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Risk of Ship Interference with Submarine Pipelines

Risque d'interférence de navires avec des conduites sous-marines

Gefahr der Kollision von Schiffen und Rohrleitungen

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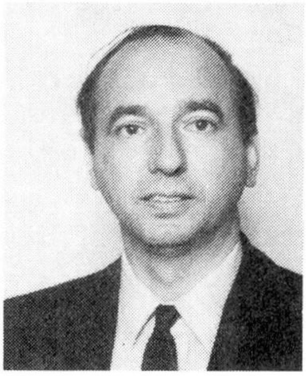

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SUMMARY
Statistical data on ship accidents and ship course aberrations exist, but data on ship interference with pipelines are negligible. This paper describes the application of a deterministic approach to the evaluation of the risk of ship-pipeline interference on the basis of available ship failure event statistics. It also refers to the evaluation of the consequences of such events.

RÉSUMÉ
Des statistiques sur les accidents de navigation et les erreurs de navigation existent, mais des informations sur l'interférence de navires sont rares. Cet article décrit une méthode déterministe de l'évaluation du risque de l'interférence des navires avec des conduites sous-marines sur la base de statistiques d'accidents de navigation. L'évaluation des conséquences de ces événements est également mentionnée.

ZUSAMMENFASSUNG
Statistische Daten über Schiffahrtsunfälle und verirrte Schiffahrtskurse sind vorhanden, doch sind Daten über Schiffskollisionen mit Rohrleitungen unerheblich. Diese Abhandlung beschreibt die Anwendung eines deterministischen Verfahrens, um die Gefahr einer Schiff-Rohrleitungskollision auf Basis vorliegender Statistiken über Schiffahrtsunfälle zu beurteilen. Sie bezieht sich auf die Abschätzung der Folgen eines solchen Unfalles.

1. INTRODUCTION

Ship accident risks (anchoring and grounding) are a dominant factor in the overall risk picture of a marine pipeline crossing of a restricted navigational channel.

This is particularly the case in the Danish Great Belt, which accommodates Transit Route T, the main shipping route between the North Sea and the Baltic, and where the shipping risks have been a very important consideration for decisions on trenching depth, route location, and the number and spacing of pipes in the gas transmission system crossing.

There exists a reasonable amount of statistical data on ship accidents and ship course aberrations, but the statistical information on ship accidents involving pipelines is negligible and certainly insufficient to build any risk evaluation up on. Thus while a stochastic approach could be used to determine the probable incidence of ship aberration events, it was necessary to use deterministic methods to interpret these events in terms of the risk of pipeline damage for the Danish Great Belt Gas Transmission Crossing. No computational tools were ready to hand, and it was therefore necessary to develop new procedures taking as a starting point published work by Fujii and MacDuff.

These new deterministic procedures were based on geometrical and soil mechanics considerations.

It is important to emphasize that calculations of the type referred to here (examples of which are given in References A, B, and C) cannot be accurate and can do no more than indicate orders of magnitude. The results derived must be interpreted in this light.

It should be noted that the examples of design and safety data relating to the Danish gas transmission system marine pipelines are presented here merely to illustrate the methodology and should not be taken as representing the final design or safety levels of that system.

2. SHIP ANCHORING

Ship anchoring events in or adjacent to shipping fairways may be classified thus:

- Anchoring following machinery failure
- Anchoring to avoid collision
- Anchoring following collision

It may surprise some people to hear that the second class of event does not occur in practice. Ships avoid collision by altering course, not by anchoring. A ship attempting to anchor at speed will merely get her anchor gear torn away.

Ships anchor when their speed has fallen to a level where they have lost or are about to loose steerage way. The loss of speed may be deliberate following a collision, or may be the result of machinery failure. In either event there is a good chance that the ship can be steered to a point outside the fairway prior to dropping anchor.

The calculation of the probability of pipeline damage in the Great Belt due to ship anchoring following machinery failure is given in Reference A.

The calculation of the probability of pipeline damage due to ship anchoring following collision is given in Reference B.

