10 shows transverse forces and figure 11 turning moments.

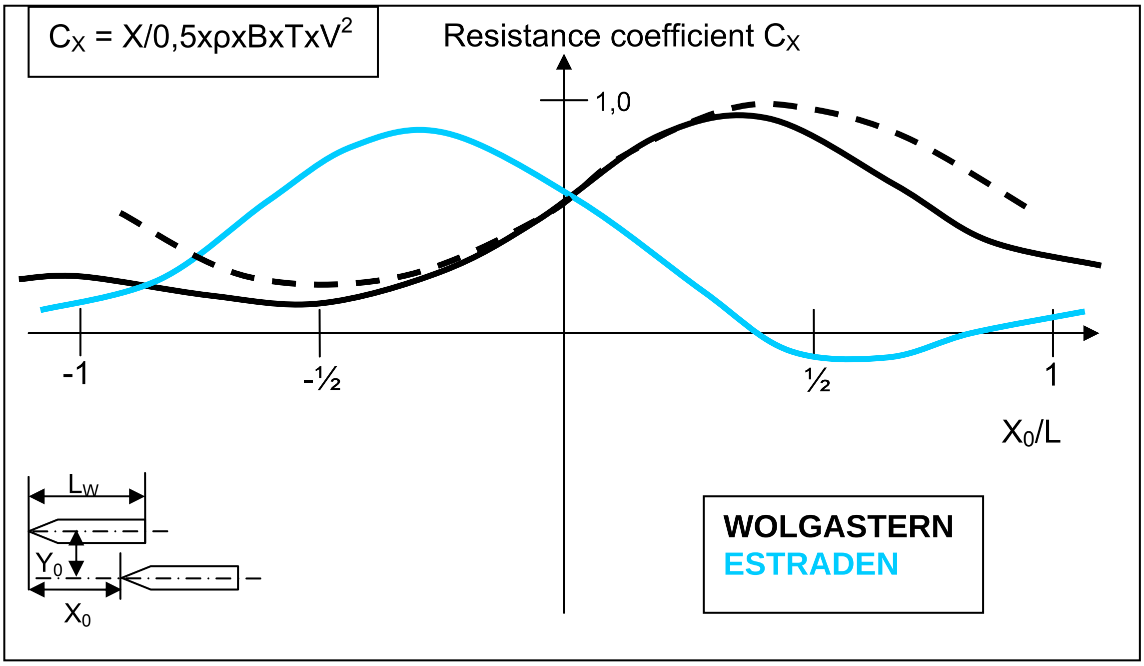



*Figure 9. Longitudinal (resistance) forces. Broken line: equal speed.*

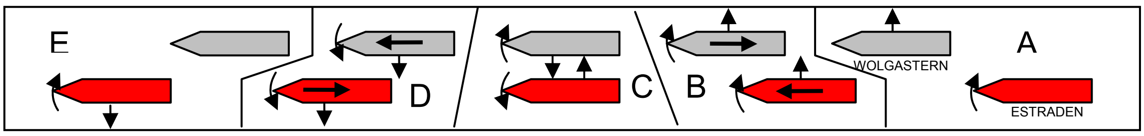



*Figure 9a. Principal scheme of forces and moments during overtaking.*

[32] Pinkster, J.A., Ruijter, M.N., The Influence of Passing Ships on Ships Moored in Restricted Waters, Offshore Technology Conference, 3-6 May 2004, Houston, Texas

[33] In the figures 9-11 L is without subscript because ESTRADEN's length nearly equals that of WOLGASTERN

Effectively, ships were trapped with each other. This phenomenon is one reason of the collision. Forces and moments acted then according to the dotted lines (only forces and moments acting on WOLGASTERN are shown in this situation).When ESTRADEN was a half ship length ahead of WOLGASTERN, the latter increased her speed in order to avoid collision by increasing steering forces. However, the ships had traveled too close each other already about four minutes and the interaction was too strong to be compensated by maneuvering.

As can be noticed, the transverse forces are attractive when the ships are side by side. At this instant the turning moments are quite small and they can be compensated by rudder moments. When ESTRADEN proceeded a little bit ahead, turning moments started to grow. They can increase so much, that they are greater than steering moments. ESTRADEN had two propellers and rudders and her steering moments could be higher than shown in the figure. Another fact complicating the maneuvering is that the turning moment depends strongly on the stagger. In position D WOLGASTERN had a tendency of turning her bow towards ESTRADEN. ESTRADEN had also similar tendency. As a result, the bow of WOLGASTERN hit amidships of ESTRADEN. Turning moments were greater than steering moments, and the collision was not possible to be avoided at that instant. Transverse forces tried to move both ships to the left. Additionally, bank effect was affecting WOLGASTERN, see chapter 2.9.

