Kołowrocki Krzysztof

Kuligowska Ewa

Soszyńska-Budny Joanna
Gdynia Maritime University, Gdynia, Poland

Climate related hazards and their critical / extreme event parameters exposure for maritime ferry critical infrastructure

Keywords

critical infrastructure, climate related hazard, identification, extreme event parameter, maritime ferry

Abstract

The article is created to identify the climate related hazards at the Baltic Sea area and their extreme event parameters exposure for maritime ferry analysis. As a result, there are distinguished possible natural hazards coming from climate/weather change having influence on the considered maritime ferry: strong winds, sea water level, precipitation, ice, fog, large waves, water temperature and air temperature. The potential hazards' parameters with their range and scale are described for the coastal environment of the Gdynia Port in Poland, the Karlskrona Port in Sweden, restricted Baltic Sea waters and open waters of the sea basin. Moreover, the impact and the consequences of critical parameters affected the components of the considered critical infrastructure are analysed as well.

1. Introduction

Shipping is a major maritime segment among the transportation systems and that is why ships are important components of so called dynamic shipping critical infrastructure [2]. The set of ships operating at the Baltic Sea waters at the fixed moment of time (or at the fixed time interval) we call the Baltic Shipping Critical Infrastructure Network (BSCIN) that is particularly described in [1]. The operation process and safety of the shipping critical infrastructure network strongly depend on the individual ships it is composed of the operating area within the Baltic Sea region [5]. Critical infrastructures, which refer to transportation systems, are very susceptible to all sorts of hazards and threats. The impact of hazards related to climate and weather conditions changes on the operation of critical infrastructures is significant [6].

The aim of this article is to identify possible climate hazards that occur in the Baltic Sea area (i.e. the coastal environment of selected ports, restricted sea waters and open waters of the sea basin) and indicate which ones pose the greatest risk to maritime ferry operating between the Gdynia Port in Poland and the Karlskrona Port in Sweden. The so called critical or extreme event parameters of climate and weather hazards are identified and their influence on the considered maritime ferry operations is presented. The consequences affected by strong winds, sea water level, rain, snow, ice, fog, large waves, water and air temperature changes are considered. The different kinds of those impacts and consequences are also discussed [4].

2. Identification of climate related hazards, their impacts and consequences for maritime ferry

Stena Line Group is an international transport and travel service company within Europe's route network. Its ferries operate at the Baltic Sea area, in Scandinavia surrounding seas and around Great Britain (*Figure 1*). Stena Baltica is a passenger Ro-Ro ship presented in *Figures 2-3* [7], operated in the years 2002-2011 between Karlskrona and Gdynia ports on regular everyday line [8]. The detailed maritime ferry route is illustrated in *Figure 4* [3].

