TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 11
Number 3
September 2017
DOI: 10.12716/1001.11.03.07

Criteria of Accidental Damage by Ships Anchors of Subsea Gas Pipeline in the Gdańsk Bay Area

K. Marcjan, R. Dzikowski & M. Bilewski
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: This paper discusses issues of the accidental anchor damage to offshore subsea pipeline as one of the most significant threat to underwater infrastructure. The density of vessel traffic over the pipeline between platform Baltic Beta and Wladyslawowo power plant has been analyzed. In order to determine the most common damages associated with heavy ship traffic, the authors used the risk model for underwater infrastructure. For this purpose ships anchor equipment has been categorized and as the results the criteria of damage to the pipeline have been discussed.

1 INTRODUCTION

During last years the demand for natural resources rapidly increased. In addition to land-based sources the submarine deposits are exploited intensively. In parallel with the extraction of sea basins resources the renewable energy sources are built and exploited on the sea. These facts necessitate the transfer of hydrocarbons and energy ashore. Under the bottom of the sea, numerous networks of pipelines and cables have been laid. Technological development allows laying pipelines and cables on the ever greater depths and the intensification of exploration and extraction materials from under bottom deposits resulted in a significant increase in the amount of undersea infrastructure. China, for example, have a 3000 km undersea pipelines and in the next decade are planning to triple the length of this infrastructure. Linked to this fact it rises the problem of the safety of such structures and the safety of the marine environment at risk of failure or damage. Statistical data indicate that a significant threat to underwater pipelines is the ships traffic especially with it the risk of damage by the anchors or directly the hull hit. Other dominant factors of damage underwater infrastructure are falling objects from oil rigs and ships during cargo and spare parts transshipment and pipelines corrosion. The statistics of damage to offshore sector pipelines are gathered in the PARLOC 2001 database. Data are collected in years 1960 -2003 and concern pipelines in the North Sea. The database includes 1,567 pipelines with a total length of 24837 km.

2 LITERATURE REVIEW

Risk of the offshore infrastructure damage is very important issue for companies operating the oil and gas fields as well for the classification societies and safety institutions which create rules and recommendations for them. They can be found for example in Det Norske Veritas or HSE recommendations [1], [2], [3], [5]. Moreover, there are scientific researches concerning safety and risk assessment in area of the risk for underwater pipeline systems. Authors continue research contained in papers [6], [7] for systems situated in the Polish economic zone.

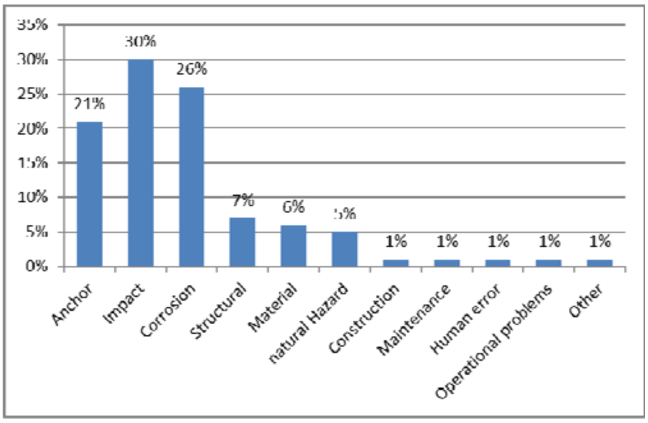

Figure 1. Underwater pipeline damage statistic. Data from PARLOC 2001 database

Database PARLOC 2001 groups the most common causes of damage to the: damage by anchors of vessels passing above the pipeline, hit by the ship's hull, corrosion, technical defects, defects in materials, natural hazards, structural defects, technical maintenance, human error, operational problems, others. Fig.1.

DNV GL classification society observed increasing amount of the lost and dragged anchors. In Fig. 2 there is the statistic of lost anchors.