It should be noted that these calculations refer to a separate assessment of pipeline vulnerability to anchor impact which is specific to a concrete-coated 30 inch pipe in the Danish Great Belt seabed soils, and calculations for other sizes of pipeline in other soils must be modified accordingly.

The calculations are also specific to the ship traffic characteristics.

3. SHIP GROUNDING

The development of a rational procedure for the evaluation of the risk of pipeline damage due to ship grounding proved even more important, and has been decisive for the selection of trenching depth in certain critical areas.

The procedure is somewhat more mathematical than that for anchor damage risk assessment. The initial calculation for the Danish Great Belt is set out in Reference C. The calculation has subsequently been slightly modified to reflect an adjustment of the pipeline trenching depth in the Great Belt to the East of Transit Route T.

This type of calculation is specific to ship traffic characteristics and seabed soil type and also to channel dimensions and shoal slope.

4. SUMMARY OF SHIP ACCIDENT RISKS IN THE DANISH GREAT BELT

The total level of ship accident risk for the Danish Great Belt Crossing as a whole is summarized in Table 1 below for a pipeline trenching depth of 1,0 metre from seabed to top of pipe. The figures relate to a single pipeline; they are doubled in the dual pipeline situation.

Table 1 - Ship Accident Risks for the Pipeline as a whole

	Anchoring Event following Engine Failure	Anchoring Event following Collision of 2 Ships	Ship Grounding Event	Total Ship Accident Events
Annual probability of accident event in Storebælt passage (Røsnæs-Omø) incl. all ship sizes	4,7	0,025	2,5	7,23
Whence expected number of events in 10 year period	47	0,25	25	72
Observed frequency of events per 10 year period	No information available	Only one event reported involving ships over 5000 DWT	10 ships of over 5000 DWT corresponding to 20 events for all ship sizes>500 BRT	
Annual probability & return period of damage (incl. rupture) to a single 30" pipeline in P.C. Route	$3{,}9 \times 10^{-3}$ 256 years	$>4{,}5 \times 10^{-5}$ <22.222 years	$2{,}74 \times 10^{-4}$ 3650 years	$4{,}22 \times 10^{-3}$ 237 years
Annual probability & return period of damage (incl.rupture) to a single 30" pipeline in Route 4	$<2 \times 10^{-3}$ > 500 years	$< 4{,}5 \times 10^{-5}$ >22.222 years	$2{,}74 \times 10^{-4}$ 3650 years	$2{,}32 \times 10^{-3}$ 431 years
Probability of damage incl. rupture) event during 30-year design life				
P.C. Route	0,12	0,001	0,01	0,13
Route 4	0,06	0,001	0,01	0,07

These risks are not distributed evenly along the length of the pipeline. The risk from anchor dragging following machine failure is concentrated in the Route T shipping channel. The effective width is regarded as 4 km; ships which still have some steerage way will aim to anchor outside this main lane; a study of the chart indicates that in Route 4 (the pipeline route finally selected) the risk will be spread over a total lateral distance of some 9 km, yielding a damage event probability of $2 \times 10^{-3}/9$ or $2{,}22 \times 10^{-4}$ per km per year.

The risk from anchor dragging following ship collision is distributed over a similar width, yielding $4{,}5 \times 10^{-5}/9$ or $5{,}0 \times 10^{-6}$ km per year.

The risk from ship grounding is concentrated in the first shoaling zones outside the main shipping channel. The critical areas are between the 14 m and 8 m depth contours. The total length between these contours, excluding the zones in Musholm Bugt which are protected from the main traffic by Slettings Grund, is some 2,5 km, i.e.: 1,5 km on the shoal east of Route T and 1,0 km on the steeper shoal towards the Fyn shore. This yields $2{,}74 \times 10^{-4}/3{,}5$ or $1{,}1 \times 10^{-4}$ per km per year.

These risk levels are set out in Table 2 together with the other general risks applicable to pipeline Route 4.

In Route 4 the total risk of serious damage or rupture, i.e.: events involving shutdown for repair, can be seen from Table 2 to be $4{,}3 \times 10^{-3}$ per annum which is about twice the ship interference risk and is synonymous with a return period of 233 years. The probability of such an event within the 30 year design life of the pipeline is thus 12 percent for a single pipeline or 24 percent for a dual pipeline system.

