APPENDIX 1 TRADEN'S VOYAGE AND WEATHER DATA.

This appendix includes a detailed description of the incident and the events of preceeding days according to ship's log book, weather forecasts, and output of the Navi-Sailor navigation program. Finnish time, i.e. UTC+2, is used in the log book.

The Navi-Sailor navigation program, which was used on the TRADEN, was set to Finnish time. The ship was on Portugese coast at longitude 10° west. The local time was thus UTC-1. The log book registered by the Navi-Sailor wrote the time (0200E), i.e. UTC+2. Some confusion is caused by the fact that the *.trk -file indicating the passed journey wrote the time as UTC. The times are corrected in the tables.

The TRADEN passed Lisbon at noon on October 17, 2001, and turned towards north. The cape of Cabo Razo was passed at a distance of about 12 nautical miles.

Table 1. TRADEN's voyage on Wednesday 17 of October 2001, according to pages 230–231 of the log book.

UTC+2	Position	Heading and speed	Weather	
1600	39° 43.3' N 009° 45.0' W	HDG= 355°, 14.6 knots	SE 4 bf	
2000	41° 41.6' N 009° 51.0' W	HDG= 330°, 13.9 knots	SSW 4 bf	The ship started to roll in high swells. TRADEN turned to north-west.
2400	41° 22.04' N 010° 32.3' W	HDG= 319°, 12.8 knots	WSW 5 bf	The ship had to be steered according to waves. The ship turned towards left.

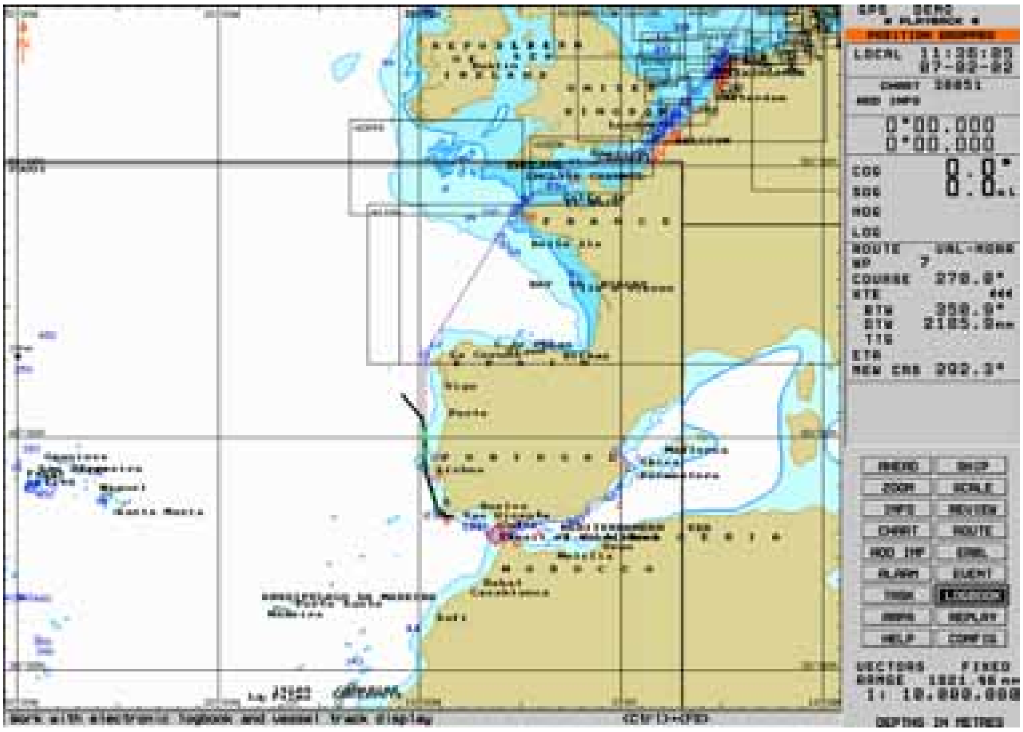
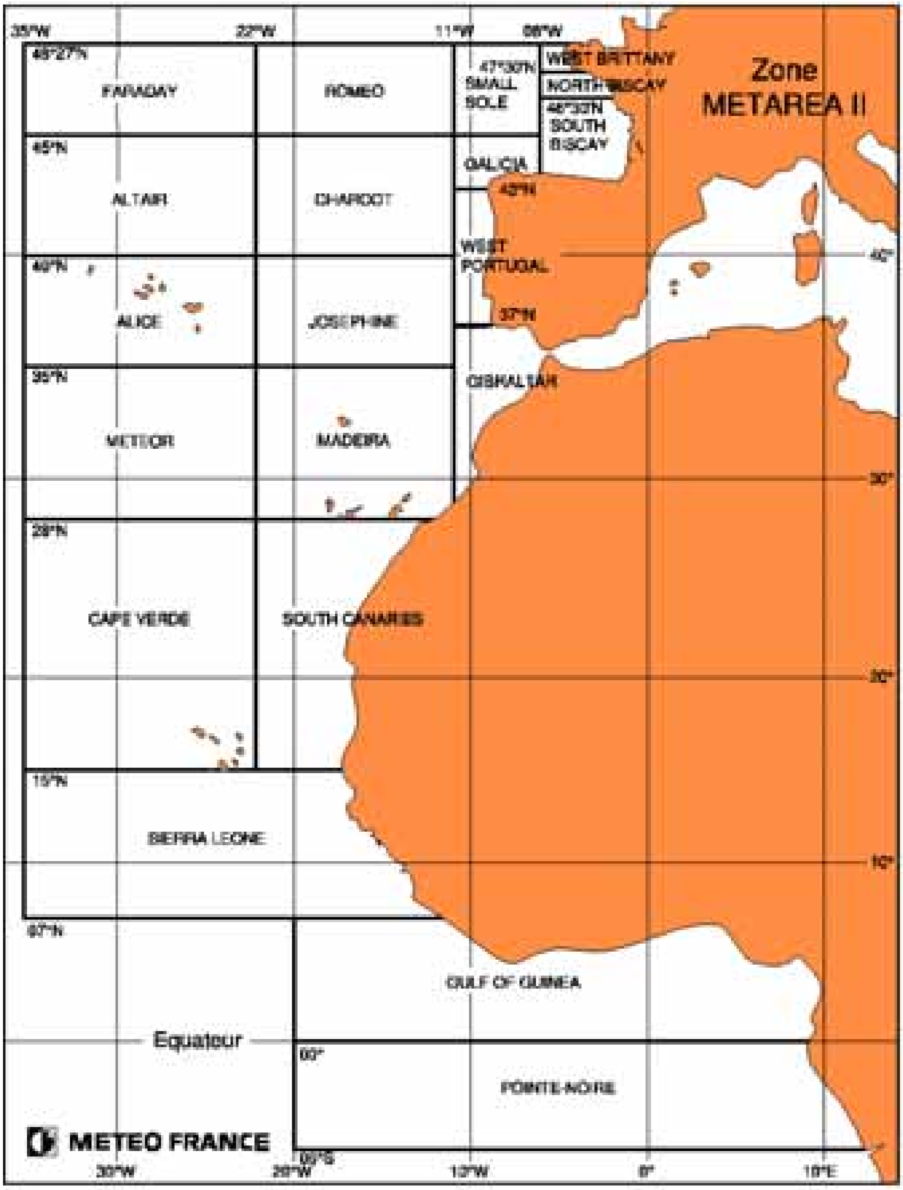


Figure 1. TRADEN's route on October 17, 2001 *(Navi-Sailor)*

Appendix 1/2

Weather forecasts received by the TRADEN were given for the following forecast areas, which are shown in Figure 2.



Zones couvertes par le bulletin diffusé par la France.

Figure 2. Weather forecast areas.

According to general synopsis of the weather forecast for the area ”West Portugal” on October 17, 2001, the weather was ”Complex low 982 hPa 47N18W by 17/00hUTC, deepening and moving North, 962 hPa 53N18W by 17/18UTC. Numerous thunder-squalls with severe gusts.”

Table 2. Weather forecast for the area "West Portugal" (except in far north) October 17, 2001.

Hour UTC	WIND		TOTAL SEA	Primary SWELL		
	Dd	ff (knots)	H1/3 (m)	Dd	H1/3 (m)	T(s)
00	SSE to SSW	15 to 30 from south to north of area and gusts	2.5 to 4.5 from south to north	NW	1.5	14
06	SSE to SSW	20 to 30 from south to north and gusts	2 to 5 from south to north	NW	2	12
12	SW	15 to 30 from south to north and gusts	2.4 to 4.6 from south to north	WNW	2	11
18	SW to W	15 to 25 from south to north and gusts	2.4 to 4.8 from south to north	WNW	2.5	12

WIND: ff is the mean wind speed in knots (average wind speed over a 10 minutes period, at 10 meters)
SEA: H1/3 is the mean of the third highest waves in m (characteristic high).
Primary SWELL: the more energetic swell in an area,
T is the period in seconds.