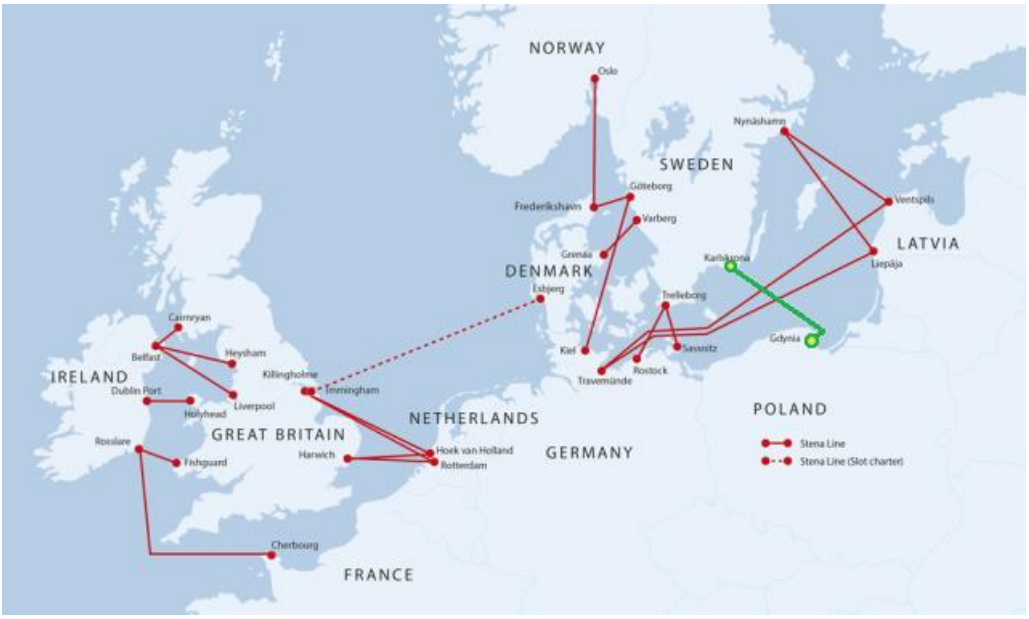

Figure 1. Ferry routes in Scandinavia, around Great Britain and the Baltic countries, including the considered route between Gdynia and Karlskrona (green line)

Figure 2. The starboard of Stena Baltica

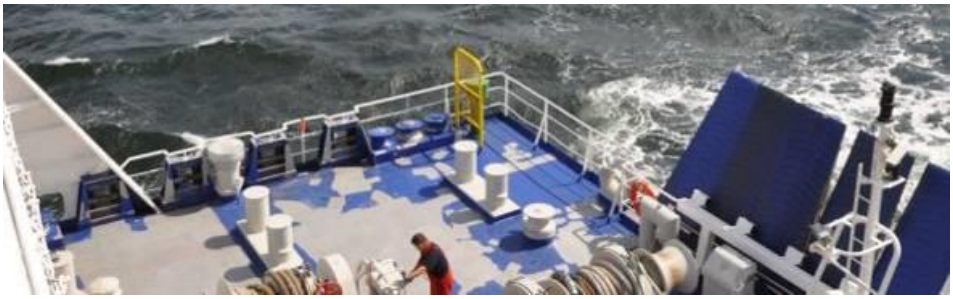

Figure 3. The stern of Stena Baltica

Figure 4. Maritime ferry route between Karlskrona and Gdynia ports

Considering different environmental conditions of the considered maritime ferry technical system dependent of its operating area, the climate-weather hazards and their consequences in the following three cases should be analyzed [2]:
- Maritime Ferry operating at Gdynia Port and Karlskrona Port waters;
- Maritime Ferry operating at Baltic Sea restricted waters in Gdynia bay and Karlskrona bay;
- Maritime Ferry operating at Baltic Sea open waters between Gdynia bay and Karlskrona bay.

The chance of risk affecting the maritime ferry as the component of the critical infrastructure in the Baltic Sea network area can result from the combination of more than one meteorological hazard. Further, based on the data about ranges of hazard parameters in Contributions to generating Questionnaire of End User Needs [4] and in [3], in the following subsections, we distinguish the possible intervals that contain the values of the hazard parameters for the three distinguished areas.

2.1. Climate-weather hazards for maritime ferry operating at Gdynia port and Karlskrona port sea waters

Considering the ranges and states of hazard parameters given in Contributions to generating Questionnaire of End User Needs [4] and [3], the possible hazard parameters intervals for the maritime ferry operating at Baltic Sea waters between Gdynia and Karlskrona ports are presented in *Table 1*. They represent the scale of climate-weather hazards impact on the considered critical infrastructure.

The individual hazard parameters influence on maritime ferry may bring the following consequences described below [4].

a) *Wind speed*.

Winds over 20-25 m/s cause risk of collision with other ships and may cause contact with port's facilities and other external objects during entering, leaving or mooring operations in harbour. Additionally the risk of grounding may occur in Karlskrona port. Due to large wind exposed area, ferry is very sensitive to winds within extreme range (Northerly wind in Gdynia and South-easterly wind in Karlskrona). Wind speed factor can make berthing impossible due to excessive drifting and list. Because of the strong wind appearance, the vessel has to stay in port. Any manoeuvring has to be aborted and the vessel traffic may be suspended by port authorities. While the wind speed is extreme, the vessel may not be able to turn inside port turning circle. Additional mooring lines are sometimes needed and using of thrusters or the tug assistance may be necessary.

b) *Wind direction*.