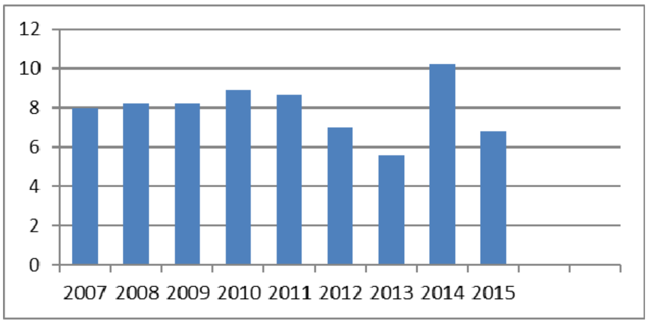

Figure 2. Anchor lost per 100 ship year. Data from DNV GL

Scenarios of the subsea pipelines system risk assessment should take into consideration the following factors: vessels passing the pipeline, including oil rig support ships (supply vessels, floating cranes, ships, surveillance and diving vessels), merchant ships and ferries, fishing vessels. By assuming emergency situations, there should be considered situations of emergency anchors dropping or dragging (important data are type and weight of anchors) and bottom trawling (network type, trawl thrust) as well as the characteristics of the pipeline: the type (steel, flexible), the depth of the basin, deep depressions in the ground, pipeline diameter, wall thickness and pipe lagging. Model of risk assesement is presented in Fig. 3. To analyse the damage important is to check if the dredged anchors are able to catch the pipeline system, what is analysied in this paper.

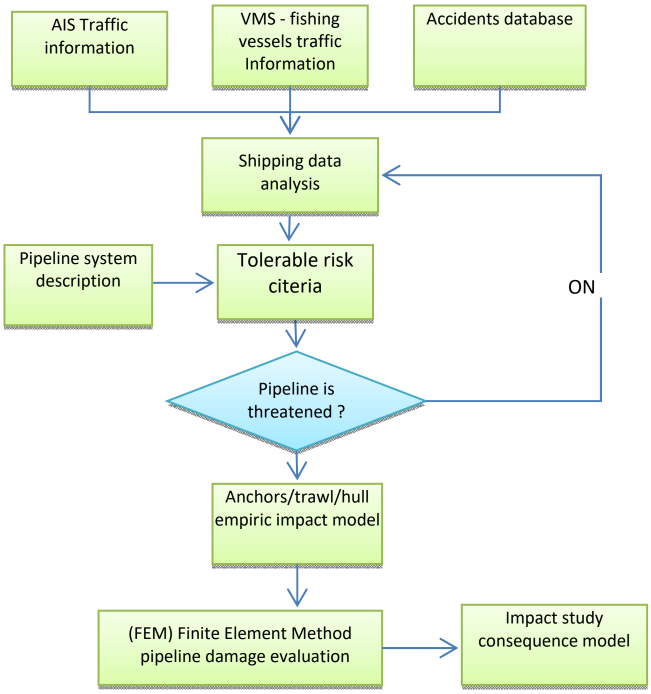

Figure 3. Model of the risk analysis for offshore pipeline

3 OFFSHORE ACTIVITIES IN THE POLAND'S ECONOMIC ZONE

The exploitation of underwater resources by Polish companies takes place in Poland's economic zone. In the complex process of subsea exploitation, the extraction of oil and/or gas is one of the last stages. Starting from the development of a geological model of production sites making use of geophysical survey, the operations include the assembly and fixing of drilling and production platforms and underwater systems of pipelines and networks, seaborne transport of hydrocarbons to land, movement of drilling rigs to new locations and periodical reconstruction of existing wells. Given below are upstream activities related to the oil and gas production and operation and maintenance of existing wells located in the Polish economic zone:

1 exploration is performed by:
   – seismic reflection survey vessels Polar Duke and *St. Barbara* that carry out 3D seismic survey within the licensed area of exploration in fields B21 and B16 (Fig.4), and drilling of exploration holes.
   – drilling holes for geophysical survey and measurements, executed by Petrobaltic, Lotos Petrobaltic rigs.
2 production performed by various types of rigs:
   – jackup – stationary production rigs,
   – jackup – mobile drilling rigs,
   – jacket – stationary unmanned production rigs.
3 exploration and exploitation wells are established in licensed areas; exploitation wells are used for oil and gas extraction as well as injection of deposit water and seawater filtered to optimize the production.
4 transfer of gas via an underwater pipeline to Wladyslawowo.

5 transshipment from a single buoy mooring (SBM) situated near the Baltic Beta rig and carriage of oil by the mt IKARUS III to Gdańsk.
6 transshipment from a single buoy mooring (SBM) situated near the Lotos Petrobaltic rig and carriage of oil by the mt Apatyth to Gdańsk.
7 continuous supplies to the rigs by offshore vessels and supervision provided by standby vessels; at present, the vessels employed for the purpose are the tugs *Agath*, *Bazalt* and *Kambr* and support ships *Aphrodite I* and *Sea Force*.
8 jackup rigs towage to new drilling locations.
9 submarine work: diving and maintenance, use of remotely operated vehicles (ROV).