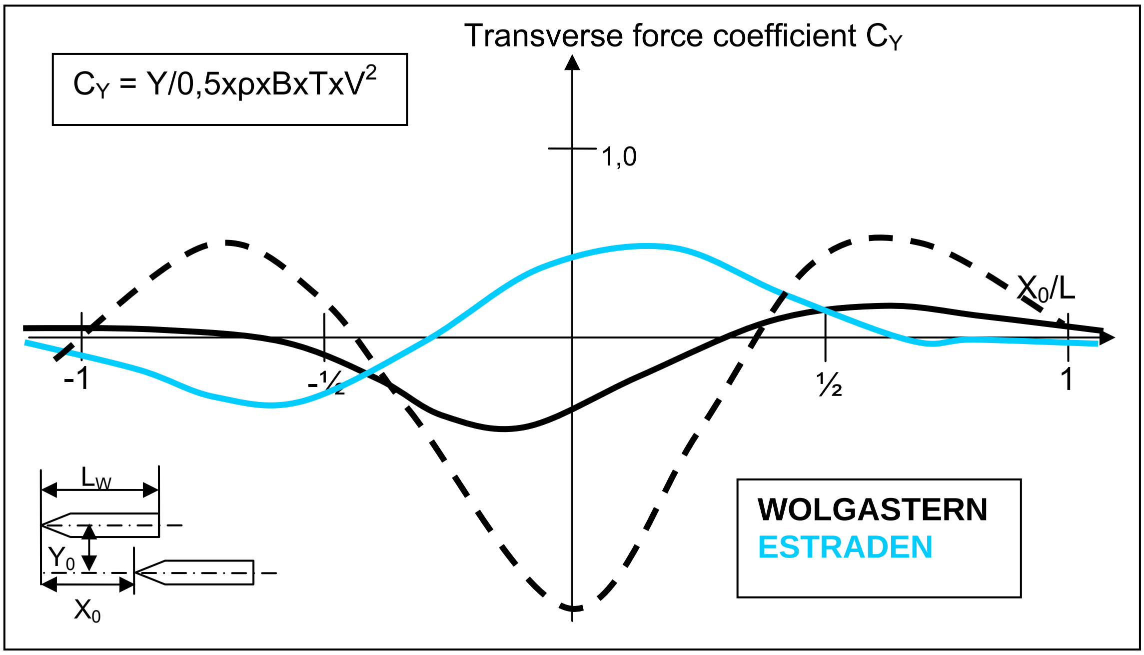



*Figure 10. Transverse forces. Broken line shows situation at equal speed.*

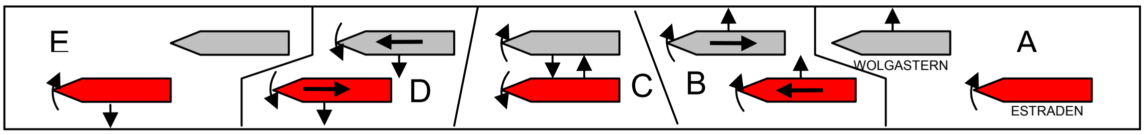



*Figure 9a. Repeated.*

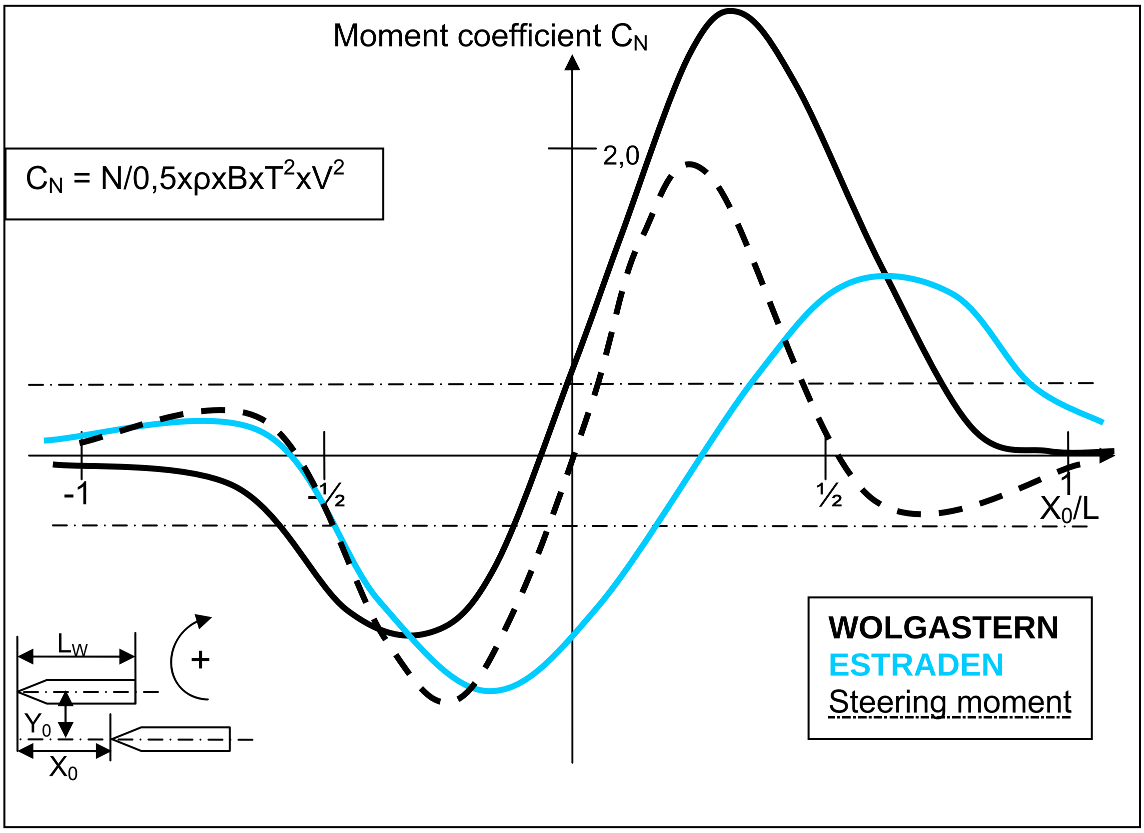



*Figure 11. Turning moments. Broken line shows situation at equal speed.*

### 2.8.2 Head on encounters

**LENA or RIROIL 5 encountering ESTRADEN and WOLGASTERN.** ESTRADEN met two times an encountering vessel: first LENA and later RIROIL 5. The following figures 12–14[34] show the interaction forces and moments acting on ESTRADEN in this situation, based on reference 4. The effects on the other vessel are opposite. Relative water depth and separation in the model tests deviated considerably from the actual. The separation between LENA or RIROIL 5 and ESTRADEN was 40–50m (distance between sides 20–25m, figures 2 and 6), not 33m as in model tests. The ratio h/T was