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Hydrodynamic Conditions and Traffic Volume Against Reliability of Inland Waterway Transport

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Abstract

Analysis of the impact of navigation conditions and traffic intensity on the reliability of inland waterborne transportation on the Oder River is presented in this paper. It was shown that present hydrologic conditions in this waterway do not allow to meet basic standards that every transportation system must comply with. Fundamental reasons are the low water depth and ice cover on the route. Ship failures and accidents have minor influence on reliability. The number of accidents on the Oder River depends on traffic intensity and amount of ships. The number of accidents is influenced by conditions of navigation. Such relationship is not observed on the German waterways. There the inattention of crew and excessive ship speed are the fundamental reasons of accidents.

1. Introduction

The basic requirements to be fulfilled by any transport system is reliability and punctuality. In terms of inland waterway transport of great importance are the hydrological conditions of waterways and reliability of the fleet. The hydrological conditions limit the duration of the navigation season and transport fleet use factor. There is a large dependence on the climatic conditions that occur in the catchment area of the waterway. Two factors are essential:

- period of ice presence in the waterway,
- amount, duration and area of precipitation.

The period of presence of ice is independent of the technical and organizational conditions. The second factor makes it necessary to close the navigation way of

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the reasons so inadequate like the rainfall (low water level) and because of very heavy rain. At the high-water level the shipping is also suspended. Through proper hydro-technical structures these negative impacts can be partially minimized. This requires the construction of storage reservoirs and waterways canalizations. These investments, despite their costs, are very vigorously opposed by the environmental movement.

In Polish conditions, the analysis of reliability and safety of inland waterways transport can be made for ODW (Oder Waterway). For many years, in this waterway there is a regular transport of goods (as far as conditions allow this).

ODW is a waterway with diversified hydro-technical parameters. Due to the problem of reliability it is important to divide it into:

- channeled Oder (from Kędzierzyn-Koźle to Brzeg Dolny with the Gliwice Channel),
- free flowing Oder (from Brzeg Dolny to Szczecin).

An area which limits and determines the transport is the section between Brzeg Dolny and Nysa Łużycka estuary. For several years, the conditions that exist below the lock system in Brzeg Dolny (river bottom erosion), in principle, prevent the regular transport across the navigable section of ODW. The water transport is concentrated on the routes Gliwice – Wroclaw and Szczecin – West European waterways. Improving of the navigation conditions, which allow the use of the Oder for its entire length may be made after finalization of construction of the new lock system in Malczyce. The completion of this project is 2016. This will mean that the construction cycle will be 20 years, which is the world record. Because of the profitability of waterway transport in the Poland, the minimal draft, at which the owner is not making a loss is 1.1 m (if the transport of goods takes place in both directions). In another case (the transport of goods in one direction) the draft at which the owner is not making a loss is 1.4 m.

There are no basically consistent and comparable data on the causes of breaks occurred in realization of transport tasks by the inland vessels. The recommendations of the EU's statistical office, are given the definitions of water transport accidents [4]. Focus is given on the injuries. The failures and their nature are treated very generally and selectively. Thus, a large freedom in the statistical data is provided by the administration of individual sections of the waterways.

In Polish conditions, the information about interruptions in shipping should be collected by the regional inspectorates of inland waterway transport (ship failures, collisions, etc.) and by the regional administration of waterways – RZGW (interruptions in shipping due to hydro-technical conditions, hydro-technical equipment failures).

2. Influence of Hydro-Technical Factors and Meteorological Factors on the Degree of Reliability of Transport

Channelled Oder

The length of this section is 186 km, and Gliwice Channel is 41.2 km in length. It is assumed that the shipping season runs from 15.03 to 15.12, hence 275 days. In the entire section of the channeled Oder there is guaranteed transit depth of 1.80 m, which ensures the operation of the fleet with a draft of 1.7 m. Occasionally, during very dry periods on the section between Oława and Ratowice (length 4 km) the depth is decreased to 1.4 m. It has no significant effect on the traffic intensity. Opening and closing of the shipping season is dependent on the several factors. These are as follows:

- presence of ice,
- hydro-technical conditions (too low or too high water levels),
- completion of hydro-technical structures repairs,
- preparation of waterway for navigation.