Table 2 - Pipeline Route 4. Depth 1,0 m from seabed to top of pipe

Chainage	KP 0,5 – 1,5	1,5 – 8	8 – 12	12 – 17	17 – 21,0	21,0 – 23,5	23,5 – 28,4	28,4 – 29,4	total risk per year
Offshore activities	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$2{,}9\times10^{-4}$
Anchoring after machine failure	~ 0	~ 0	$2{,}2\times10^{-4}$	$2{,}2\times10^{-4}$	~ 0	~ 0	~ 0	~ 0	$2{,}0\times10^{-3}$
Anchoring after collision	~ 0	~ 0	$5{,}0\times10^{-6}$	$5{,}0\times10^{-6}$	~ 0	~ 0	~ 0	~ 0	$4{,}5\times10^{-5}$
Ship grounding	$1{,}1\times10^{-4}$	0	0	0	0	$1{,}1\times10^{-4}$	0	~ 0	$2{,}7\times10^{-4}$
Anchoring intentional but position erroneous	$\sim 10^{-6}$	$\sim 10^{-6}$	~ 0	~ 0	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$2{,}0\times10^{-5}$
Trawling	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0
Dropping of heavy objects	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	~ 0	$\sim 10^{-6}$	$\sim 10^{-6}$	$2{,}7\times10^{-5}$
External corrosion	$4{,}5\times10^{-5}$	$2{,}3\times10^{-5}$	$2{,}3\times10^{-5}$	$2{,}3\times10^{-5}$	$2{,}3\times10^{-5}$	$4{,}5\times10^{-5}$	$2{,}3\times10^{-5}$	$4{,}5\times10^{-5}$	$7{,}4\times10^{-4}$
Other external loadings	-	-	-	-	-	-	-	-	-
Total external loadings	$1{,}7\times10^{-4}$	$3{,}5\times10^{-5}$	$2{,}6\times10^{-4}$	$2{,}6\times10^{-4}$	$3{,}5\times10^{-5}$	$1{,}7\times10^{-4}$	$3{,}5\times10^{-5}$	$5{,}7\times10^{-5}$	$3{,}4\times10^{-3}$
Internal corrosion	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	$8{,}8\times10^{-4}$
Other internal loadings	-	-	-	-	-	-	-	-	-
TOTAL RISK PER KM PER YEAR	** $2{,}0\times10^{-4}$	$6{,}5\times10^{-5}$	* $2{,}9\times10^{-4}$	* $2{,}9\times10^{-4}$	$6{,}5\times10^{-5}$	** $2{,}0\times10^{-4}$	$6{,}5\times10^{-5}$	$8{,}7\times10^{-5}$	$4{,}3\times10^{-3}$

* These figures are unaffected by trenching depth

** These figures are highly sensitive to the local trenching depth

The highest level of risk per unit length of pipeline is seen to be 2,9 x 10^{-4} per km per year. This compares with a typical landline figure of 2,3 x 10^{-4} per km per year for all damage and leakage; the landline figure for serious damage only is probably an order of magnitude lower.

It should be noted that the risk level in the main channel, which is predominantly derived from anchor damage following ship machinery failure, is not sensitive to trenching depth, whereas the risk level on the shoals where grounding can occur is highly sensitive to the trenching depth assumption.

If the pipeline lies untrenched on the sea bottom, the risk level in the critical ship grounding zones is substantially greater than the generally accepted level.

5. PIPELINE DESIGN CONSIDERATIONS IN THE GREAT BELT

5.1 Choice of Trenching Depth

When these risk levels are compared with those generally prevailing for land and marine pipelines it can be concluded that, with a general trenching depth of 1,0 metre from seabed to top of pipe, the level of risk associated with ship accidents is within the range normally regarded as acceptable.

The question remains as to whether there are any reasonable steps which could be taken further to reduce or eliminate the ship accident risks.

The trenching depth required to eliminate all risk of pipeline damage due to anchoring is indicated in Table 3 below.