for ESTRADEN about 2 and for LENA and RIROIL 5 about 1.5, when model test results are for the value 1.2. In general, however, these results correspond principally with the situation in Kiel Canal. According to the reference 5 the increase of water depth decreases forces and moments by two thirds and the increase of separation decreases them by 20 per cent. Both encounters lasted about one minute, and the interaction did not have time enough to fully develop. The opinion of investigators is that these encounters were not risky because of adequate water depth and moderate separation. However, dangerous situation developed because ESTRADEN was forced to proceed clearly too near to WOLGASTERN due to these encounters.

[34] Subscript "E" in these figures means ESTRADEN

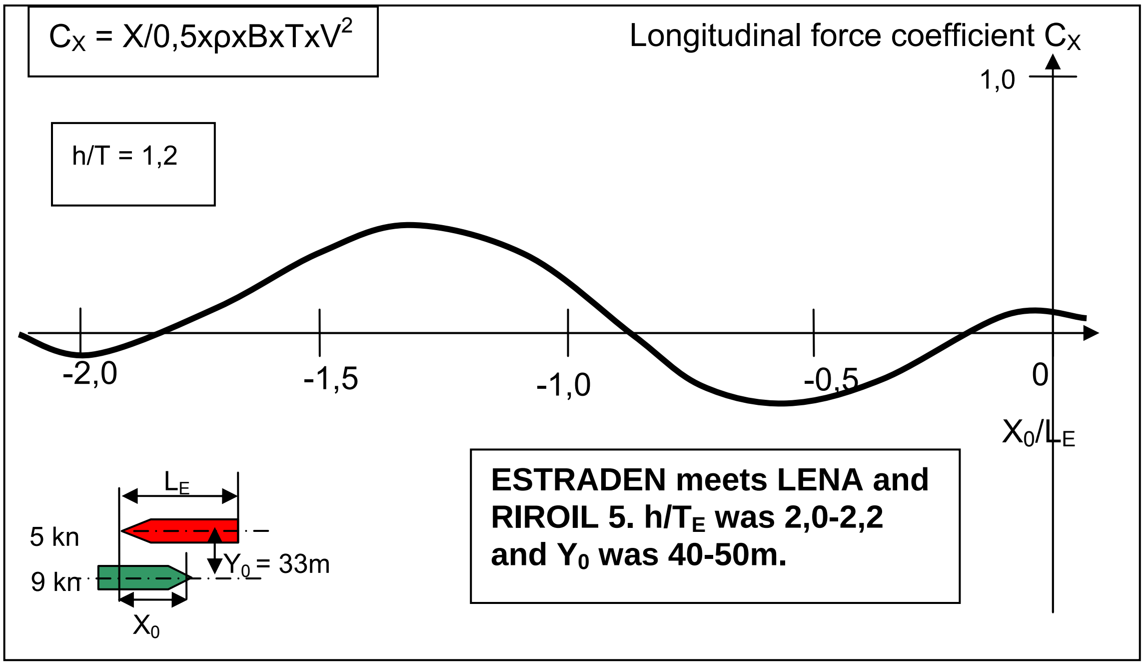



*Figure 12. Longitudinal forces at head on encounter acting on bigger and slower ship.*