During the shipping season there are the breaks caused by presence of the following factors:

- too low water levels, which do not guarantee the required depth,
- too high water levels, which prevent the crossings under bridges,
- presence of ice,
- failures of the hydro-technical structures.

In calculations of the number of days of break in shipping, the breaks were included, which last at least one full day (from 6.00 AM to 10 PM – fixed time of the operation of locks), during which the transit could not take place, the continuous movement of vessels, on the route Koźle – Wrocław – Brzeg Dolny. There were no the counted breaks lasting for several hours because they do not have a substantial effect on the cargo transit rhythm.

The shipping breaks were caused mainly by the following reasons [2]:

- occurrence of swollen and flood flows, which imply laying of weirs,
- failure of mechanical devices in locks and weirs (failure of a gate drives, gate locks, sector malfunctions, failure of the needles, failures of needle dams),
- obstruction of gates and locks by underwater obstacles,
- lack of electricity supply in barrage facilities that prevent their exploitation,
- vessels accidents blocking navigation route (for example sinking of the barge),
- necessity of lowering water level in weirs area to allow work related with crossing Oder river with equipment and facilities (pipelines, cables, construction of bridges, etc.),
- execution of hydro-technical structures conservation works and waterway regulatory work carried out in the shipping season,

- earlier appearance of ice phenomena in the lock channels and Oder river, preventing the exploitation (devices manoeuvring) locks and weirs.

In the period from 1980 to 2008 (29 years), the total number of days of navigation was 7975. During this period, the actual number of days of navigation was 7559, representing 94.8% of the statutory period of navigation. The total number of days of break in navigation – 747 days, were caused by the following reasons:

- occurrence of flood risk – 552 days,
- failures of hydro-technical devices – 151 days,
- other reasons (low water levels, vessels malfunctions, presence of ice) – 44 days.

The predominant reason for the breaks in navigation of the channeled Oder are the flood risk. The breaks due to the high water level are 74%. The interruptions due to low water levels are caused by a controlled water release from area between the weirs to guarantee the adequate water levels on the free flowing Oder section. This operation is carried out occasionally to allow the transport down the river ships built in shipyards located in Koźle, Wrocław, Malczyce and Nowa Sól.

The data on the Gliwice Channel cover the period from 2000 to 2010. The flood of 1997 destroyed the previous data. In the analyzed period, the shipping was not always possible within the statutory period. The overall statutory number of navigation days was 3025, days of shipping were 2850 (94.2%). In this period there were 57 interruptions caused by the accidents. Most of the breaks were the results of the flood situations – 40 days. The breaks due to failure of the hydro-technical structures – 11 days. The other days of break were caused by the other factors.

Free flowing Oder

The length of this section, from Brzeg Dolny to Szczecin, is 469 km. The shipping season can last from 1.1 to 31.12. (365 days). The breaks can be caused by occurrence of the following factors:

- too low water levels, which not guarantee the required depth,
- too high water levels, which prevent crossings under bridges,
- presence of ice.

The analysis of free-flowing Oder in the period from 01.1980 to 31.12.2007 showed that for the total 9860 days, the route was closed for 888 days, due to the presence of ice for 722 days (7.3%) and due to the high water level for 166 days (1.7%).

The decisive factor in the occurrence of breaks is the low water levels. The transit depths of free-flowing Oder are determined by the depth of the section from Brzeg Dolny to the estuary of Kaczawa river (km 280-315). In the analyzed period, the transit depth 1.3 m and lower was present for 5029 days, which represents 51% of the analyzed period.

From the shipowner perspective point of view it is an insignificant total number of days of occurrence of the transit depth. It is important to know the duration of specified uninterrupted (continues) number of days with the fixed transit depth. For the free flowing Oder this characteristic durations are 3, 6 and 9 days. They define

the average duration of the cruise Wroclaw-Szczecin (3 days), Szczecin-Wrocław (6 days) and circular cruise – 9 days [5]. The table 1 shows the percentage of the transit depth duration depending on the duration of the cruise.