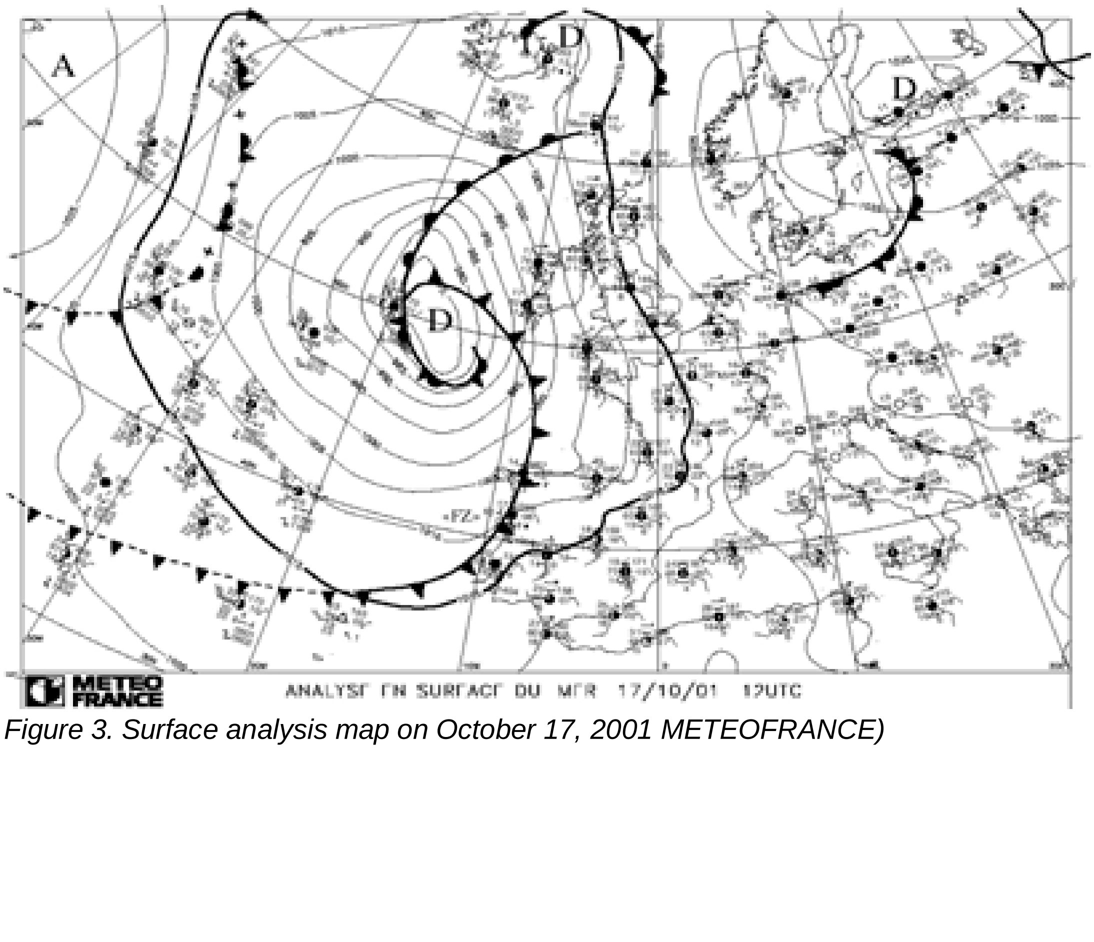


Figure 3. Surface analysis map on October 17, 2001 METEOFRANCE)

Appendix 1/4

Table 3. TRADEN's voyage on Thursday 18 of October 2001, according to pages 230–233 of the log book.

UTC+2	Position	Heading and speed	Weather	
0400	42° 05.5' N 011° 14.3' W	HDG= 320°, 13.8 knots	WSW 5	Varying headings were used according to waves. From west high swells, which increased during the night.
0855	42°34.925N 11°57.870W	HDG=004.9 11.0 knots		The ship turns rapidly to starboard.
0856	42°34.760N 11°57.976W	HDG= 038°, 11.5 knots		Steered in following seas appr. 060°. Heavy rolling.
0928	42°38.377N 11°48.505W	HDG= 003.8° LOG 11.2 knots		Rapid turn to port.
0929	42°38.505N 11°48.579W	HDG= 311.3° LOG 9.6 knots		New main direction appr. 315° relative to seafloor.
1109	42°52.302N 12°08.277W	HDG= 315.3° LOG 12.9 knots		
1128	42°55.483N 12°11.648W	HDG= 323.8° LOG 13.0 knots		Main direction appr. 336° relative to seafloor.
1200	43°00.998N 12°17.146W	HDG= 321.3° LOG 13.7 knots	SW 5-6	Steered according to waves.
1600	43°44.650N 12°53.401W	HDG= 317.2° LOG 12.0 knots	SW 6-7	Varying directions according to seaway.
1620	43°47.456N 12°56.678W	HDG= 281.2° LOG 5.0 knots		Drift was 26° to starboard.
1620 - 1630	Dominating course 240°-260°. Very high seas.		W-SW 8-10	Ship turned against wind and high seas – ship rolls heavily (appr. 20°-25°).
1630 - 1650	Ship steered with varying courses 240°-260°.			Ship rolls still heavily from one side to another, **the second tier of containers from the bow on weather deck (WD) has become partly loose and moves**.
1634	43°47.719N 12°57.921W	HDG= 224.0° LOG 3.4 knots		Turn port towards wind. Drift was 15°. Container had obviously just become loose.
1637	43°47.542N 12°58.149W	HDG= 212.1° LOG 6.2 knots		Steered against wind for two minutes. Containers obviously secured because speed has been increased.
1640	43°47.202N 12°59.289W	HDG= 243.5° LOG 8.6 knots		Main direction relative to seafloor is approximately 248°. Drift is approximately 5°.
2000	43°33.423N 13°39.972W	HDG= 255.8° LOG 10.7 knots	W-SW 9-10	According to log book head seas throughout the watch.
2026	43°32.055N 13°46.337W	HDG= 269.5° LOG 10.6 knots		Turned approximately to west.
2200	43°33.316N 14°07.303W	HDG= 283.4° LOG 10.3 knots		Confused seas. Head waves according to master's advice.
2400	43°33.753N 14°34.562W	HDG= 271.4° LOG 10.2 knots	W 8-9	Confused seas. Head waves according to master's advice.

In the log book the situation is described on page 287 as follows:

On October 18, 2001, at sea.

At 1620 the ship is turned against the sea, heeling angles ≈ 20° from one side to another. Announcement from the deck: four containers (20') of the second tier on port side (from the bow) on the weather deck are moving sideways and are partly loose from chain securings. The entire crew tries to prevent container movements by adding lashing chains to all containers on the deck. Trailer horses among others were placed between containers and bulwark (approximately 1 m).

At 1700 containers of the third tier on the weather deck start to move sideways. Large heeling angles and slamming impacts continue. Lashing of containers is continued throughout the night.

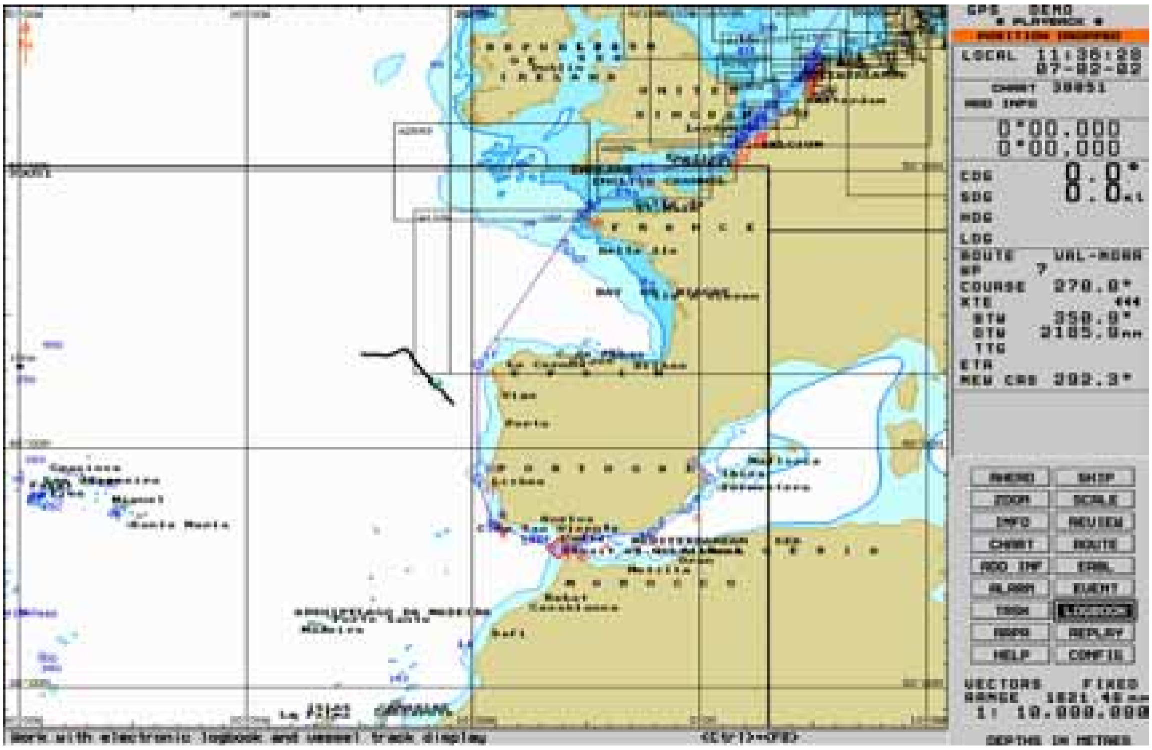


Figure 4. TRADEN's route on October 18, 2001. *(Navi-Sailor)*

Appendix 1/6

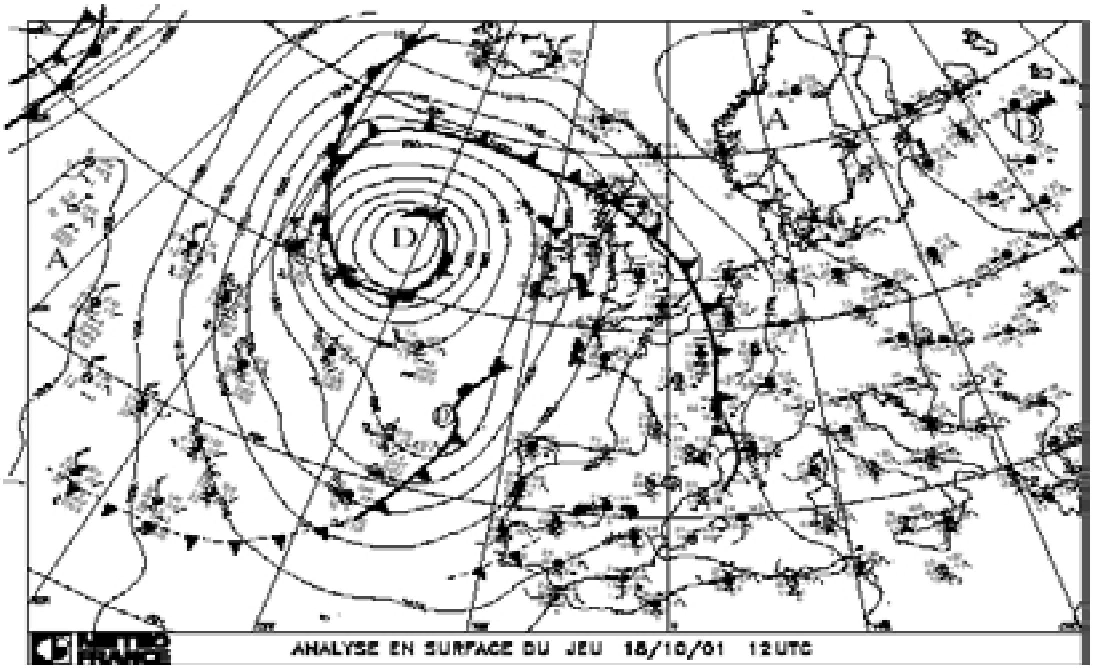


Figure 5. Surface analysis map for 1200 UTC on October 18, 2001 (METEOFRANCE)

General synopsis of the weather forecast for the area “Charcot”:

Low 965 hPa by 53N20W at 00h UTC, then 53N21W at 12h UTC. Frontal trough along 14W, north of 35N by 18/12UTC, with new low 989 hPa around 44N14W. Numerous thundersqualls with severe gusts.