Northerly winds cause risk of collision with other ships and/or contact with port's facilities and other external objects during turning and mooring operations in Gdynia. Southeasterly winds in Karlskrona cause risk of grounding or contact with port's facilities and other external objects. Those winds with extreme speed (over 15-20 m/s) can cause risk of collision, contact or grounding and berthing difficulties. Easterly winds cause too high or too low water level for safe loading and discharging. With adverse wind directions additional mooring lines and possibly thrusters have to be used to stay alongside (parallel position to berth) ferry quay. Extreme easterly winds may increase water level, while the extremely westerly winds decrease water level in Gdynia harbor. Vessel may not stay safely alongside without additional means of keeping her in position.

c) *Sea water level*.

Too high water level can cause problems during loading and discharging operations by ro-ro ramps and passenger's gangway. Lack of minimum under keel clearance (UKC) may be a reason to cease voyage in order to avoid danger of grounding.

d) *Sea water temperature, fog and ice conditions*.

Too high sea water temperature can cause minor problems with cooling of various ship's systems. Fog can cause risk of collision with other ships or contact with port facilities and other external objects. Ice conditions in port can affect safe berthing. During severe winters sea ice occurs and normal vessel traffic in port is not possible. Assistance of ice-breakers is sometimes needed. Ice accumulated between ship, quay and/or behind cause berthing difficulties. Harbor tug assistance may also be needed. Vessel has to come alongside in order to lower passenger's gangway and ro-ro ramps.

e) *Air temperature*.

High air temperature can cause minor problems with cooling of various ship's systems. Very low temperature during precipitation can cause icing. Ice conditions in a port can affect safe berthing. Fog

cause risk of collision with other ships or can cause contact with port facilities and other external objects. Vessel may manoeuvre with reduced speed and extreme caution and limited visibility may occur while the fog density is between 0 m and 200 m.

f) *Precipitation.*

Very heavy rain or snowfall with squalls can cause risk of drifting and collision with other ships. It may also cause dangerous contact with port facilities and other external objects. Vessel may manoeuvre with reduced speed and extreme caution. Extreme heavy precipitation level can cause risk of accident due to the limited visibility.

Resilience strengthening strategy to climate-weather hazards for Maritime Ferry operating at Gdynia Port and Karlskrona Port waters is described in [4]. According to the primary answers of our consultants (stakeholders) from industry, there are distinguished the following resilience strategies for the particular hazards affecting the Maritime Ferry operating at ports sea waters.

The winds blowing alongside the maritime ferry route may need to deploy additional mooring lines, use of thrusters (depending on wind force and direction) and main engines and/or consider the tug assistance. During maneuvering, compulsory assistance of tugs and pilot shall be considered, while wind speed inside Gdynia port is 7 B (14-17 m/s) or above.

Table 1. Hazard parameters impact matrix for maritime ferry operating at ports sea waters

Hazard parameter	**Range / state**							
Wind speed [m/s]	0 – 5.5	5.5 – 8	8 - 17			17 – 33+		
Wind direction (GDY) [azimuth degrees °]	0 - 22.5, 337.5 - 360 N	22.5 - 67.5 NE	67.5 - 112.5 E	112.5 - 157.5 SE	157.5 - 202.5 S	202.5 - 247.5 SW	247.5 - 292.5 W	292.5 - 337.5 NW
Wind direction (KAR) [azimuth degrees °]	0 - 22.5, 337.5 - 360 N	22.5 - 67.5 NE	67.5 - 112.5 E	112.5 - 157.5 SE	157.5 - 202.5 S	202.5 - 247.5 SW	247.5 - 292.5 W	292.5 - 337.5 NW
Sea water level [cm]	415 - 450		450 - 500		500 - 550		550 – 620+	
Wave height [m]	0 – 5.5				5.5 – 14+			
Sea water temperature [°C]	-1 – 5	5 - 8	8 - 11	11 - 14	14 - 17	17 - 20	20 – 27.5+	
Air temperature [°C]	-30 - -10		-10 - -3	-3 - 4	4 - 11	11 - 18	18 - 25	25 – 40+
Soil temperature [°C]	-30 - -10		-10 - 25					25 – 40+
Precipitation rainfall level [mm/h]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Precipitation snowfall level [cm/d]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Ice conditions thickness [cm]	0.1 – 12.5		12.5 - 18.75	18.75 - 25	25 – 50+			
Fog density [m]	0 - 200		200 - 500		500 - 750		750 – 1000+	