On the base of data from RZGW Szczecin for the period 1982-2007 [7], respectively, for the certain sections, the transit depth in % of the navigation season, calculated from January 1 to December 31 were as follows:

- section from the Nysa Łużycka estuary to Warta estuary: above 1.4 m – 52.8%, the allowable navigation – 85.6%,
- section from Warta estuary to Hohensaten: above 1.4 m – 70%, the allowable navigation – 87%.

The above data indicate that the area limiting the transit depth is the section below Brzeg Dolny (transit depth above 1.4m about 40% of the navigation season, Table 1).

In the current hydrological conditions the transport across the whole ODW is not meeting the basic standards for the reliability and timeliness in the realization of transport tasks. Such the requirements are fulfilled in the case of transport tasks limited to realize in the channeled Oder section.

Table 1

Transit depth in function of travel length

Dept h [m]	Travel length [days]			
	1	3	6	9
1,3	51%	43%	38%	34%
1,4	46%	38%	32%	28%
1,5	40%	32%	27%	23%
1,6	35%	28%	23%	20%
1,7	31%	24%	19%	16%
1,8	27%	20%	16%	13%

3. Effect of Failures and Shipping Accidents on the Reliability

The analysis is based on the data provided by the Offices of Inland Navigation from Kedzierzyn-Kozle, Wroclaw and Szczecin in the period from 1980 to 2000. During this period, 773 shipping accidents were registered [3]. After year 2000, those inland navigation authorities have recorded neither failures nor accidents. This follows from the fact that the crews do not report the failures or accidents due to their negligible harm. Of this number 81 can be classified as accidents resulting from failure or unsatisfactory technical condition of the vessel. The others are the result of careless manoeuvring or bad navigation condition (too shallow water). The bad conditions are primarily the low water levels. If you consider that the low water

levels is the transit depth of less than 1.4 meters or operating vessel with margin of water under the hull bottom less than 20 cm, then the total number of 771 accidents 273 of them can be classified as a result of low water level. The number of stranding is shown in Table 2. Table 3 shows the number and types of damage in shallow water. Number of shallow water accidents is greater than the number of stranding or collision with underwater obstacles. This follows from the fact that more damage occurred at the same time.

Of the total number of 273 accidents, 105 took place on the channelled Oder, and 168 on the free flowing Oder. The most accidents took place in the channeled Oder in sections with the transit depths 1.6 m (12 cases) and 1.8 m (87 accidents). For those transit depths the majority of accidents took place in the downstream movement – 60 cases, and upstream – 9. The rest of accidents took place in the channels and at the lock's entrances and exits. A large number of accidents on the channeled Oder, happened with a minimum margin of water under the hull bottom, this indicates an insufficient caution by the crew. The factors that may reduce the number of such the failures should be to increase the propulsion engine power and to equip the pushed trains with a bow rudder on the front barge. The increase in engine power will allow to decrease the stopping distance. Improving the features of the ship is important, especially where the stopping maneuvers may occur very often, i.e. in sections of the channelled waterway. In the free flowing Oder the most accidents and failures are recorded in the section Brzeg Dolny – Ścinawa and this decreases downstream to the smallest values below the estuary of Warta. The section Brzeg Dolny – Ścinawa is considered as the area with the worst navigation conditions, section which often prevents the navigation in the free flowing Oder.

For almost 500 cases (Table 4), which occurred due to the other than a low water level, 65 are the accidents resulting from the failure of devices or vessel equipment. The other are the careless crew or other associated with the difficult navigation conditions (small bight radius, strong winds, underwater obstacles). Total of these 299 accidents took place on the channelled Oder, remaining on the free flowing Oder.

Apart from the accidents and failures as a result of careless crew and lack of proper assessment of the vessel technical condition, the basic cause of accidents are the poor navigation conditions on the waterway.