Table 4. Weather forecast for the area ”Charcot” on October 18, 2001.

Hour UTC	WIND		TOTAL SEA	Primary SWELL		
	Dd	ff (knots)	H1/3 (m)	dd	H1/3 (m)	T(s)
00	SW to W	20 to 30 and gusts	4.2 to 6 from south to north	WNW	3.5	12
06	SSE to SSW	20 to 30 and gusts	4.2 to 5.1 from south to north, but 3.6 in far south-east of area	WNW	3	12
12	In W: W to NW. In E: S to SSW	In W: 20 to 30 and gusts. In E: 25 to 30 and gusts	4 to 4.7	WNW	3	11
18	SW to NW	20 to 30 and gusts	4 to 5	SSW	3	10

Table 5. TRADEN's voyage on Friday 19 of October 2001, from 0000 to 1200 according to pages 232–233 of the log book.

UTC+2	Position	Heading and speed	Weather	
0043	43°34.076N 14°42.037W	HDG= 282.8° LOG 6.7 knots		Turned slightly starboard. Speed decreases.
0200	43°35.959N 14°54.174W	HDG= 281.0 LOG 6.9 knots	W-SW 8-11	Ship heels occasionally heavily 20°-20°. Slamming impacts. Crew is lashing cargo on WD and MD decks. Heading was mainly between 270° and 280°. Wind direction and speed varies..
0500	43°39.536N 15°20.028W	HDG= 276.3 LOG 6.2 knots	W-SW	Lashing of cargo is continued on the weather deck (WD). Lashing of cargo is completed on the main deck (MD).
0800	43°44.546N 15°44.722W	HDG= 276.5 LOG 6.6 knots		
1000	43°47.353N 16°02.468W	HDG= 286.0 LOG 6.5 knots		Cargo lashing continued.
1100	43°49.373N 16°11.519W	HDG= 287.0 LOG 7.5 knots	N-NW	Ship's situation announced to FINISTERRE RADIO. **Agreed to be 'stand by' 2182 kHz.** According to maritime declaration the shipping company was informed already earlier with Inmarsat – C, i.e. telex.
1200	43°51.120N 16°20.599W	HDG= 289.0 LOG 7.5 knots		
1415	43°56.795N 16°42.125W	HDG= 281.8 LOG 6.3 knots		**Announcement of second officer that the aftmost train on the main deck (MD) has fallen down from the trestle and broken chain lashings. Containers on the weather deck became loose again.**

In the log book the situation is described on page 287 as follows:

On October 19,l 2001 at sea.

At 0800 movement of all containers has been eliminated with hoisting wire ropes attached to strong ship structures. Chains are added to containers on the main deck. Cargo on the main deck has remained in lashings to the deck.

At 1414 an announcement from the main deck: The aftmost railway carriage has fallen from the aftmost trestle and broken the container lashings on the bow side.

At 1436 part of containers on the main deck are moving. Ship is heeled about 10°-15° to starboard to minimise loose cargo movement on the starboard side. Noise of moving cargo is still heard from the cargo hold. Lashings on the weather deck are improved, ship's crew is not any more allowed to go to the main deck for securing.

Table 6. TRADEN's voyage between 1415 and 2400 on Friday October 19, 2001, according to pages 234–235 of the log book.

UTC+2	Position	Heading and speed	Weather	
1430	43°56.964N 16°44.884W	HDG= 277.6 LOG 9.2 knots	SW	Ship rolls heavily to both sides. The second officer announces from the main deck that a part of containers is moving. He is proposed to leave the main deck. Heel to starboard increases.
1500	43°57.869N 16°50.610W	HDG= 284.8 LOG 8.7 knots	NW 8-11	Steered towards waves to find a heading, which could diminish violent ship motions. **The master's preliminary announcement about possible abandon of the ship.**
1510	43°58.283N 16°52.515W	HDG= 285.6 LOG 8.5 knots		**Sent VHF DSC distress alert.** Ms DOLE AFRICA acknowledged the alert at 13 miles' distance and announced to change course towards the TRADEN. ETA was 2-3 hours.
1520	43°58.733N 16°54.349W	HDG= 285.3 LOG 9.4 knots		**Sent MF and HF DSC distress alerts**
1550	44°00.089N 16°59.511W	HDG= 294.0 LOG 7.6 knots		**Sent Inmarsat distress alert**
1600	44°00.551N 17°01.123W	HDG= 291.3 LOG 7.8 knots		Starboard list 20°. List reduced by 5°.
1745	44°06.083N 17°16.718W	HDG= 289.1 LOG 7.2 knots		**The master gave a GENERAL ALARM for "ship abandon".** Heading varied between 270° and 220°.
1800	44°06.960N 17°19.286W	HDG= 288.3 LOG 7.5 knots	WNW 11	High head seas. Appr. 10-15 m high individual waves.
2100	44°18.732N 17°42.596W	HDG= 321.3 LOG 6.7 knots		Course changed more towards beam wind. The second officer announced from the main deck that all trains are partly loose from their lashings. The trestles had collapsed.
2400	44°36.780N 17°47.821W	HDG= 329.6 LOG 5.5 knots		

All means of sending distress alerts were used on October 19, 2001, as described on page 283 of the log book.

MF/HF Distress alert sent and acknowledged.

VHF DSC Distress sent and acknowledged.

Both EPIRB buoys activated on the deck above the wheelhouse. Several MRCC stations acknowledged the alerts, which was discovered from the Inmarsat calls.

INMARSAT Distress sent and acknowledged with telex.

Vocal emergency communication on MF/2182 and HF/14125 frequencies.

More detailed information about transmission times is in the radio journal.

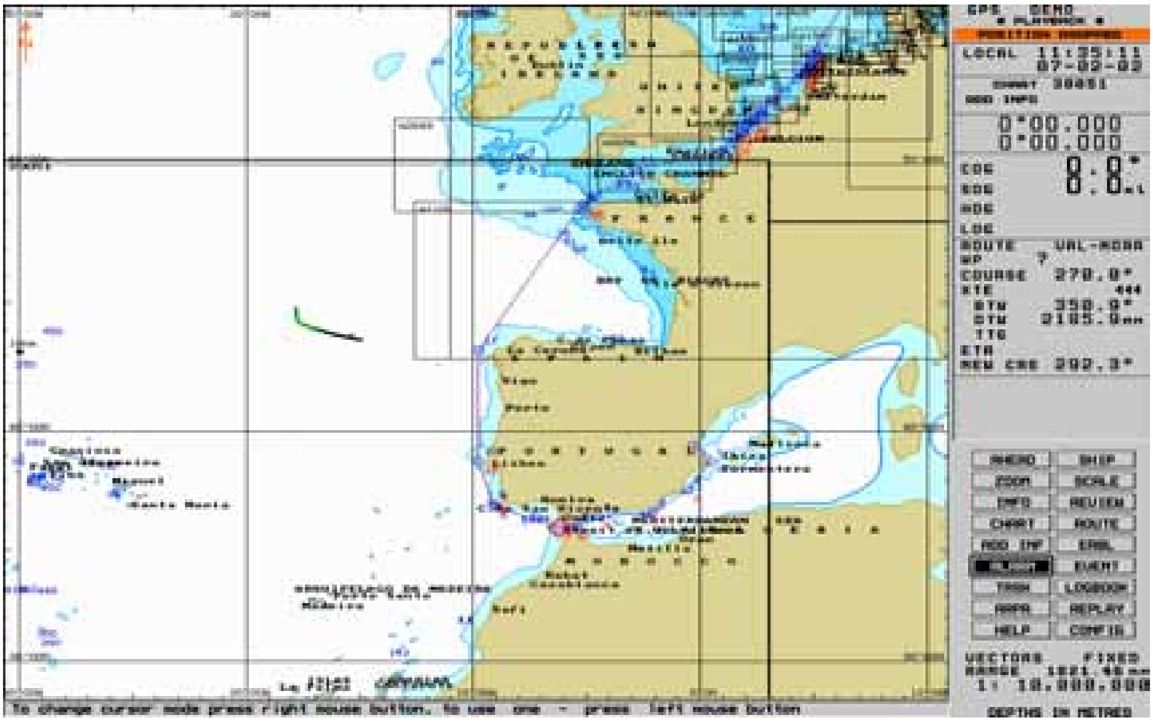


Figure 6. TRADEN's voyage on October 19, 2001. *(Navi-Sailor)*

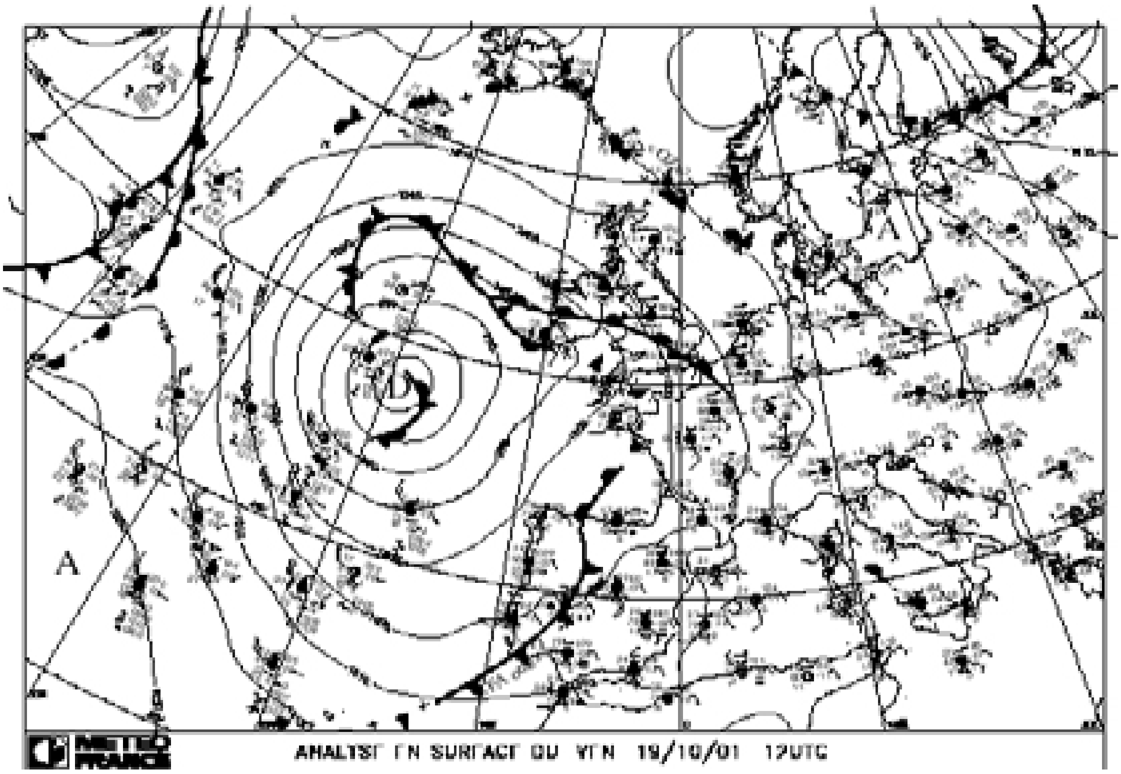


Figure 7. Surface analysis map for 1200 UTC on October 19, 2001 (METEOFRANCE)