The system of gas transfer from Baltic Beta to Wladyslawowo consists of the following items: The gas compression station on an oil rig Baltic Beta.

1 submarine transmission pipeline with a length of 82 km and a diameter of 115 mm. The pipeline has been constructed according to the technology of Precision Tube Technology of Houston company. Steel pipes are insulated with poliethylan
2 the station separation, gas storage and preparation of fuel for the power plant with a capacity of 120 000 Nm3 / day
3 Wladyslawowo power plant with 2 gas turbines and two heat recovery boilers of total electric power approx. 12 MWe and heat approx. 18 MWt, 3 peak boilers for gas and oil with a total capacity of 15 MW.

Underwater pipeline and the underwater infrastructure in Baltic Beta safety zone is shown in the (Fig.4). Pipeline characteristic:

Material of pipe: Steel X65C, pipe tension parameters: Re = 455 Mpa, Rm = 540 Mpa. Protection: 3 layers: Valspar epoxide material, Dupont epoxide polymer, polyethylene material. Internal diameter 114,3 mm, external diameter 101,6 mm. First transmission of natural gas was in August 2002 and first heating season using natural gas started in Wladyslawowo – Autumn 2003r.

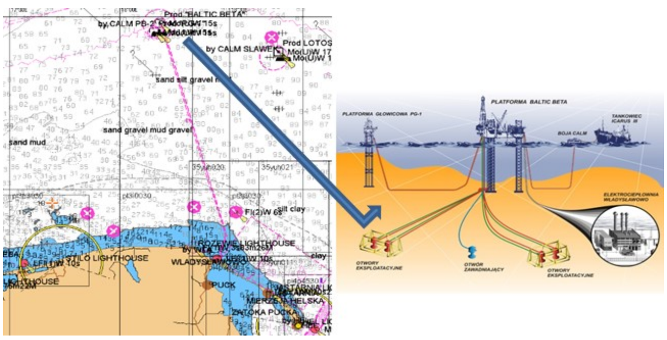

Figure 4. Underwater pipeline from Baltic Beta oil rig to Wladyslawowo power plant and scheme of the underwater infrastructure. Source: http://www.lotos.pl/, ENC chart

4 SHIPS PASSING DISTRIBUTION OVER THE UNDERWATER PIPELINE

The AIS data of vessel traffic over the pipeline have been decoded and analyzed. Character of encoding AIS information's is based on 6-bit the ASCII (the total number of characters in the 6-bit code is 64) as opposed to the ASCII 7 bit. An example of decoded AIS massages has been presented in the table Fig.5.

	time timestamp without time	mmsi integer	nav_stat smallint	latitude real	longitude real	sog real	cog real	hdg real
1	2011-07-01 00:00:36	304877000	0	55.2173	13.3748	12.5	95	511
2	2011-07-01 00:00:38	211274670	0	55.1903	13.3078	13.9	98.5	101
3	2011-07-01 00:00:55	210230000	0	55.2332	13.9812	8.6	271.3	276
4	2011-07-01 00:01:05	276161000	0	55.2278	13.9101	11.9	273.9	274
5	2011-07-01 00:01:19	245114000	0	55.1853	13.782	10.3	97	94
6	2011-07-01 00:10:35	304877000	0	55.2142	13.4357	12.6	96	511
7	2011-07-01 00:02:34	304950000	0	55.264	12.9662	14.2	276	274

Figure 5. Decoded AIS data in table form.

In order to determine the frequency and to indicate the places where the ships pass over the submarine pipeline the AIS data from two summer months (June and July of 2011) were used. In those month's there was highest vessel traffic density. In the Fig. 6and 7 below the ships passing distribution is presented depending on the latitude of the exact place where ships were crossing over the pipeline. The pipeline is divided into 13 sections (every 3 minutes of latitude) or approximately every 3 nautical miles. In designated section in the period from June to July 2011 the pipeline was passed by 2,334 ships nearly 39 ships a day.