Table 2

Number of ship strandingor collision with underwater obstacles (shallow water)

Failure type	Section		Sum
	Channelled Oder	Free flowing Oder	
Stranding	49	76	125
Underwater obstacle	38	64	102

The collisions of vessels on the channelled Oderwere are associated with meetings of the ships in various stages of passage through the barrages. It usually was a

Table 3

Types of damages in shallow water

Type of damage	Ection		Sum
	Channelled Oder	Free flowing Oder	
Hull penetration	80	103	183
Damage to the hull or equipment	9	18	27
Damage to the propeller, rudder	22	63	85
Other damages	59		354

Table 4

Types of accidents in conditions different than the shallow water

Type of accident, damage	Section		Sum
	Channelled Oder	Free flowing Oder	
Ship collision	43	52	95
Collision with hydro-technical structure	133	6	139
Collision with bank, wharf	58	39	97
Ship stranding, collision with underwater obstacle	20	28	48
Ship damage due to presence of ice	5	3	8
Anchor damage, loosing	2	27	29
Propeller, rudder damage	20	15	35
Fire on board	2	8	10
Drowning of man	4	7	11
Other accidents, damages	12	14	26
Total	299	199	498

consequence of the crewcareless. Their number could be reduced by improving the manoeuvrability and stopping ability of the ships. The second region with a large number of collisions is the section below the Warta mouth. The reasons for these collisions are the bad weather conditions (wind, fog). A better navigation equipment (radars) can significantly contribute to improving of safety on this section of ODW. A large number of collisions with the hydro-technical structures primarily refers to the pushed trains. The most of them took place during the passage through the lock (hitting the rails, lock's head). The reduction of these collisions is possible by improving the maneuverability of inland fleet. The cases of ship stranding resulted from the silt in enter into the lock's channels (channelled Oder), lack of river depth near wharf, leaving main waterway during the overtaking manoeuvres. The loss of anchor was followed by the emergency anchoring maneuver at the high speed to avoid a collision. The damages to the screws and rudders were the result of hitting the solid obstacles (logs, cables, ropes, stones). The collisions with the river banks, wharf were the consequences of the lack of maneuverability in the difficult weather conditions and navigation (strong winds, poor condition of lock's entrance channels, small bight radius).

In Figures 1 and 2 the ratio of the number of failures to load of the pushed barges operated on the Oder in years 1980–2000 is shown. The presented results are based on the statistical data contained in the statistical yearbooks. The decrease in the number of failures is related to the following:

- decrease in the freight calculated in tonnes of cargo,
- decrease in the number of operated pushed barges,
- change in the fleet management system in ODRATRANS.

Changing the fleet management system is a switch to the fleet lease to the crew. In this system the vessel (motor barge, pusher with pushed barges) becomes a property of the crew. In the interest of the crew is to take care of the technical condition of the fleet. For the minor accidents, the crew does not report the incident, carrying out any repairs on their own.