Weather forecast for the area "Charcot":

"Low 974 hPa by 51N21W at 00h UTC and 977 hPa by 47N19W, moving south south-east and filling."

Table 7. Weather forecast for the area "Charcot" on October 19, 2001.

Hour UTC	WIND		TOTAL SEA	Primary SWELL		
	Dd	ff (knots)	H1/3 (m)	dd	H1/3 (m)	T(s)
00	WSW to WNW	20 to 30 and gusts	4 to 4.5, but 4.8 to 6 in far northwest of area		2	11
06	SW to WNW	20 to 30 and gusts	3.2 to 4.4 from south to north, but 4.8 to 6 in far northwest of area		2.5	11
12	*In W*: WSW to WNW. *In E*: SSW or SW	*In W*: 25 to 35 and gusts. *In E*: 15 to 25 and gusts	3.2 to 6.4 from southwest to northwest of area		3	12
18	*In W*: W to WNW. *In E*: SSW to SW.	*In W*: 25 to 36 and gusts. *In E*: 15 to 25 and gusts	3.2 to 6 from East to West of area		3	15

Table 8. TRADEN's voyage on Saturday morning 20 of October 2001, according to pages 234–235 of the log book. .

UTC+2	Position	Heading and speed	Weather	
0200	44°47.501N 17°50.056W	HDG= 335.5 LOG 5.0 knots		The intention is to keep a list 15°–20° for the ship. The second officer reduces the list by pumping in engine room to wing tank 2. Heading 330°–340° and speed 4–5 knots.
0400	44°57.221N 17°53.896W	HDG= 349.0 LOG 5.0 knots	NW 8–11	Heading 340°–350° and speed approximately 4 knots.
0600	45°05.599N 17°56.560W	HDG= 336.5 LOG 3.7 knots		Situation unchanged in cargo hold. List 15°–20. Very high waves.
0800	45°14.527N 17°59.506W	HDG= 344.1 LOG 6.3 knots		List 15°–20°.
0950	45°24.432N 18°07.765W	HDG= 332.1 LOG 4.5 knots		
0955	45°24.652N 18°08.006W	HDG= 323.8 LOG 2.5 knots		
1000	45°24.732N 18°08.136W	HDG= 325.6 LOG 1.6 knots		Situation unchanged in cargo hold . List 5°–10°. Ship rolls.
1005	45°24.779N 18°08.146W	HDG= 014.3 LOG 0.1 knots		TRADEN's speed was only 0–2.5 knots according to recorded data at 0955–1010, when the raft was launched. See Figure 15. According to ship's log book this took place later.
1010	45°24.822N 18°08.173W	HDG= 000 LOG 0.2 knots		

The entire crew started to feel exhausted in the morning October 20 according to master's interview.

On pages 283–284 of the log book it is briefly stated that on October 20, 2001, the raft was launched but it was filled with water, the painter line broke and the raft was lost. It was damaged later when a ship tried to save the raft.

Table 9. TRADEN's voyage on Saturday afternoon 20 of October 2001, according to pages 234–237 of the log book.

UTC+2	Position	Heading and speed	Weather	
1100	45°28.614N 18°04.494W	HDG= 078.9 LOG 14.1 knots		Ship's log book at 1100–1130: "Starboard raft is launched. Bow thruster is used to keep the ship at a heading providing shelter to the starboard side. Release units ready. M/s DOLE AFRICA, m/s DONCAN ISLAND and RESCUE AIRCRAFT MOS 91 are in the vicinity. High seas prevent manning of the raft. The raft was lost".
1140	45°30.069N 17°51.104W	HDG= 080.0 LOG 14.4 knots	NW 6	Beam waves from the stern. List 5°–10°. Speed 14 knots. Rescue situation is interrupted. Ship continues under escort of m/s DOLE AFRICA.
1603	45°45.400N 16°22.159W	HDG= 060.5 LOG 15.4 knots		Heading changed 20° to port.
1736	45°56.665N 15°52.169W	HDG= 064.0 LOG 15.6 knots	WSW 3	Escort responsibility from m/s DOLE AFRICA to m/s TURM ALICE.
2400	46°39.866N 13°40.630W	HDG= 064.9 LOG 15.7 knots	WSW 2-3	

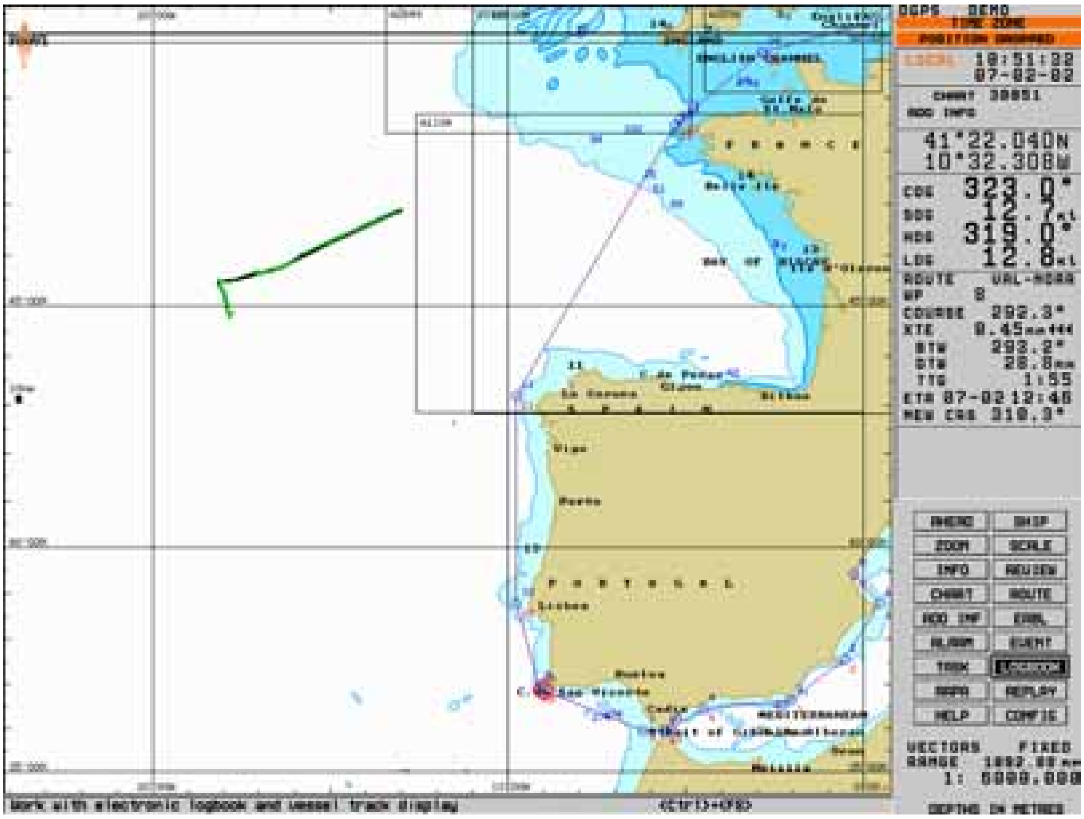


Figure 8. TRADEN's route on October 20, 2001. *(Navi-Sailor)*

General synopsis of the weather forecast for the area "Romeo" on October 20, 2001.

"Low 984 hPa 300 miles northwest of Cap Finisterre at 00h UTC, slowly moving east and filling 990 hPa at 12h UTC."

Table 10. Weather forecast for the area "Romeo" on October 20, 2001.

Hour UTC	WIND		TOTAL SEA	Primary SWELL		
	Dd	ff (knots)	H1/3 (m)	Dd	H1/3 (m)	T(s)
00	Cyclonic, mainly orth-westerly in west part and mainly southeast-erly in east	*In W* : 20 to 30 and gusts *In E* : 15 to 25 and gusts	4 to 4.5	WNW	3	15
06	Cyclonic, mainly north-westerly in west part and mainly southeast-erly in east.	20 to 30 and gusts, but 15 to 25 and gusts in far east	4 to 4.5	WNW	3.5	12
12	Variable but cyclonic in far southeast	05 to 15, but locally 20 in far southeast	3.3 to 4, but 4.5 around 46° north and 13°30 west	WNW	3	11
18	Variable but cyclonic in far southeast	05 to 15, but locally 20 in far southeast	2.25 to 3.25 from northwest to south-east of area	WNW	2.5	10

Table 11. TRADEN's voyage on Sunday 21 of October 2001 when the situation established according to pages 236–237 of the log book.