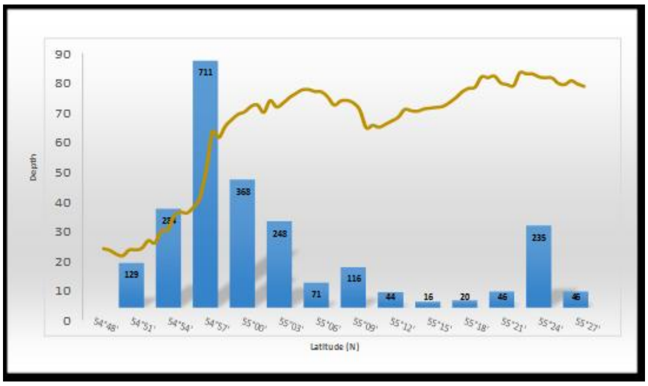

Figure 6. Ships passing distribution over the underwater pipeline with bathymetry curve

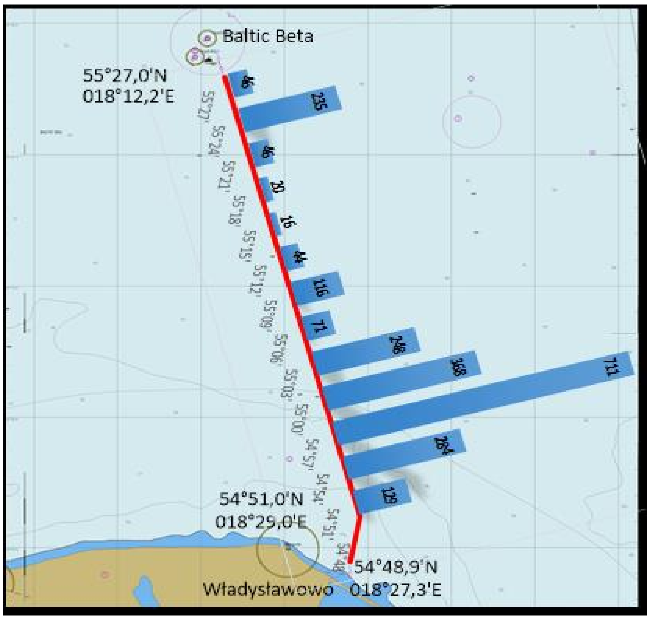

Figure 7. Ships passing distribution over the underwater pipeline

Tolerable risk criteria for pipeline damage by dredged anchor

Various parameters have an hooking subsea pipeline by dredged anchor. One of them is geometric parameter of the anchor versus pipeline diameter. The most important is length between anchor shank and top of the anchor fluke. A principle sketch is shown in Fig 8.

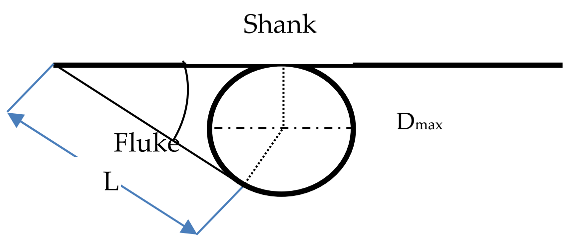

Figure 8. Anchor hooking geometry

The minimum fluke length L can be calculated as follow:

$$L = \frac{D_{max} \sin\alpha}{2\left(1-\cos\alpha\right)} - \Delta L \qquad (1)$$

where:

D_{max} – maximum pipeline diameter,

α – angle between shank and fluke,

ΔL – correction for width of the shank.

For diameter of the analysed pipeline 115 mm the minimum length of the fluke is 158 mm. Comparing with the catalogue of anchors Fig. 9 every available anchor is able to hook this pipeline. Fluke length is E value in Fig. 9.

Weight (kg)	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	ØF (mm)
50	575	410	184	378	300	15
75	660	480	210	429	340	15
100	723	510	230	474	375	20
125	780	550	245	511	405	20
150	835	580	264	544	430	20
180	888	625	281	578	454	20
200	915	645	290	594	470	25
225	950	670	300	622	493	25
240	985	694	312	644	510	25
275	1020	710	322	666	527	25
300	1050	738	330	685	543	30
325	1075	758	338	703	557	30
360	1100	778	346	719	570	30
400	1150	810	360	752	595	30

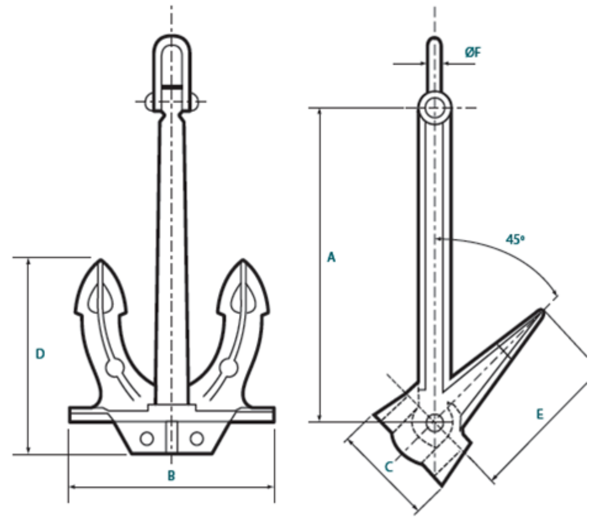

Figure 9. Example of the anchor dimension catalogue.