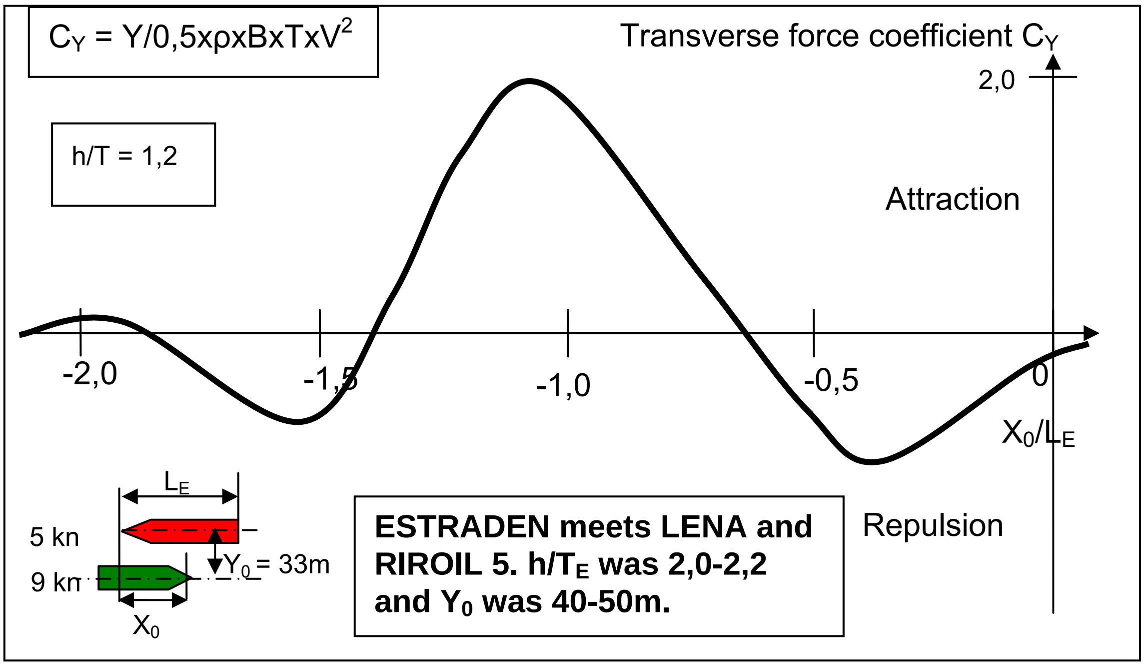



*Figure 13. Transverse forces at head on encounter acting on bigger and slower ship.*

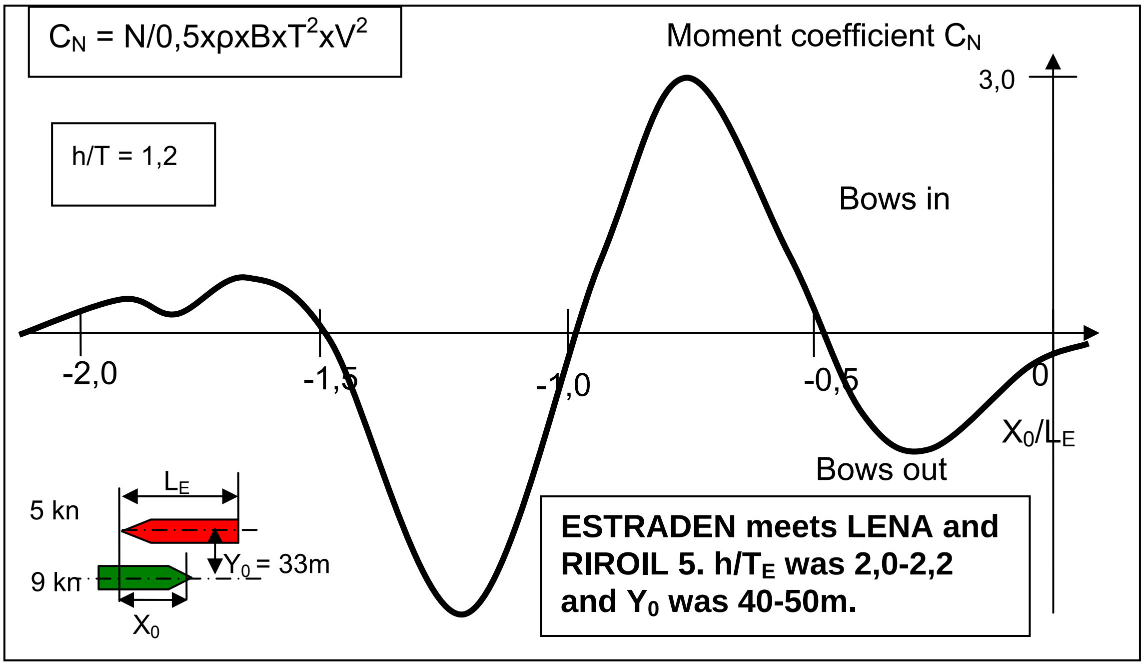



*Figure 14. Turning moments at head on encounter acting on bigger and slower ship.*

**Three ships side by side.** Reference 18 includes a calculated case where a vessel meets two vessels, which are proceeding at same speed, one behind the other. These two vessels travel with the same speed and the stagger is 1.5 times the ship length. The encountering vessel meets first the vessel which is further in transverse direction (bigger separation).Forces and moments are calculated only for the encountering vessel. For the other vessels results of two ship encounters are assumed valid. In our accident case the situation was different. Moreover, according to the reference 12, it might not be correct to calculate the total effect based on partial effects.