UTC+2	Position	Heading and speed	Weather	
0400	47°03.977N 12°20.348W	HDG= 065.0 LOG 14.8 knots	WSW 2-3	**Cargo stationary in cargo hold**
1600	48°25.474N 08°23.978W	HDG= 066.4 LOG 15.2 knots		**Cargo stationary on deck and in cargo hold**

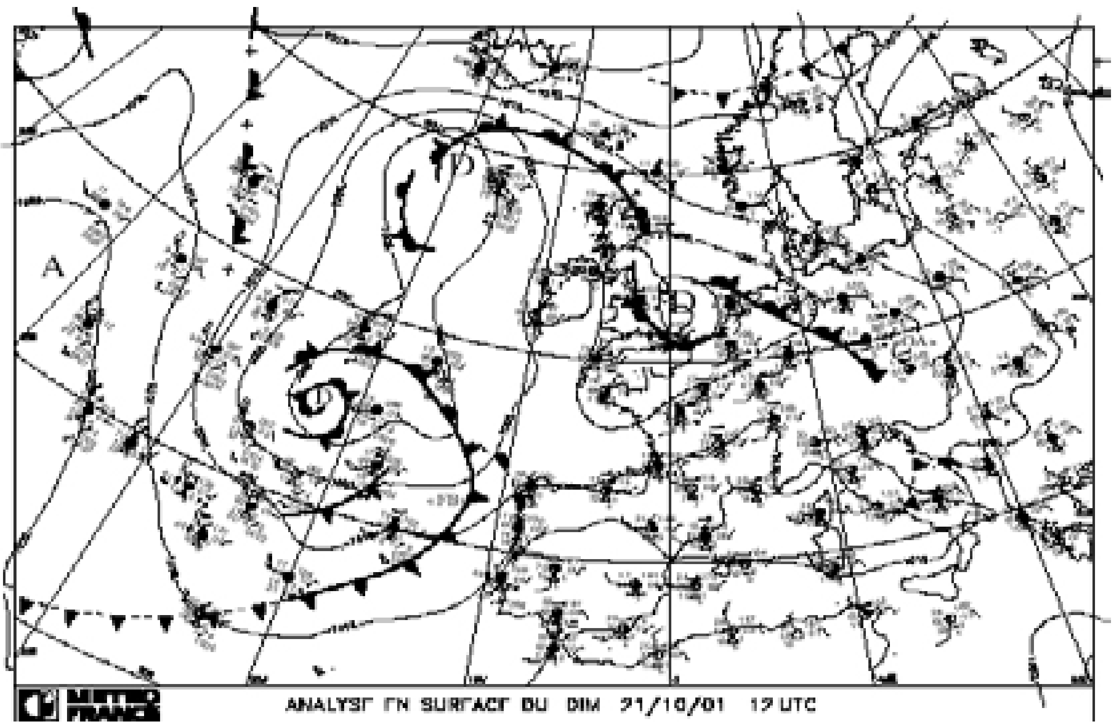


Figure 9. Surface analysis map for 1200 UTC on October 21, 2001 (METEOFRANCE)

General synopsis of the weather forecast for the area "Romeo" on October 21, 2001:

"Low 998 hPa by 46N10W at 00h UTC, slowly moving eastwards. Low 994 hPa 47N25W at 00h UTC, moving east, 995 hPa by 46N21W at 12UTC, then moving north-east."

Appendix 1/14

Table 12. Weather forecast for the area "Romeo" on October 21, 2001.

Hour UTC	WIND		TOTAL SEA	Primary SWELL		
	Dd	ff (knots)	H1/3 (m)	dd	H1/3 (m)	T(s)
00	Variable	05 to 15	2 to 3 from northwest to southeast.	W	2	10
06	Variable	05 to 15	1.8 to 2.8 from northwest to south-east.	W	2	10
12	Variable, but SSE in far east of area	05 to 15, but 15 or 20 in far east.	1.8 to 2.6 from northwest to south-east.	W	1.6	09
18	Variable, but SSE or S in far east of area	05 to 15, but 20 or 25 in far east.	2 to 3 from northwest to southeast.	W	1.5	09

APPENDIX 2: CALCULATION OF MOTIONS AND ACCELERATIONS OF MS TRADEN

Deltamarin Ltd
11.3.2003

Appendix 2/2

Contents

0 INTRODUCTION

This appendix is a compilation of Deltamarin's report, which was completed during the investigation of TRADEN's incident caused by a cargo shift in the Atlantic, October 19, 2001.

In this work the accelerations acting on the railway carriages and a container were calculated in conditions corresponding to the ones prevailing during the cargo shift.

Calculated accelerations were compared accelerations published by the IMO and classification societies.

A separate investigation on stability was carried out, where cargo shift, wind and roll motion were taken into account.

1 SUMMARY

The cargo shift of ro-ro ship TRADEN took place when the ship encountered a storm in the Atlantic and she had to steer according to waves during approximately two and half days.

According to observations on board, the highest waves were approximately 15 m in height and the maximum roll amplitude was approximately 25°. In addition, the ship encountered slams, which caused hull vibrations and increased loads acting on cargo securing devices.

Seakeeping calculations were carried out in irregular waves with significant wave height equal to 7.5 m to evaluate the accelerations and forces acting on the cargo and cargo securing devices. Wave periods were selected in accordance with periods observed in the Atlantic nearest to the place of the incident. Calculations were carried out in head waves, and bow waves with heading angle 30° from the bow.

According to the seakeeping calculations the highest roll amplitude was 27.5° for 60 hours' time of exposure and 20% exceeding probability. The highest transversal acceleration acting on the aftmost railway carriage was 5.3 m/s^2, the highest vertical acceleration was 3.7 m/s^2, and the highest longitudinal acceleration was 1.6 m/s^2.

The IMO accelerations are exceed notably in transverse and vertical directions, and slightly in longitudinal direction. The accelerations given by the classification societies considered, are in all cases larger than the IMO accelerations, and on average quite close to the accelerations calculated for the aftmost railway carriage.

According to the separate stability investigation, the ship was not close to capsizing when subject to contemporary effects of cargo shift, wind and roll motion. If cargo securing had not been successful, capsize might, however, have been quite probable.

2 BASIS OF CALCULATIONS

2.1 Ship data

Ship data for the TRADEN relevant within this investigation are shown in Table 1. Stability data are based on the NAPA calculations of the investigation.

Table 1. Ship data for the TRADEN.

Length, overall, *Loa* (m)	129.20
Length between perpendiculars, *Lpp* (m)	120.40
Bradth, moulded, *B* (m)	19.20
Draft, design, *T* (m)	6.30
Draft, aft, used in calculations, *TA* (m)	5.287
Draft, fore, used in calculations, *TF* (m)	4.276
Draft, midships, used in calculations (m)	4.78
Volume of displacement (m^3)	7220
Block coefficient, c_B	0.65
Design speed (kn)	15.5
Speed, used in calculations (kn)	7.0
Longitudinal location of centre of buoyancy, *LCB* (%)	-1.40
Vertical centre of gravity above base line, *KG* (m)	7.32
Transverse metacentric height, GM_0 (m)	1.48
Pitch radius of gyration, k_{yy} (m)	30.1
Roll radius of gyration, k_{xx} (m)	6.72

Six Pendolino railway carriages were stowed on the main deck of the ship. The aftmost one got loose from the trestle and broke the supporting lashings. Also all other carriages got partially loose from their lashings. Another important object with respect to cargo securing is the set of containers on the weather deck and containers of the second tier from the bow got loose from their lashings.

Centres of gravity of the aftmost and foremost railway carriages were chosen as positions for evaluation of accelerations. In addition, the centre of gravity of an upper container of the second tier from the bow on the weather deck was selected according to the Trim and Stability Information Booklet, Table 2. The longitudinal x-coordinate is measured from the aft perpendicular, positive forward, the transverse y-coordinate is measured from the longitudinal centre plane, positive starboard, and the vertical z-coordinate is measured from the base line, positive upwards.

Table 2. Locations of acceleration calculation.

Position	*x* (m)	*y* (m)	*z* (m)
Aftmost railway carriage	55	-7.5	8.79
Bowmost railway carriage	110	-3.0	8.20
Container on the weather deck	70.7	-7.5	17.64

2.2 Environmental data

The sea was rough in the Atlantic during the time of the cargo shift, October 19th, 2001, and had prevailed so already from the early hours of the preceding day.

Wave heights and periods are essential in this work and visual wave observations exist from the observations onboard ms TRADEN and from the report of Meteo France (Anon. 2002).

According to the visual wave observations from the TRADEN the maximum wave height was in the range from 10 m to 15 m during the time of the cargo shift. Wind force was estimated to be 11 in Beaufort scale, which is the highest value recorded during the storm in the log book. According to the maritime declaration given by the master the highest waves were over 12 m in height, and wind force over 11 in Beaufort scale. Existence of confused seas is also significant, and the master had never experienced such before in this sea area.

According to the report of Meteo France, the largest significant wave height in the area ”Charcot” was 6.4 m during the day of incident. The highest swell height was 3 m, and the longest wave period was 15 s. Highest wind speed presented in the report is 35 knots and gusts. Several weather warnings were issued during the day of the incident and the day before and after. According to these the wind force was 8–9 Beaufort, wind from the west or north-west, gusts and high sea. These wind forces correspond to an average significant wave height of 7.5 m according to the World Meteorological Organization

Visual wave observations on other ships yielded the maximum significant wave height 6 m for wind waves and 7 m for swells. It can be estimated that the sea was fully developed due to the long fetch and sufficient long duration of the wind.

It can be concluded on basis of wave data that even 15 m high waves might have occurred during the day of the incident, October 19, 2001. In other words the estimation given in the log book appears to be realistic.

The Global Wave Statistics (Hogben et al., 1986) includes wave data for the Bay of Biscay. Largest significant wave heights in west winds during September – October are over 14 m and the significant wave height 7.5 m is exceeded with a probability of 2.3 %, or during about eight days a year. Wave data for the Bay of Biscay are used in this work, because Bay of Biscay is located nearest to the place of the cargo shift.

3 RESULTS OF SEAKEEPING CALCULATIONS

3.1 Motions and accelerations

Seakeeping calculations in regular waves for evaluating accelerations acting the cargo were carried out with the linear strip theory program SHIPMO (Anon. 1998). Statistical studies in irregular waves were carried out with the program WASCO (Anon. 1997).

Speed of advance used in the calculations was 7 knots, which correspond to the real ship speed during the cargo shift.

Drafts at bow and stern were obtained from the stability calculations with real loading condition, and are shown in Table 1.

The significant wave height used in the calculations is 7.5 m according to data presented in Chapter 2.2 Wave period has also a remarkable effect on ship motions and accelerations. The calculations were carried out for all wave periods observed in Bay of Biscay for the significant wave height 7.5 m (Hogben et al., 1985). Zero up-crossing periods lie in the range from 6.5 s to 11.5 s, and the calculated maximum values were selected for each motion component and acceleration.