Second condition is depend on vertical distance of the anchor chain can reach during dragging. Anchor chain is never vertical due to interaction between chain and water. That is illustrated in the Fig 10.

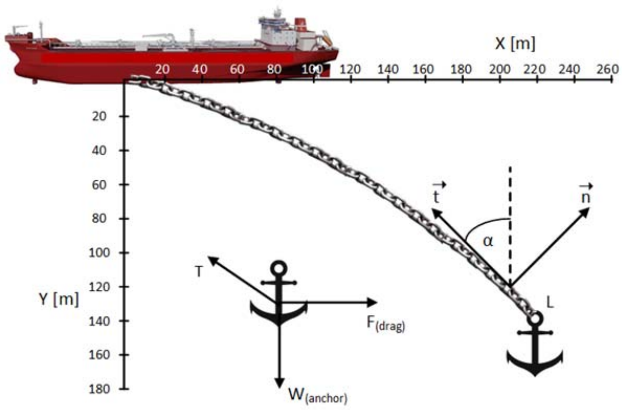

Figure 10. Force distribution in dredged anchor chain

Equation of dredged anchor forces can be written in accordance Newton's Law as follow:

$$\sum \vec{F} = m\vec{a}\left(l,T\right) = \vec{0} \qquad (2)$$

$$m\vec{a}\left(l,T\right) = \frac{\partial}{\partial x}\left(T\vec{t}\right) + f_n\vec{n} + f_t\vec{t} + mg\vec{k} \qquad (3)$$

where:

m- mass of the chain per unit length,

g- acceleration of gravity,

$\vec{a}\left(l,T\right)$ - acceleration of the chain,

l – coordinate along the chain,

f_n – normal drag force per unit length,

f_t – tangential drag force per unit length,

$\vec{n}$ – normal unit vector,

$\vec{t}$ – tangential unit vector,

$\vec{k}$ – unit vector in the direction of gravity.

There are two components of drag force:

$$f_n = C_{Dn} \rho_w \frac{D}{2} v^2 \cos^2 \alpha \tag{4}$$

$$f_t = C_{Dt} \rho_w \frac{D}{2} v^2 \sin^2 \alpha \tag{5}$$

where:

C_{Dn} - normal drag coefficient,

C_{Dt} - tangential drag coefficient (DNV301),

ρ_w – seawater density.

D - anchor chain diameter.

In consequence we can write two differential equations:

$$\frac{dt}{dl} - C_{Dt} \rho_w \frac{D}{2} v^2 \sin^2 \propto - mg \cos \propto = 0 \tag{6}$$

$$-T \frac{d \propto}{dl} - C_{DN} \rho_w \frac{D}{2} v^2 \cos^2 \propto - mg \sin \propto = 0 \tag{7}$$

For the above differential equation initial conditions are as follow:

$T(0) = W_{anchor,}\ \alpha(0) = 0$

Weight of the anchor in the water is reduced:

$$W_{anchor} = m_{anchor} \quad g \quad (1 - \frac{\rho_w}{\rho_{steel}}) \tag{8}$$

Parameters of ships anchors equipment have been found using Equipment Number (EN) in classification societies regulations. The classes of the ships have been correlated with ships length.

Solving the equations we can determined if chain anchor system are capable to reach the subsea pipe. That can be done using Runge-Kutta method. C-sharp programming language has been used.

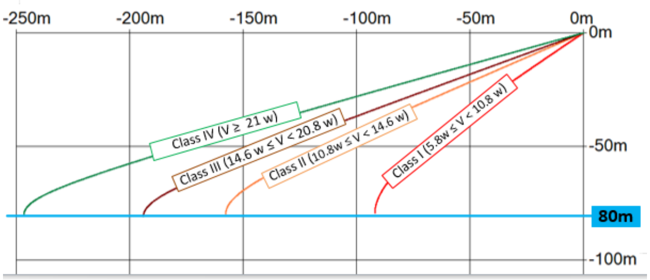

Figure 11. Vertical distance of dragged anchor chain for 4 classes of the ships passing over the subsea pipeline.