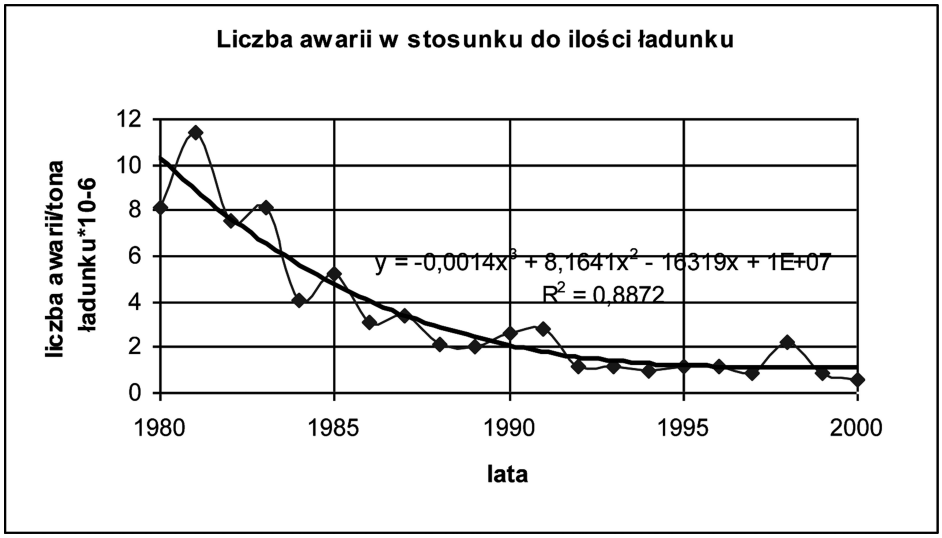

Fig. 1. Number of failures in relation to the volume of cargo

There is a clear and obvious connection between the number of failures, and the number of transported goods and tonnage of the operated pushed barges (Fig. 1 and 2). The decrease of freight implies a significant decrease in the volume of traffic. This should be an explanation for the reduction in the number of failures. The second factor that contributed to the decline and stabilization of the number of failures in the 90s was the introduction of the fleet lease system by the crew. Increase in the number of failures that occurred in 1998 could be caused by the changes in the river current caused by the flood in 1997.

The analysis of accident and failures in ODW shows that the main factor increasing the risk of failures and problems with realization of the transport task are the hydro-technical conditions on the waterway. They increase the risk of failure presence, as well as the failure to the load delivery on time, or even interrupt the

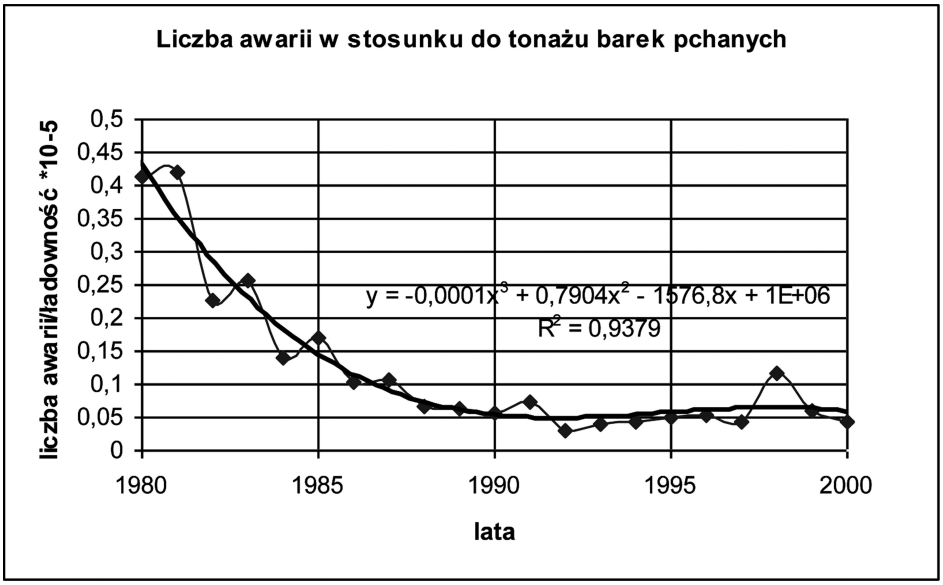

Fig. 2. Number of failures in relation to the tonnage of pushed barges

transport tasks – the lack of necessary transit depth. A large percentage of the accidents is the result of careless crew. To increase the safety, the new fleet should have the greater reserves of propulsion power and a better maneuverability. These elements can offset the negative impact of unfavourable navigational conditions (wind, shallow water) on the safety of navigation. The technical condition of operated ships and applied technical solutions do not generally affect the number of failures. It can be assumed that the reliability of the mechanisms and devices of the vessel is satisfactory.

The estimated data were grouped to undesirable events and acquiring (on the first level of decomposition of the transport system) two groups of events. For the inland waterway transport system these are the events caused by the faults and errors of the waterway infrastructure and restrictions created by the improper flows and events related to the damages and vessels service (pushers and barges). The outweigh the events from the first group (hydro-technical conditioning) is with contribution over 0.99. [6].

4. Accidents and Breaks in Shipping on the Waterways of Western Europe

There will be presented the data on failures and accidents on the German waterways with the highest traffic volume in 2009 [8], [9], [10]. The data refer to regions as follows:

– WSD Mitte – interior channel with adjacent branches,
– WSD West – the Rhine to the Dutch border and West German channels,
– WSD Südwest – Upper and middle Rhine, Moselle, Neckar, Saar.