- no impact or no direct impact
- low impact
- medium impact
- high impact
- extreme state

2.2. Climate-Weather hazards for maritime ferry operating at Baltic Sea restricted waters of Gdynia bay and Karlskrona bay

Considering the ranges and states of hazard parameters given in Contributions to generating Questionnaire of End User Needs [4] and [3], the possible hazard parameters intervals for the maritime ferry operating at Baltic Sea restricted waters of Gdynia and Karlskrona bays are presented in *Table 2.* They represent the scale of climate-weather hazards impact on the considered critical infrastructure.

The individual hazard parameters may bring the following consequences for maritime ferry described below [4].

a) *Wind speed*.

Winds over 15 m/s from the ship's side cause drifting and list (heel) due to large wind exposed area. Ferry is very sensitive to winds within extreme range. Risk of grounding, collision with other ships and contact with external objects exist. Due to the strong wind vessel has to adjust/alter heading in order to keep course.

Table 2. Hazard parameters impact matrix for maritime ferry operating at Baltic Sea restricted waters

Hazard parameter	**Range / state**							
Wind speed [m/s]	0 – 5.5	5.5 – 8	8 - 17			17 – 33+		
Wind direction (GDY) [azimuth degrees °]	0 - 22.5, 337.5 - 360 N	22.5 - 67.5 NE	67.5 - 112.5 E	112.5 - 157.5 SE	157.5 - 202.5 S	202.5 - 247.5 SW	247.5 - 292.5 W	292.5 - 337.5 NW
Wind direction (KAR) [azimuth degrees °]	0 - 22.5, 337.5 - 360 N	22.5 - 67.5 NE	67.5 - 112.5 E	112.5 - 157.5 SE	157.5 - 202.5 S	202.5 - 247.5 SW	247.5 - 292.5 W	292.5 - 337.5 NW
Sea water level [cm]	415 - 450		450 - 500		500 - 550		550 – 620+	
Wave height [m]	0 – 2		2 – 5.5		5.5 – 14+			
Sea water temperature [°C]	-1 – 5	5 - 8	8 - 11	11 - 14	14 - 17	17 - 20	20 – 27.5+	
Air temperature [°C]	-30 - -10		-10 - -3	-3 - 4	4 - 11	11 - 18	18 - 25	25 – 40+
Soil temperature [°C]	-30 - -10		-10 - 25					25 – 40+
Precipitation rainfall level [mm/h]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Precipitation snowfall level [cm/d]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Ice conditions thickness [cm]	0.1 – 10		10 - 20	20 - 30	30 – 50+			
Fog density [m]	0 - 200		200 - 500		500 - 750		750 – 1000+	

- no impact or N/A
- low impact
- medium impact
- high impact
- extreme state

b) *Wind direction*.

Northerly wind cause risk of collision with other ships or contact with external objects at Gdynia Road. South-easterly wind at approach to Karlskrona causes risk of grounding. During strong winds vessel has to adjust heading to keep course.

c) *Sea water level*.

Lack of required minimum under keel clearance (UKC) may be a reason to cease voyage in order to avoid danger of grounding in Karlskrona (shallow waters, submerged rocks).

When the waves are very high or extremely high, vessel can roll and pitch significantly. Its speed should be adjusted or reduced. Damages to ship's construction can cause off hire; extreme sharing forces, stresses and bending moments of hull can occur.

d) *Air and water temperature, fog and ice conditions*.

High air temperature can cause minor problems with cooling of various ship's systems. Very low temperature during precipitation can cause icing.

Fog and ice conditions on the ports' roads cause risk of collision with other ships or contact with external objects. During severe winters sea ice may occur and vessel traffic can be obstructed. Assistance of ice-breakers can be needed.

During ice condition on the Gulf of Gdansk and Karlskrona approach vessel has to proceed with reduced speed. Risk of collision or contact with external objects exists.