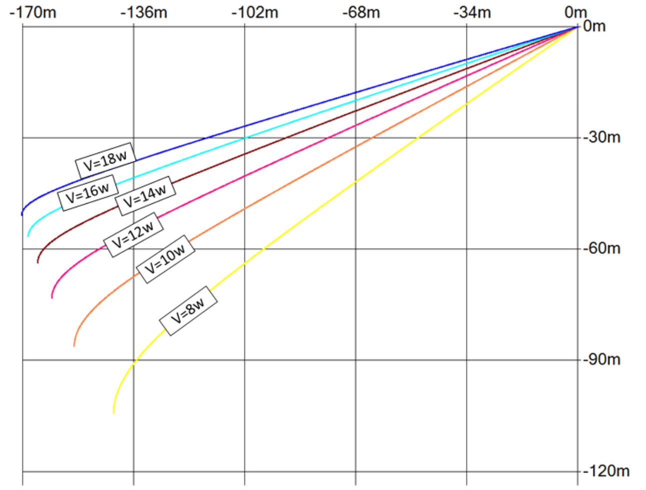

Figure 12. Results of the vertical distances of the dredged anchor chain ship class II for various speeds.

For the calculation of the speed of vessels, with which the anchor will be in contact with the bottom depending on the length of the vessel, the following classes of vessels:

- Class I: vessels of 30m-60m (Fig.11 - brown) for this class of ship was the weight of the anchor in the range of 360 kg - 900 kg, chain length 123.8m - 178.8m. Ships of this class are dragging anchor at a depth of 80m while moving at a speed 5.8w ≤ V <10.8 in.
- Class II: ships with a length of 60m - 80m (Fig.11 - green) for this class of assumed importance anchor in the range of 1020 kg - 1590 kg, chain length 179m - 206.3m. Ships of this class are dragging anchor at a depth of 80m while moving at a speed 10.8w ≤ V <14.6 in.
- Class III: vessels of 80m - 93m, while oil tankers up to 123 m (Fig.11 - blue color); adopted for this class of anchor weight in the range 1700 kg - 3500 kg, the chain length of 212m - 250m. Ships of this class are dragging anchor at a depth of 80m while moving at a speed of 14.6 ≤ V <20.8 in.
- IV class vessels over 93m, while the tankers with a length of more than 123m. For those ships anchor regardless of their speed will be dragged at depths greater than 80m.

In Fig.11 80 m depth line is marked, which is maximum depth over the pipeline.

Towed anchor arrangement of passing ship will stabilized at certain water depth. The drag forces are proportional to the velocities squared. This implies that the tow depth is less for high velocities. Example is shown in Fig. 12.

5 CONCLUSIONS

1 To determine risk of damage of the underwater infrastructure it is necessary to check the ships traffic over pipeline systems. One of the method is to analyze AIS data.

2 The classification rules are source to determine anchor systems equipment of the passing ships.

3 Assign the correct anchor equipment to each ship is done by segregation the ships using their length and correlating with equipment number.

4 Besides length and weights of ships anchors system speed is important value to determine vertical distance of dredged anchors.
5 Using the results of the research it is possible to find which ships are threat for pipeline.

BIBLIOGRAPHY

[1] DNV, DNV-OS-301, Offshore Standard, Position Mooring, 2010,
[2] DNV, DNV-OS-F101 Submarine Pipeline Systems, 2010,
[3] DNV-RP-F107, Risk Assessment Of Pipeline Protection, October 2010,
[4] Dzikowski R., Ślączka W., Analysis of IWRAP mk2 application for oil and gas operations in the area of the Baltic Sea in view of fishing vessel traffic, Scientific Journals of The Maritime University of Szczecin, 2014,
[5] HSE, Guidelines For Pipeline Operators On Pipeline Anchor Hazards, 2009,
[6] Kyriakides S., Mechanics of Offshore Pipelines, The University of Texas at Austin and Edmundo Corona University of Notre Dame, 2007,
[7] MacDonal M., "PARLOC 2001" The update of loss of containment data for offshore pipeline", Prepared for The Health and Safety Executive, The UK Offshore Operators Association and The Institute of Petroleum, 12 June 2003