**Encounter of LENA, figure 2.** ESTRADEN was already over half a ship length side by side with WOLGASTERN and both vessels proceeded with nearly equal speed. They had a tendency to turn to the right. Approaching LENA enforced this tendency at first, but when she was aside with ESTRADEN, the tendency went to opposite direction. At the same time, LENA and ESTRADEN were attracted towards each other. Before LENA had passed ESTRADEN fully, these vessels tried to turn away from each other. Direct effect of LENA on WOLGASTERN is evaluated small, but it might have strengthened ESTRADEN's effect on WOLGASTERN.

**Encounter of RIROIL 5, figure 6.** At this instant ESTRADEN was about half a ship length ahead of WOLGASTERN and the speeds were still nearly equal. Now both vessels tried to turn weakly to the left. When RIROIL 5 started the encounter hers and ESTRADEN's bows tried to turn outwards. This decreased ESTRADEN's trend to turn away from WOLGASTERN. When the encounter continued, ESTRADEN tried once more to turn to the left and at last to the right. The direct effect of RIROIL 5 on WOLGASTERN is assumed small, too. Indirectly, via ESTRADEN, the effect might have been similar to the preceding encounter.

**Other encounters and overtakings.** LENA met ANTJE just after the latter had overtaken WOLGASTERN. ANTJE was forced to quickly move ahead of WOLGASTERN, which could affect negatively the steering of the latter. LENA had met TURCHESE at 02:28 and RIROIL

5 had met TURCHESE at 02:31 seemingly in a normal way thanks to adequate space. One minute later RIROIL 5 met ANTJE without any problems. It is normal in Kiel Canal that ships overtake and meet frequently. In this case, however, the vessels were in many occasions in close proximity, which might have generated disturbing flows and interactions affecting negatively the overtaking of WOLGASTERN by ESTRADEN.

### 2.9 Distance from the bank

WOLGASTERN was during the overtaking close to the sloping bank. Her right side was moving in shallower water than the left side. LENA and RIROIL 5 were in a similar situation on the southern side for a while. WOLGASTERN came from a broader water area to a narrower one during the encounter with LENA, figure 2. In this position the bow has most often a tendency to turn out and the bank attracts the ship. The effect is weaker than at vertical bank. In very shallow water the trends might change sign. But, model tests results in case of sloped banks have so far been very limited and therefore the evaluation methods of sloped banks on the ship maneuverability have not been available. References 13, 14, 16, 19–21 describe results of model tests for bank effect, but mostly in case of vertical or flooded bank. Reference 23 includes many new results of sloped banks in case of one ship moving in the canal. Based on these results a method for the evaluation of the forces and moments in a channel with sloped banks is in development in Belgium.[35]

### 2.10 Amount of ships side by side

The rules of Kiel Canal give limits for overtaking and encountering based on place and size (traffic group) of vessels. Outside the siding place overtaking of WOLGASTERN was prohibited. All overtakings and encounters studied in connection with this accident were carried out inside the limits of siding places. The rules have no clear statement concerning the encounter of three vessels. The opinion of the investigators is that the encounters having three vessels of the sizes in this case were risky. Blockage was about 3,3 (11,5x(100+11,5/tan13 = 1725 divided by 9x27+5,9x25,2+6,3x20,6 = 520), which is clearly below 15, which is the limit when the channel starts to be felt narrow (reference 7).

### 2.11 Maneuvering

This is strongly based on references 1 and 4. Rudder force depends on the flow velocity hitting the rudder. This velocity is strongly affected by propeller slipstream. The importance of the slipstream is attenuated in shallow water, where water moves with the ship. Then the flow hitting the rudder is coming mainly from the propeller. Therefore it is dangerous to stop the propeller in shallow water. The right way to enhance the steering is to increase the revolutions. So, the action by WOLGASTERN was principally right one, when she increased the speed. Only the total situation was already out of control because the vessels were too close to each other. It seems that the navigators of WOLGASTERN did not understand this.

WOLGASTERN increased her speed, which might have worsened her maneuvering characteristics. According to the reference 1 ship may have some critical h/T ratio. Around that value the maneuvering characteristics may change abruptly. At the model tests reported the boundary value of h/T was 1.4. WOLGASTERN proceeded in water of changing depth

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[35] For project description, see http://www.bankeffects.ugent.be/

(h/T varied between 1.15 and 1.40). It is possible that for WOLGASTERN h/T ratio was critical at some instants.

The ESTRADEN increased her speed in order to overtake the WOLGASTERN and to improve her maneuverability, too. At the same time the WOLGASTERN asked the ESTRADEN to increase the speed in order to complete the overtaking. It seems that nobody on these vessels realized that the speed increase increased strongly the interaction forces.