Calculations were carried out in short crested waves because the TRADEN encountered confused sea. In addition to the main heading, other headings were taken into account for deviation ± 60° from the main heading.

Results from calculations in short crested seas are shown as maximum values in Table 3. The maxima depend on the number of wave encounters and as the ship had to steer according to waves for about 60 hours, the results were obtained using the number of waves encountered during this time. Probability of exceedance is 20%, which implies that the maximum values are allowed to be exceeded once during five voyages provided the weather conditions remain unchanged.

Table 3. Maximum accelerations in short-crested irregular seas for significant wave height Hs = 7.5 m.

Position	Acceleration amplitude (m/s^2)					
	Transverse		Vertical		Longitudinal	
Heading angle	180°	150°	180°	150°	180°	150°
Aftmost railway carriage	4.58	5.28	3.09	3.68	1.58	1.32
Bowmost railway carriage	5.00	5.53	10.26	9.43	1.45	1.27
Containers on weather deck	5.69	6.49	4.35	4.51	3.02	2.63

Maximum values for the roll motion calculation in an analogous way are shown in Table 4.

Table 4. Maximum roll motion amplitudes in short-crested irregular waves for the significant wave height 7.5 m.

Heading angle	Maximum amplitude (°)
180° (head waves)	23.7
150° (bow waves)	27.5

The theoretical values shown in Table 4 lie quite close to the estimated values of the log book (25°). Such a large roll motion decreases the operability of the crew and the root-mean-square value obtained from calculations, 5.7°, lies very close to the recommended upper limit of operability for merchant ships, 6°. Vertical acceleration in particular effects the crew's operability and the location of the wheelhouse near the bow increases the effect of pitch motion on vertical acceleration.

The ship encountered slams in addition to high accelerations due to large relative motion between the ship and water surface. This caused the bow to rise above water and bounce back with a quite high velocity.

The number of slams can be calculated when at the relevant location the relative velocity between the ship and water exceeds a certain limit, in addition to emersion from the water. The critical velocity by Ochi (Ochi, 1964) is commonly used:

$$V_{crit} = 0.093\sqrt{gL_{pp}} \ ,$$

where g is the acceleration of gravity, and L_{pp} is the length between perpendiculars.

The frequencies of slamming at location $0.1L_{pp}$ from the bow calculated in short-crested irregular waves are shown in Table 5.

Table 5. Slamming frequencies in short-crested irregular waves at $0.1L_{pp}$ from the bow with the significant wave height 7.5 m.

Heading angle	Frequency (slams/hour)
180° (head waves)	155
150° (bow waves)	127

Values in Table 5 imply that due to the long time of exposure a remarkable amount of slams were encountered. During 60 hours the number of slams is 9300 in head waves and 7620 in bow waves. The accelerations caused by slam-induced hull vibrations can not be taken into account with the method of calculation used in this work but they have had obviously a remarkable effect on the lashing loads.

3.2 The IMO accelerations

The IMO has published guidelines for calculating accelerations for ro-ro ships of various size, Figure 1. Transverse accelerations include the effects of gravitational acceleration, as well as heave and pitch effects parallel to the deck. Vertical accelerations do not include the static weight component.

Transverse acceleration a_y in m/sec^2										Longitudinal acceleration a_x in m/sec2
on deck high	7.1	6.9	6.8	6.7	6.7	6.8	6.9	7.1	7.4	3.8
on deck low	6.5	6.3	6.1	6.1	6.1	6.1	6.3	6.5	6.7	2.9
tween deck	5.9	5.6	5.5	5.4	5.4	5.5	5.6	5.9	6.2	2.0
lower hold	5.5	5.3	5.1	5.0	5.0	5.1	5.3	5.5	5.9	1.5
0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	L
Vertical acceleration a_z in m/sec^2										
	7.6	6.2	5.0	4.3	4.3	5.0	6.2	7.6	9.2	

Figure 1. The IMO accelerations.

Accelerations of Figure 1 were derived with the following assumptions:

1 Operation in unrestricted area
2 Operation during the whole year
3 Duration of the voyage 25 days
4 Length of ship is 100 m
5 Service speed is 15 knots
6 $B/GM_0 \geq 13$

The accelerations should to be corrected if ship's length, speed or B/GM_0 relation differs from the assumed values. For shorter voyages the accelerations may also be corrected but this correction has not been considered in this work.

When correcting the accelerations according to the length and extrapolating to 7 knots' speed, the final correction coefficient 0.64 is obtained. Accelerations as shown in Figure 2 were thus obtained for the TRADEN for railway carriages on the main deck and a container on the weather deck (corresponding to "deck low" in Figure 1).

Appendix 2/10

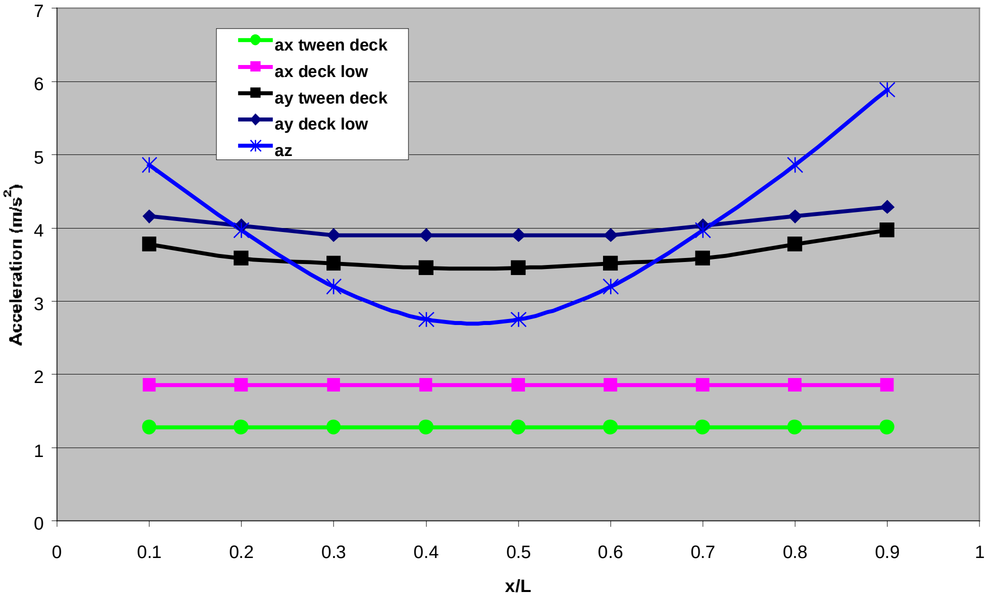


Figure 2. Accelerations corrected according to ship's length and speed.

The B/GM_0-relation is approximately 13 implying that no correction with respect to this relation is needed. When applying the values of Figure 2 for the relevant locations, the acceleration values shown in Table 6 are obtained. Results of seakeeping calculations in irregular waves are also shown.

Table 6. The IMO accelerations and calculated maximum acceleration amplitudes in irregular short-crested waves with significant wave height Hs = 7.5 m.

Position	Acceleration amplitude (m/s^2)								
	Transverse			Vertical			Longitudinal		
Heading angle	180°	150°	IMO	180°	150°	IMO	180°	150°	IMO
Aftmost railway carriage	4.58	5.28	3.45	3.09	3.68	2.72	1.58	1.32	1.28
Bowmost railway carriage	5.00	5.53	4.00	10.3	9.43	5.99	1.45	1.27	1.28
Container on the weather deck	5.69	6.49	3.88	4.35	4.51	3.10	3.02	2.63	1.86

Results of Table 6 are also shown in Figures 3 to 5.

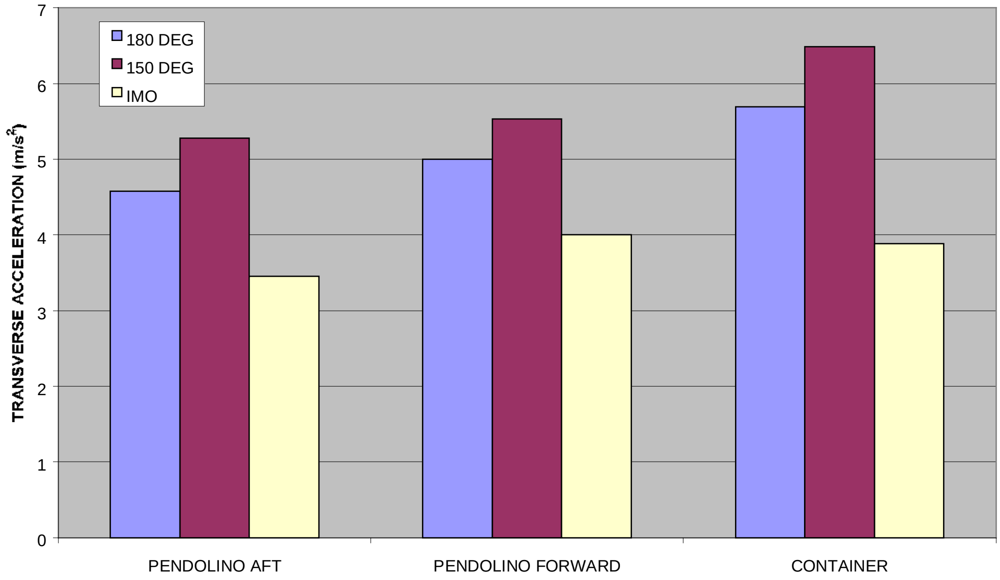


Figure 3. Transverse maximum accelerations and IMO accelerations.