When the fog density is less than 200m, vessel may manoeuvre with reduced speed and extreme caution.

e) *Precipitation*.

Very heavy rainfall and snowfall with squalls can cause risk of drifting and collision with other ships or contact with external objects. Vessel may manoeuvre with reduced speed and extreme caution. Moreover, limited visibility may occur while the rain or snow precipitation is in its extreme state.

Resilience strengthening strategy to climate-weather hazards for Maritime Ferry operating at Gdynia Port and Karlskrona Port waters is described in [4]. According to the primary answers of our consultants (stakeholders) from industry, there are distinguished the following resilience strategies for the particular hazards affecting the maritime ferry operating at Baltic Sea restricted waters.

During strong winds, vessel has to adjust heading to keep her inside the limits of fairway.

In order to reduce influence of high water level or extreme wave height, vessel has to proceed with safe speed and extreme caution. Use of anti-rolling system may be also necessary.

Assistance of ice-breakers is necessary for safe manoeuvring during extreme water temperature. De-icing systems should be used in order to keep the most sensitive systems running in very low air temperatures. On the ports' roads various position fixing and additional information systems should be used for controlling and monitoring vessel's position. Moreover, due to the extreme ice conditions or extreme temperatures, vessel speed has to be reduced.

During maneuvering in restricted visibility (precipitation, ice, fog conditions) additional look-outs can be posted. When necessary, harbour's tugs can be used to break the ice on the fairway. Fog sound signals must be also used when needed.

2.3. Climate-weather hazards for maritime ferry operating at Baltic open sea waters between Gdynia bay and Karlskrona bay

Considering the ranges and states of hazard parameters given in Contributions to generating Questionnaire of End User Needs [4] and [3], the possible hazard parameters intervals for the maritime ferry operating at Baltic Sea open waters between Gdynia and Karlskrona bays are presented in *Table 3*. They represent the scale of the climate-weather hazards impact on the considered critical infrastructure.

The individual hazard parameters may bring the following consequences for maritime ferry described below [4].

a) *Wind speed and wind direction*.

Winds over 15 m/s from the ship's side can cause drifting and list (heel) due to large wind exposed area. Ferry is very sensitive to winds within extreme range. Risk of collision with other ships and very unlikely contact with offshore installations exist. Due to the strong wind, vessel has to adjust or alter heading in order to keep course (*Figure 5*). Significant leeway can also occur.

b) *Wave height*.

Wave height is also dangerous for the considered maritime ferry. In case of adverse sea conditions an alternative (not direct) route should be executed in order to avoid excessive rolling and/or pitching. Often ferry is delayed on arrival to the port of destination. Moreover, in extreme conditions, great sharing forces, stresses and bending moments can occur.

c) *Air temperature, fog*.

Too high air temperature can cause minor problems with cooling of various ship's systems. Low temperature during precipitation can cause icing of ship's construction.

During fog conditions, despite of the limited visibility, vessel may sail with extreme caution. Reduced speed is recommended.

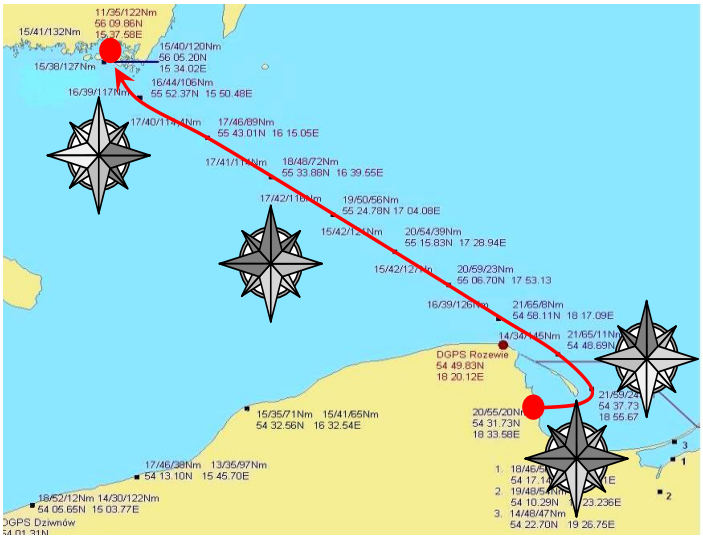

Figure 5. Wind direction impact on maritime ferry during its route.