During encounters and overtakings of ships in confined waters the forces and moments change sign very quickly with the changing stagger. This fact creates strict demands for the maneuvering in confined waters: one should be able to anticipate the expected changes of forces and moments at the right time. Pilots and helmsmen should get additional theoretical schooling and training at simulators concerning navigation in confined waters.

WOLGASTERN proceeded near the northern side of the channel and on her right side the water depth was shallower. It may be assumed that this could have a braking effect and the ship would turn to the right towards the bank. In reference 4, figures 14 and 15, some results of model tests in a channel of Audorf-Rade –type are shown. WOLGASTERN's speed was about 5 knots resulting in Froude depth number of 0,23. The moment acting on WOLGASTERN tries to turn the ship outwards and it is about one fifth of the moment in overtaking situation. The effect of overtaking ESTRADEN was opposite as seen from figure 10. The net effect was to turn WOLGASTERN to the right as reported. This trend was successfully handled by turning the rudder to the port. When ESTRADEN was half a ship length ahead, the turning moment changed sign and it was already so big that the rudder forces were inadequate to stop the turning of the WOLGASTERN to the left towards ESTRADEN.

### 2.12 Effect of propulsion machinery

Reference 1 handles quite extensively the effect of propeller bias in shallow water. ESTRADEN had two propellers and rudders and there was no bias. WOLGASTERN's presumably right handed propeller tried to turn the ship to port, which had to be compensated with the rudder. In deep water this turning moment of the propeller increases with the increasing revolutions. In shallow water the tendency is the same, but there might exist a combination of speed and h/T ratio changing the direction of the moment (or it approaches zero) to the surprise of the helmsman.

## 3 Conclusions

Based on the reasoning in the preceding chapters the investigators have come to the following conclusions:

a. ESTRADEN and WOLGASTERN were too close to each other for all too long time
b. ESTRADEN was forced to be close to WOLGASTERN due to the encountering vessels
c. The WOLGASTERN had to steer a long period too close to the canal bank
d. ESTRADEN did not move to the left after the encounter of RIROIL 5

e. The speeds of ESTRADEN and WOLGASTERN exceeded the limits stated in the Kiel Canal rules
f. Due to the high speeds maneuvering difficulties increased

Due to high speeds and close proximity in shallow water interaction forces exceeded maneuvering forces and WOLGASTERN collided with ESTRADEN.

A general conclusion based on this literature study is that no good method for the calculation of forces and moments is available for sloped banks. That is a remarkable, because this type of bank is very common.

In addition to the very theoretical and mathematical reports directed to fellow researchers a general overview concerning maneuvering in restricted waters would be very useful. According to the opinion of the accident investigators reference 4 by Dr. Dand is he best of this kind so far.

## 4 References

From literature study the following helpful references have been found. They are handling interactions in deep and shallow waters between two or more vessels including navigation in channels and also the bank effect. Results corresponding exactly to this case were not found, but many similar. At the classical model test by Dand in references 1–5 the models were forced to a straight course. Therefore no steering effects are included, nor the effects of small heading changes in real situation. Some of the most recent calculations try to include these effects in various ways. One example is reference 15, but the resistance was held constant.

It seems that the results of Dand are most suitable for this case. In fact, many authors of these references compare Dand's results with their calculations. Most often a good correlation has been achieved. Full scale results are very scarce and therefore the verification of calculations or model tests is lacking so far.

1. Dand, I.W., (NMI R6), Hydrodynamic Aspects of Shallow Water Collisions, November 1976.

2. Dand, I.W., (NMI R7), Some aspects of Tug-Ship Interaction, January 1977.

3. Dand, I.W., (NMI R8), Ship-Ship Interaction in Shallow Water, March 1977

4. Dand, I.W., (NMI R38), The Physical Causes of Interaction and its Effects, April 1978

5. Dand, I.W., (NMI R108), Some measurements of interaction between ship models passing on parallel courses, August 1981.

   These reports handle various model tests, their results and theoretical matters. Parameters are: vessel size and speed, stagger and separation, relative water depth. Also propeller bias is discussed. NMI R38 includes a good general description of the theory without complicated mathematics. (NMI = National Maritime Institute).

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 changing the stagger and separation. In full scale the speed was 10–20 knots. The speeds of the models were equal. This does not correspond to ESTRADEN-WOLGASTERN-case, but the general trend is the same.

7. Müller, E, Manövrieren bei Fahrwasserbeschränkung. A ship is overtaking another in the channel. Results are shown at h/T equaling 2,0 and with two separations $Y_0/L$ = 0,227 and 0,454. The smaller separation corresponds in this accident to 10 m distance between the sides. When the distance is doubled, the forces and moments are decreased by 50 per cent. However, the speeds are about 50 per cent higher than in our case. General trends are similar to the Dand's results.

8. P.Kaplan and K Sankaranarayanan, Hydrodynamic interaction of ships in shallow channels, including effects of asymmetry.