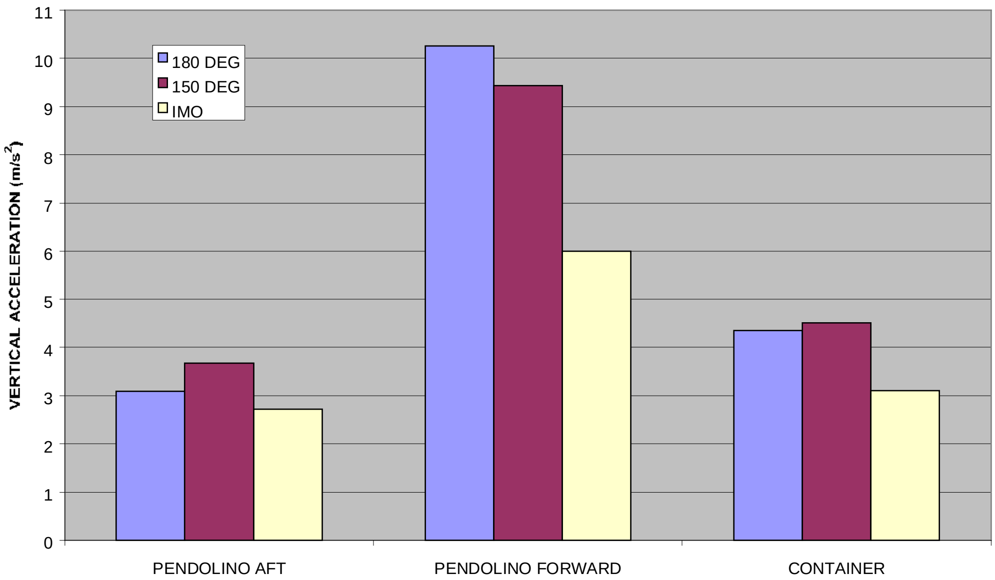


Figure 4. Vertical maximum accelerations and IMO accelerations.

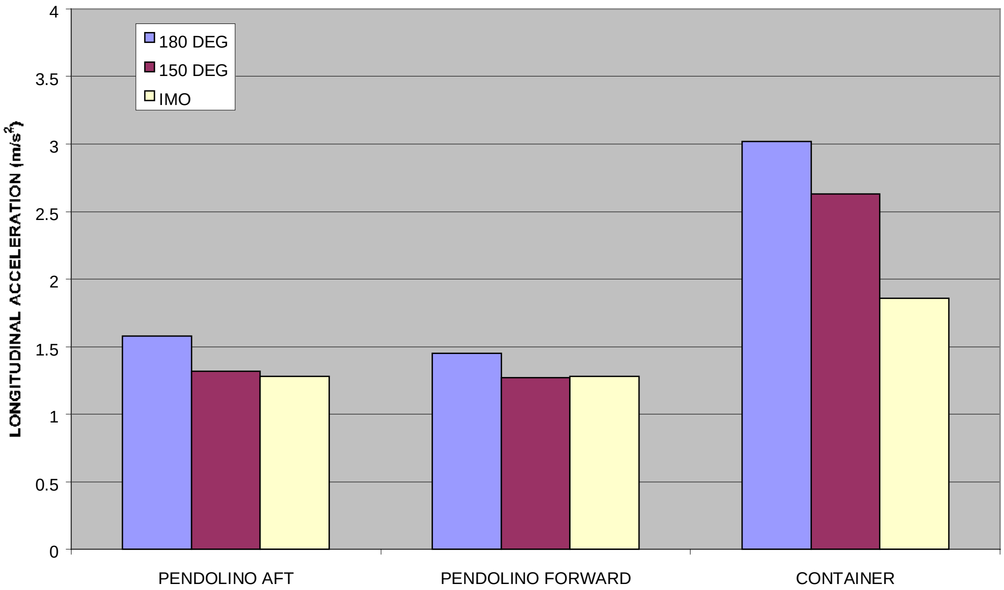


Figure 5. Longitudinal maximum accelerations and the IMO accelerations.

The results show that the IMO accelerations are exceeded clearly for the transverse and vertical accelerations. The longitudinal accelerations exceeded also the IMO accelerations, but in most cases to a smaller extent than for the other components of accelerations.

3.3 Design accelerations of classification societies

Regulations of various classification societies include design acceleration values, which are presented and compared in the following. Different rules deviate from each other, but details are not discussed in this work. However, the rules are applied in a way that makes the accelerations comparable with the calculated results and the IMO accelerations. The static weight component is subtracted from the vertical acceleration if needed.

Table 7 shows the periods of motions and maximum amplitudes as well as the maximum accelerations for the aftmost railway carriage.

Table 7. Motion characteristics and accelerations calculated according to the rules of classification societies.

Classification society	Bureau Veritas	Det Norske Veritas	Lloyd's Register of Shipping
Roll angle (°)	22.5	34.4	28.7
Roll period (s)	11.5	12.3	11.0
Pitch angle (°)	9.57	11.8	8.07
Pitch period (s)	8.99	6.31	5.48
Transverse acceleration (m/s^2)	4.70	6.99	5.45
Vertical acceleration (m/s^2)	3.32	5.66	5.51
Longitudinal acceleration (m/s^2)	2.10	2.79	2.10

Results of Table 7 show that the rules of classification societies give essentially higher accelerations than the IMO guidelines. Comparison is shown in Figure 6.

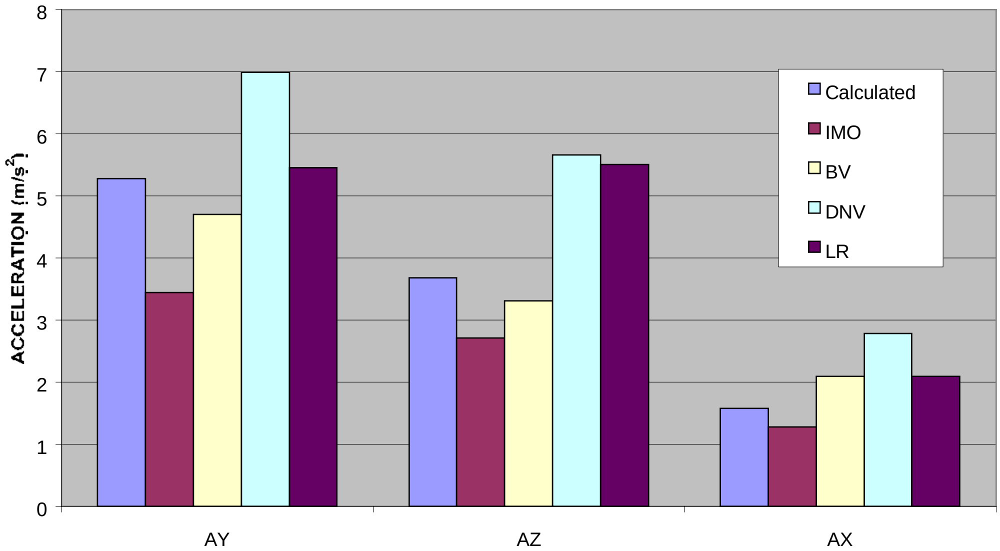


Figure 6. Acceleration comparison for the aftmost railway carriage.

As a conclusion of the acceleration comparison, it is discovered that the values computed for the TRADEN lie quite close to the average values of classification societies. In addition, it is discovered that if the corrections based on ship's length and speed were not taken into account in the IMO accelerations, the differences with results of classification societies were remarkably smaller. Knott (2002) recommends that this correction is ignored if the correction coefficient is smaller than one.

4 STABILITY IN WAVES

The effects of the cargo shift, roll and wind, and their contemporary effects were studied by stability calculations carried out with the NAPA software. The calculations were carried out by Ship Consulting Ltd. The objective was to estimate how close to capsizing the ship was in real conditions, and what effects a large cargo shift would have had on the situation. Rolling amplitude used in the study is 25° as estimated on board.

The following cases were taken into account:

- transverse cargo shift causing a list of 20°
- transverse cargo shift of *B/2*
- wind and rolling
- wind, rolling, and a transverse cargo shift of *B/2*

The static and dynamic stability curves without cargo shift are shown in Figure 7. The stability calculation shows that the ship satisfied the stability criteria of IMO Resolution A.749 in the present loading condition.

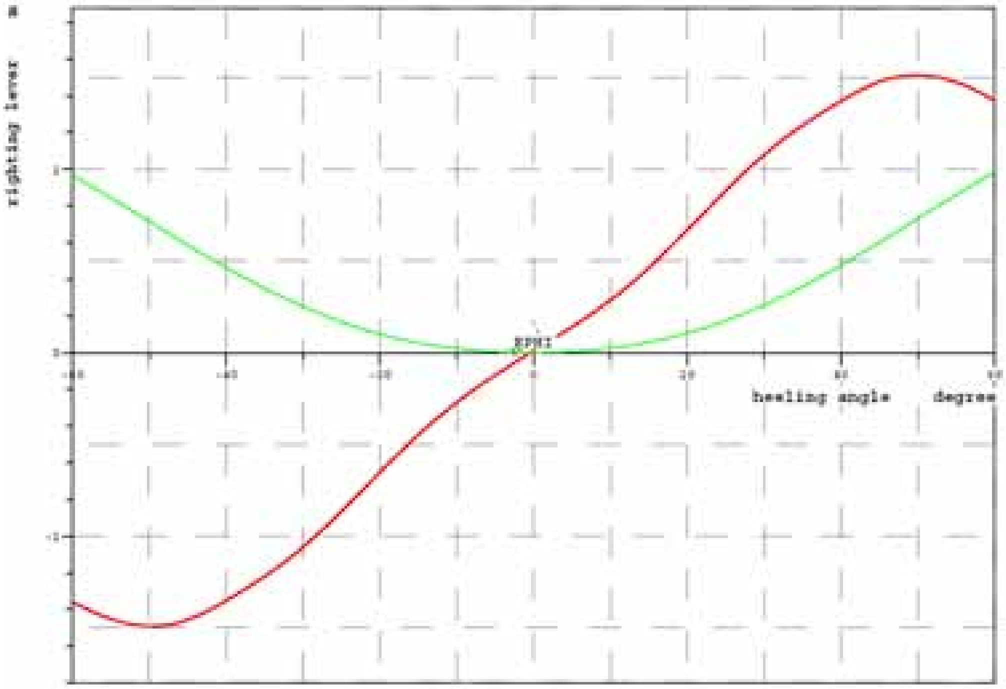


Figure 7. Static and dynamic stability curve without a cargo shift. The static stability curve is shown in red in Figures 7 to 10.

The stability calculations were also used to show that a transverse cargo shift of 4 m would be needed to obtain a list of 20°, which was observed in the worst case. The ship fulfils in this condition the IMO stability criteria of Resolution A.749 with an exception of one criterion.

A cargo shift equal to ship's half-breadth, i.e. in practice a very large cargo shift, causes itself already a list of 35.5°. In this case the stability criteria based on area between static stability curve and horizontal axis are not satisfied.