In Figure 3 the map of German waterways with the specific areas of the administration of waterways is shown. The number of failures, volume of traffic, number of aircraft operated on a particular sections of waterways in the described administrative regions is presented in Table 5. The results are based on the statistics provided by the administration of region waterways, published on the website www.elwis.de. The Figure 4 shows the distribution of accidents due to their nature. The vast majority of accidents are the result of crew error, and existing navigation trammels. The navigation obstacles are mainly the locks and bridges.

Table 5

Number of failures in selected waterways of Germany

		WSD SUDWEST			
Waterway	Load [mill tonnes]	Number of Ships quantity	Failures quantity	Ratio [Failures/ Load] x10-6	Ratio[Failures/ Number of Ships] x10-3
Upper and middle Rhine	80,1	31 444	181	2,26	5,76
Mossele	11,7	11 207	61	5,21	5,44
Neckar	6,5	8 952	27	4,15	3,02
Saar	3	2 749	5	1,67	1,82
		WSD MITTE			
Uelzen	16,89	28 325	42	2,49	1,48
Braunschweig	10,312	16 774	31	3,01	1,85
Minden	10,707	15 417	24	2,24	1,56
Hann, Munden	0,557	20	9	16,16	450,00
Verden	2,865	5 258	14	4,89	2,66
		WSD WEST			
Ren Emmerich	137,94	140 406	90	0,65	0,64
WDK	15,68	20 116	30	1,91	1,49
RHK	12,904	17 841	24	1,86	1,35
DHK	6,148	8 399	3	0,49	0,36
DEK	10,339	14 526	51	4,93	3,51
KuKa	3,534	5 513	5	1,41	0,91

A significant cause of the accidents is not following the speed limits in the channels and errors during berthing to the wharf. This leads to the accidents related to ship squatting and grounding. This may be due to the lack of sufficient training and experience of the crew. The traffic volume and waterway parameters affect the number of collisions. This is evident in the case of the shipping channels and rivers

Fig. 3. Map of German waterways with administrative division

where the conditions are not favourable to navigation. This applies to the Moselle, and the upper and middle Rhine. A large number of locks, numerous meanders, high speed of current interfere with navigation. This leads to a relatively greater number of accidents when compared to the Rhine in the area and bellow the connection with the West German channels (Fig. 3). The failures defined as the ”a stream, wave

impact" are the negative impacts of the ship traffic on the waterway bottom due to the propeller slipstream and emerging wave system.

There has been a large number of accidents caused by the sports (tourist) boats. This particularly applies to the waterways which are the branches of the main routes, such as a section of the Weser, to the south of middle channel (WSD MITTE – Hann, Mundek). For the total nine accidents in this section, seven were caused by the sports boats.