   Theoretical results are compared with model test results. Two Panamax bulker models were encountering with full scale speed of 7 knots, h/T =1,15 and 1,225, $Y_0/B$ was 1,25–2,0. One run was carried out with the stationary other ship (h/T = 1,225, $Y_0/B$=2,0). This gives some information to our encounter situations, results are very similar to Dand's ones.

9. Katsuro Kijima, Manoeuvrability of ship in confined water.

   This report describes theory and model tests. A bigger ship overtook a smaller one (L = 160 m, B = 26,84 m and L = 100 m, B = 16,77 m), in a channel with a breadth of 200 m. Speeds were 4 and 5 knots, h/T = 1,2 and 1,92. The separation varied between 30–100 m (corresponding distance between sides was 8–78 m) and $Y_0/B_2$ varied between 1,8–6). With the steering simulated in a certain way[36], the ship was tried to be held on a straight course. Result: the overtaken smaller vessel turned at the end to the aft part or amidships of the overtaking vessel. This simulation gave for a safe distance between sides 50–60 m, which corresponds to $Y_0/B_1$ = 2 and $Y_0/B_2$ = 3,3. These results can not be applied to our case, because of the big differences in ship sizes. Moreover, the channel walls were vertical.

   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. Used for squat evaluation.

11. Hamn-Ching Chen, Woei-Min Lin, Daniel A. Liut, Wie-Yuan Hwang, Validation and Application of Chimera RANS Method for Ship-Ship Interactions in Shallow Water and Restricted Waterway, 24th Symposium on Naval Hydrodynamics, Fukuoka, Japan, 8–13 July 2002

12. Hamn-Ching Chen, Woei-Min Lin, Daniel A. Liut, Wie-Yuan Hwang, An advanced viscous flow computation method for ship-ship dynamic interactions in shallow and restricted waterway, International Conference on Marine Simulation and Ship Maneuverability, MARSIM '03, 25th–28th August 2003, Kanazawa, Japan.

    References 11 and 12 compare results calculated by CFD to the model test results of Dand at head on encounter and overtaking situations plus passing a stationary ship. The authors conclude that the correlation is quite good (computations and model test did not correspond to each other in every aspect). They calculated also a case where two sips passed third ship which was moored at a quay. The conclusion was that one should not evaluate interactions of several ships by summing up

[36] Rudder angle $\delta = \delta_0 + 5(\psi-\psi_0) + 5r'$, where ψ is the heading and r' is angular velocity. Index 0 is initial value.

interactions of individual ships.

13. Marc Vantorre, Guillaume Delefortrie, Katrien Eloot, Erik Laforce, Experimental investigation of ship-bank interaction forces, same conference as the preceding reference. By model tests and mathematical model the effect of the distance from vertical bank was investigated using three models.

14. Vantorre, M., Laforce, E., Verzhbitskaya, E., Model test based formulations of ship-ship interaction forces for simulation purposes, IMSF 2001. Describes the results of preceding reference. Results are not applicable in this case because of high speeds. The stagger is defined not the same way as by Dand (or in this accident investigation). The stagger is defined by Dand as the distance between bows. The authors define this distance between the midpoints of the ships. Therefore one should subtract 1,0 from the parameter $\xi$ used in this reference at encountering situation. Also the directions of forces and moments should be checked. Taking these adjustments into consideration the results correspond to the Dand's ones.

15. Lee, C., K. and Kijima, K., On the Safe Navigation Considering the Interaction Forces Between Ships in Confined Water, same conference as the preceding one. Safe overtaking separations have been calculated for several different ships. Parameters are: relative speed, water depth, wind, steering angle and steering constants in wide shallow water. Results: the separation could be as low as 0,3xL (possibly below that), if rudder angle bigger than 15 degrees are applied. If the relative speed decreases, the safe separation grows.

16. Li, D.Q., Ottoson, P. and Trägårdh, P., Prediction of Bank Effects by Model Tests and Mathematical Models, same conference as the preceding one. Model test program included tests with sloped bank channel. Three h/T values were used (1,1, 1,2 ja 2,5) of which two first are applicable in our case for WOLGASTERN. Ropax model was used in the tests with sloped banks. The load of propeller was noticed to have a directly proportional effect on the turning moment (bow out) and on the attractive force between bank and ship.

17. Yasukawa, H., Simulation of Ship Collision Caused by Hydrodynamic Interaction between Ships, same conference as the preceding one. The author developed the equations of motion of two ships in close proximity including steering for shallow waters. Equations have been solved in case of two equal ships, h/T = 1,2, distance between sides was 0,25xB (in our case this would correspond to 8m). So, the ships are very close to each other. Froude number was 0,1 and the ships proceeded with the same speed. (Consequently, speed was 7,6 knots and Froude depth number 0,465). This corresponds roughly to the end situation of our case. A second calculated situation was an overtaking with a speed ratio of 2,0.