In addition to the cargo shift, also wind and waves affected the ship. Both wind and wave directions varied in practice, and the TRADEN encountered confused sea conditions to a remarkable extent during the storm. Figure 8 shows the effect of wind without a cargo shift. Wind speed is 40 m/s, wind force coefficient is 1.0, location of wind force is 8.0 m upwards from half-draught, and the lateral area of the ship is 1320 m^2. Figure 8 shows that the ship heels approximately 5° by wind action.

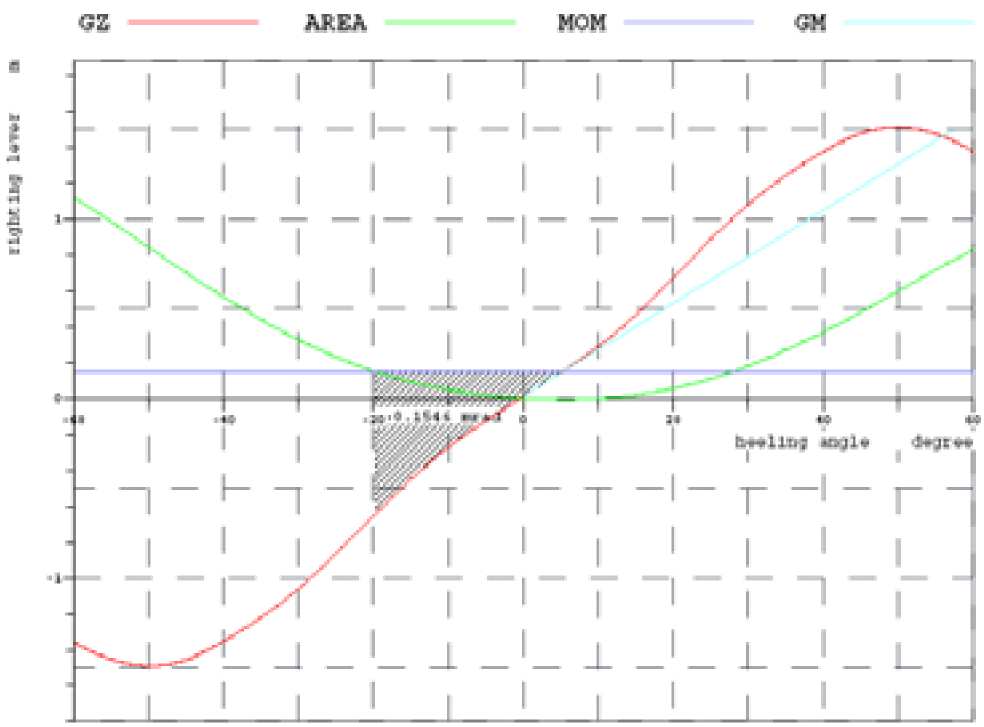


Figure 8. The effect of wind and rolling on stability without a cargo shift.

When the cargo shift causing a list of 20° is taken into account, the situation is changed as shown in Figure 9.

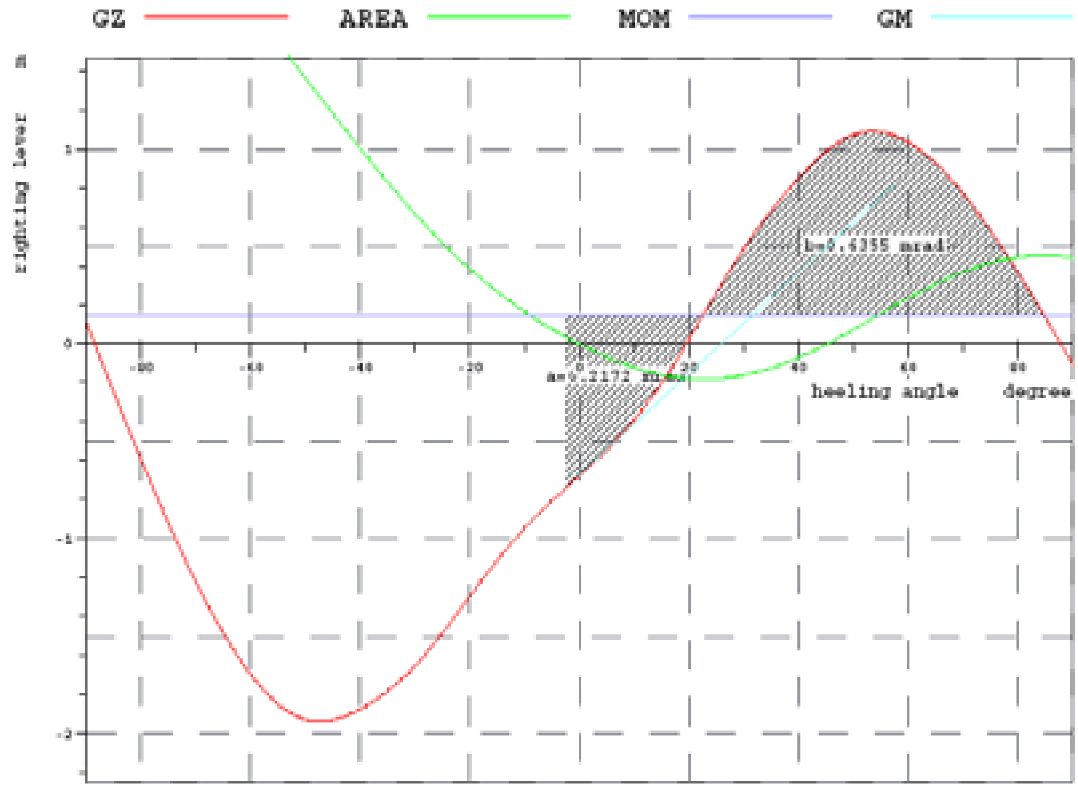


Figure 9. The effects of wind, rolling and a transverse cargo shift of 4 m on ship stability.

Figures 8 to 10 show areas representing work carried out by the wind moment (a) and the restoring moment (b) when the ship is rolling with an amplitude of 25º. The work of the wind moment in Figure 9 is clearly smaller than the work by the restoring moment, which implies that the ship does not capsize and is not near capsizing either.

In addition, Figure 10 shows how the situation had changed in case a large cargo shift equal to ship's half-breath had taken place. This figure shows that the situation changed essentially. The work by the wind moment is already larger than the work by the restoring moment and the ship would have capsized. With very large heeling angles it would also be probable that leaking holes would be immersed, and the associated progressive flooding would have contributed to capsizing of the ship.

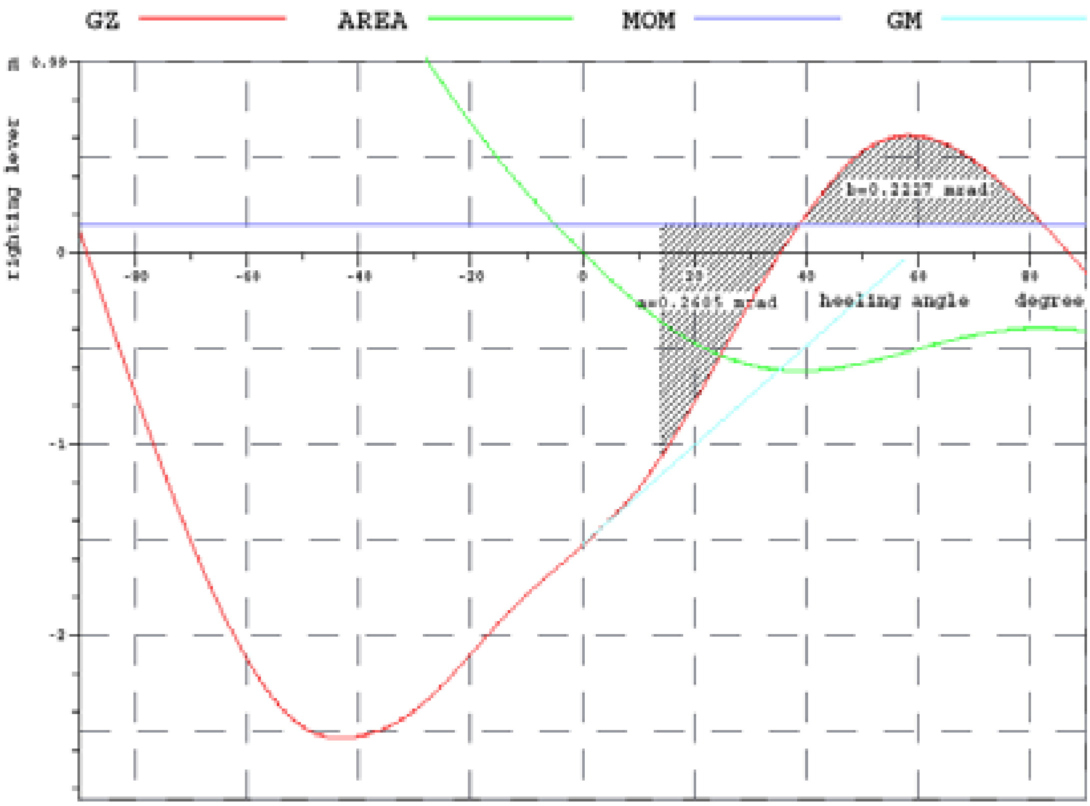


Figure 10. The effect of wind, rolling and a cargo shift equal to ship's half-breadth on ship's stability.

5 CONCLUSIONS

This appendix studied TRADEN's seaworthiness and stability in conditions corresponding to the cargo shift in the Atlantic on October 19, 2001.

Ship's motions in waves, accelerations acting on the cargo, and probability of slamming were calculated with a strip-theory-based computer program. The accelerations were compared with the design accelerations by IMO and by classification societies.

The ship encountered a storm for two days during the voyage. On-board estimation was maximum wind force 11, and maximum wave height 10–15 m. The seakeeping calculations were carried out in short crested irregular waves with a significant wave height of 7.5 m. All wave periods observed in the Atlantic near the place of the incident for the current wave height were used in the calculations.

Calculated accelerations exceed the IMO accelerations in the transverse and vertical directions in particular. The longitudinal IMO accelerations were exceeded slightly.

The accelerations of classification societies differ from each other to some extent but they are in all cases larger than the IMO accelerations. The accelerations from the seakeeping calculations lie quite near the accelerations of the classification societies.

The ship satisfied the required stability criteria at the current loading condition. However, the cargo shift causing a list of 20° reduced stability, but the ship was not close to capsizing due to contemporary action of strong wind and a roll motion with amplitude of 25°. A large cargo shift together with strong wind and waves would probably have caused the ship to capsize.

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