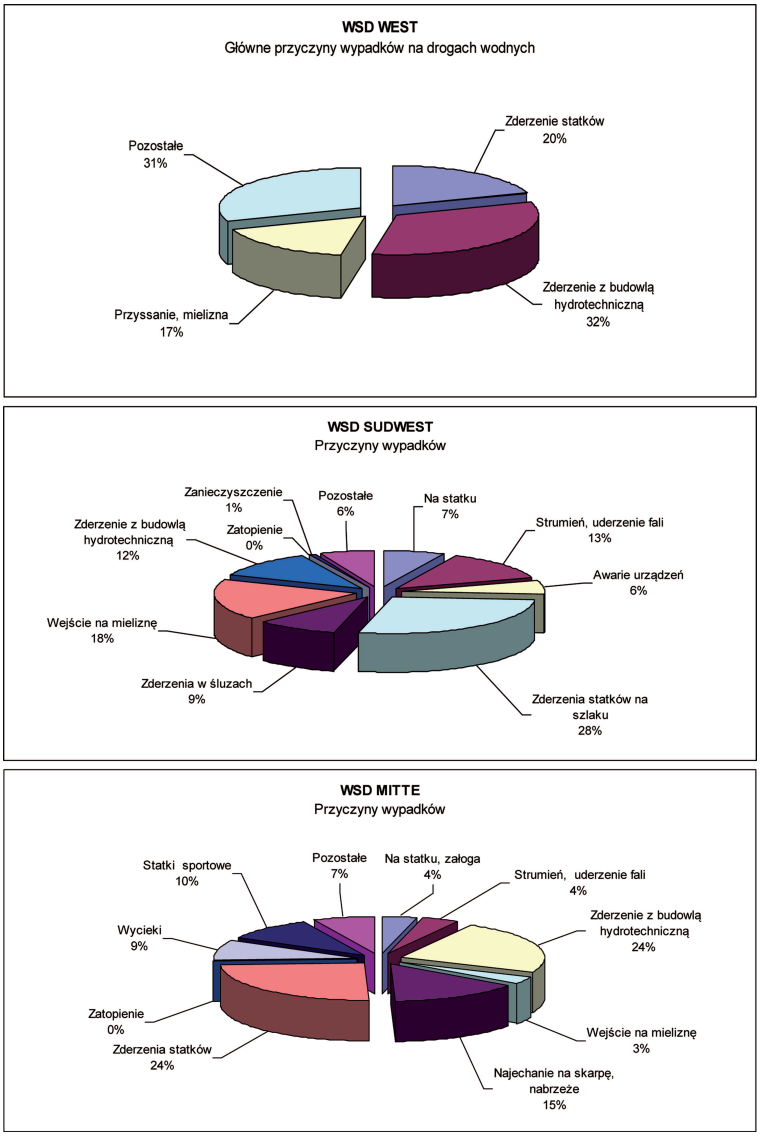

Fig. 4. Types of accidents on the waterways of Germany [8], [9], [10]

In comparison to the number of failures on the Oder in case of German waterways there is no relation between the traffic volume (fleet size) and number of accidents. This means that the number of cases is determined by the conditions of navigation – the parameters of the waterway. A relatively higher number of accidents in relation to the volume of traffic on the Oder may be due to the lower standards of vessel equipment. The safety of navigation in the restricted waterway is strongly influenced by the power of propulsion system. *The vessels designed and operated in Poland in the 70s and 80s of the last century were characterized by the underestimated propulsion power due to the necessity of minimizing the consumption of liquid fuels.* There is no significant number of accidents resulting from the failure of equipment of the ship.

This group failure is classified as the 'other'. In relation to the total number of accidents on the German waterways there is low number of accidents resulting from the failure of mechanical equipment. *Within this group the hydro-technical equipment failures and malfunctions of equipment of the ship are included.*

5. Summary

The inland waterway transport is perceived as a system with a small number of accidents. The accidents that occur do not cause the significant difficulties in the realization of transport tasks. In fact, there aren't recorded fatalities resulting from the accidents or other incidents involving the inland ships. The occurred accidents did not cause a danger to the natural environment. The primary causes, types of accidents on the waterways of Europe are as follows:

– collision of vessels on the waterway and in situation of passing lock,
– ship collision with wharfs, the banks and hydro-technical structures,
– squatting and stranding of the ship,
– damage to the banks and bottom of the waterway as a result of the destructive effects of waving and propeller slipstream,
– the other, also related to accidents on board of the ship.

The primary reason for the failure is the crew inattention and excessive vessel speed in the waters of limited depth and width.

In Poland, on the Oder river there was a clear dependence on the number of accidents and traffic volume. With regard to the waterways in Germany there is no such the dependence. This is confirmed also by the Rhine Commission accessible data[1]. In the Polish conditions, the reliability of water transport is mainly affected by the hydro-technical conditions – the breaks in shipping caused by the low and high water levels, presence of ice in the waterway. In the waterways under the administration of WSD Südwest (upper and middle Rhine, Mosel, Saar, Neckar) the interruptions in shipping in the years 1970-2009 did not exceed 4% of the statutory navigation time [9]. The longest break was 3.96% at the Neckar River and was the result of the high water level. In the administration, there is a lack of data of the breaks in shipping.

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