18. Varyani, K.S., McGregor, R.C., Wold, P., Identification of Trends in Extremes of Sway-Yaw Interference for several Ships Meeting in Restricted Waters, Schifftechnik Bd.49-2002/Ship Technology Research Vol. 49-2002. Theoretically encounter situations of two and three vessels have been calculated and the results have been compared to available model test results. Some results are useful for the encounters of ESTRADEN and WOLGASTERN by LENA and RIROIL 5.

19. Jianbo Hua, Towards a mixed solution for ship manoeuvre simulation in restricted water, SSPA Research Report 130, 2005. This includes a description of research work carried out in SSPA during some years. Moreover, it is a good overview about

the state of the art of numerical methods concerning interactions in restricted waters.

20. Da-Qing Li, Experiments on Bank Effects under Extreme Conditions, SSPA Research Report 113, 2000.

21. Da-Qing Li, Development of Mathematical models for Predicting Bank Effects, SSPA Research Report 114, 2000. These two SSPA reports describe model test of bank effect research and they give data for the evaluation of sway and yaw coefficients at some situations. The only sloped bank tested had an inclination of 30 degrees, which is greater than in our case (13 degrees).

22. Gronarz, A., Ship-Ship Interaction: Overtaking and Encountering of Inland Vessels on Shallow Water, MARSIM 2006, 25–30 June 2006, The Netherlands. Description of model tests and their results. Final model tests were carried out with self-propelled models and with/without autopilot. Also time histories of various parameters were measured. Conclusions stated that propulsion has an effect on navigation in shallow water. With autopilot it was possible to avoid collision down to a smaller separation than without it. Overtaking and encountering situations can be treated in same way with the help of suitable transformation. Moreover, the deformation of the water surface should be taken into account.

23. E. Lataire, M. Vantorre, E. Laforce, K. Eloot, G. Delafortrie, Navigation in Confined Waters: Influence of Bank Characteristics on Ship-Bank Interaction, 2nd International Conference on Marine Research and Transportation, 28–30 June 2007, Ischia Naples, Italy. The home page of the research project has the following address http://www.bankeffects.ugent.be.

    This report describes results of model tests carried out in the University of Ghent in Belgium in order to develop a method for the evaluation of the bank effect. Test series consisted of 11,000 test runs. One of the canal profiles is quite similar to the bank slope of the Kiel Canal. The transversal position of the vessel in the channel is defined in a new way. The measurements were carried out with one model moving in the canal. Three different models were used. One may conclude based on these results that WOLGASTERN was so near to the bank that a remarkable interaction effect developed.

## Appendix 2. Accident statistics

**Damages Kiel-Canal (eastern part) 1996 - 2006**

| Kind of Damages : | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Damages with Lock Facilities | 13 | 11 | 5 | 7 | 3 | 7 | 11 | 7 | 16 | 9 | 10 |
| Collisions Ship to Ship inside the Locks | 2 | 0 | 3 | 5 | 4 | 1 | 3 | 3 | 3 | 3 | 4 |
| Collisions Ship to Ship on the Kiel-Canal | 6 | 2 | 2 | 2 | 7 | 4 | 0 | 3 | 5 | 6 | 4 |
| Damages on the Kiel-Canal with Facilities | 1 | 7 | 3 | 1 | 1 | 6 | 5 | 0 | 1 | 1 | 4 |
| Damages on the Kiel-Canal with Dolphins (Siding Areas) | 3 | 3 | 2 | 2 | 3 | 0 | 3 | 4 | 4 | 6 | 14 |
| Grounding with Damage | 1 | 3 | 2 | 0 | 1 | 4 | 3 | 0 | 0 | 2 | 1 |
| Grounding without Damage | 21 | 17 | 11 | 13 | 7 | 11 | 12 | 10 | 3 | 17 | 20 |
| Damages with Pollution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Number of Damages: | 47 | 43 | 28 | 30 | 26 | 33 | 37 | 27 | 32 | 44 | 57 |
| caused by technical failure : | 6 | 9 | 8 | 4 | 6 | 8 | 5 | 3 | 6 | 11 | 15 |

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**To:** Accident Investigation Board
Att. Mr. Martii Heikkilä

**Fax:** **00358 9 1606 7811**

23 November 2007

**Collision MV ESTRADEN / MT WOLGASTERN - Kiel Canal 02.02.2006**
**Your Ref.: C 1/2006 M**

Dear Mr. Heikkilä,

We are representing Rigel Schiffahrts GmbH as well as the master of MT WOLGASTERN in this matter. Your request for comments to the draft collision report 452/5M was passed on to us for response.

Without accepting the report in its entirety, we should just like one correction being made at the bottom of page 9 of the draft inasmuch as WOLGASTERN had not "requested ... that also the ESTRADEN should overtake her". The corresponding VHF call from the pilot of WOLGASTERN was a consent to an overtaking and by no means a request for taking any particular action at any particular time. The decision on how and where to overtake and to check if this can actually take place safely was, as usual, solely left in the hands of pilot and officer on watch of MV ESTRADEN.

Yours sincerely,

(Jan Wölper)