Table 3. Hazard parameters impact matrix for maritime ferry operating at ports sea waters.

Hazard parameter	**Range / state**							
Wind speed [m/s]	0 – 5.5	5.5 – 8	8 - 17			17 – 33+		
Wind direction (GDY) [azimuth degrees °]	0 - 22.5, 337.5 - 360 N	22.5 - 67.5 NE	67.5 - 112.5 E	112.5 - 157.5 SE	157.5 - 202.5 S	202.5 - 247.5 SW	247.5 - 292.5 W	292.5 - 337.5 NW
Sea water level [cm]	415 - 550						550 – 620+	
Wave height [m]	0 – 2	2 – 5.5		5.5 – 14+				
Sea water temperature [°C]	-1 – 5	5 - 20				20 – 27.5+		
Air temperature [°C]	-30 - -10		-10 - -3	-3 - 4	4 - 11	11 - 18	18 - 25	25 – 40+
Soil temperature [°C]	-30 - -10		-10 - 25					25 – 40+
Precipitation rainfall level [mm/h]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Precipitation snowfall level [cm/d]	0 - 25		25 – 37.5	37.5 - 50	50 – 100+			
Ice conditions thickness [cm]	-							
Fog density [m]	0 - 200		200 - 500		500 - 750		750 – 1000+	

- no impact or N/A
- low impact
- medium impact
- high impact
- extreme state

d) *Precipitation*.
Very heavy rainfall or snowfall with squalls can cause risk of drifting, collision with other ships and contact with external objects. Vessel may sail with caution, despite of the limited visibility. Vessel rolls and pitches significantly or strongly. Speed is reduced.
Resilience strengthening strategy to climate-weather hazards for Maritime Ferry operating at Gdynia Port and Karlskrona Port waters is described in [4]. According to the primary answers of our consultants (stakeholders) from industry, there are distinguished the following resilience strategies for the particular hazards affecting the Maritime Ferry operating at ports sea waters.
During strong winds vessel has to adjust heading and speed in order to follow pre-planned route.
In order to reduce influence of extreme wave height, vessel has to adjust her speed and head to avoid excessive rolling and pitching. Anti-rolling system can be needed if necessary.
De-icing systems are used in order to keep the most sensitive systems running in very low air temperatures.
During maneuvering in restricted visibility (precipitation, ice, fog conditions) additional look-outs can be posted. Vessel speed has to be reduced. Fog sound signals must be used when needed.

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References

[1] Blokus-Roszkowska, A., Bogalecka, M. & Kołowrocki, K. (2016). Critical infrastructure networks at Baltic Sea and its seaside, *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 7-14.
[2] EU-CIRCLE Report D1.2-GMU1. (2016). *Identification of existing critical infrastructures at the Baltic Sea area and its seaside, their scopes, parameters and accidents in terms of climate change impacts*.
[3] EU-CIRCLE Report D2.1-GMU3. (2016). *Modelling Climate-Weather Change Process Including Extreme Weather Hazards*.
[4] EU-CIRCLE Report D1.3-GMU4. (2015). *Contributions to generating Questionnaire of End User Needs*.
[5] EU-CIRCLE Report D1.4-GMU3. (2016). *Holistic approach to analysis and identification of critical infrastructures within the Baltic Sea area and its surroundings – Formulating the concept of a global network of critical infrastructures in this region ("network of networks" approach)*.
[6] Jakusik, E., Kolowrocki, K., Kuligowska, E., Soszynska-Budny, J. (2016). Identification of climate related hazards at the Baltic Sea area. *Journal of Polish safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 1, 99-104.
[7] Kolowrocki, K. & Soszynska, J. (2010). Safety and risk optimization of a ferry technical system. *Journal of Polish safety and Reliability Association, Summer Safety and Reliability Seminars* 1, 159-172.
[8] Kolowrocki, K. & Soszynska-Budny, J. (2011). *Reliability and Safety of Complex Technical Systems and Processes: Modeling-Identification-Prediction-Optimization*. Springer, ISBN: 9780857296931.