Table 3 - Anchor Penetration Depths

Ship Size	15,000 tdw	60,000 tdw
Anchor Weight	5,0 t	10.0 t
Penetration in Moraine Clay	2 m	3 m
Penetration in Mud	5 m	7 m

It is immediately apparent that trenching to "anchor safe depth" under these circumstances would be not only prohibitively expensive but impossible to achieve with ordinary construction methods.

In response to the continued concern of the Danish shipping authorities over the ship grounding risk immediately East of Transit Route T (at a location called Slettings Bank), however, DHI Marine Pipelines undertook a supplementary study which concentrated on the hazard to the ship's crew and the environmental pollution problem in the event of a tanker running aground on the pipeline (tankers represent approximately one half of the ship traffic in Route T).

This study built on a combination of the grounding risk computations referred to above with statistical accident data from Intertanko and oil slick movement patterns from the Danish Hydraulic Institute S. 21 current model for the Great Belt.

The conclusions of that report were that the installation of the proposed D.O.N.G. A/S gas transmission pipeline in the Great Belt on Route 4 with the trenching depths indicated in the Concept Proposal and assuming a single line is expected to yield the following risk increases:

- Existing risk of tanker disaster (i.e.: fire /explosion) in the Great Belt involving potential loss of life or serious injury to crew increased by 1,2 percent;
- Existing risk of oil pollution event in the Great Belt increased by between 0,065 percent and 1,3 percent.

The frequency of a tanker grounding event involving a single pipeline is estimated at once per 7.300 years. The frequency of a tanker larger than 40.000 DWT, i.e.: a crude oil carrier, grounding on the pipeline is estimated at once per 217.000 years.

It was nonetheless subsequently agreed with the Authorities that some risk reduction could be achieved within reasonable economic limits by trenching to a greater depth over a limited stretch of pipeline on the slope of Slettings Bank.

5.2 Number and Spacing of Pipelines in the Great Belt

Whereas the average repair time in the event of damage to a land pipeline is of the order of 1 or 2 days, the repair time in the event of damage to a 30 inch diameter pipeline in the Great Belt is estimated at upwards of a month (including dewatering and drying). A closure of this duration was found to be unacceptable in the context of security of gas supply to Zealand and Sweden. Therefore notwithstanding that the probability of failure is no worse than for other marine pipelines the consequences of such failure in terms of interruption of supply made it essential that the marine pipeline in the Great Belt be parallelled by a second pipeline.

5.2.1 Safety Distance between two Pipelines

In order to avoid damage to both pipelines from the same accident event the spacing between them must exceed the diameter of influence of any single event. The factors affecting choice of spacing include:

- Anchor dragging distance
- Stopping length of grounding ships
- Anchor spread from lay and bury barges
- Navigational considerations.

5.2.2 Anchor Dragging Distance

Under a controlled anchoring the ship will first drop anchor just before losing steerage way and starting to drift with the current. The mean anchor dragging distance in this situation will be less than 200 m even for the largest vessels passing the Great Belt.

The 200 m is the dragging distance related to areas with mud (gytja). The similar mean dragging distance in clay is less than 50 m. The thickness of the mud layer on the seabed in the Great Belt is generally less than 4 m. Boulder clay is found beneath the mud. In view of the large anchor penetration depths in mud most anchors will reach the boulder clay and the dragging distances will be less than those for deep mud.

The safe distance between two pipelines from the point of view of anchor damage is therefore of the order of 200 m.

5.2.3 Stopping Distance of Grounding Ships

When a vessel grounds on the seabed it will continue its forward movement and penetrate into the seabed. If the course of the ship in the grounding situation is parallel with the depth contours the ship will slide on the seabed for a considerable distance before its ultimate penetration is reached. This situation results in the largest stopping distances, but the smallest ultimate penetrations. It can be shown that the minimum safe pipeline separation can be expressed as:

$$z = h_{GT} k \sin^{-\frac{1}{2}}\theta \cos\theta - x_t k \sin^{-1}\theta \cos\theta$$

where h_{GT} is the maximum depth of bite of the ship on grounding perpendicular to the shore, k is the cotangent of the seabed slope, and θ is the angle between the aberrant ship's course and the channel centreline.

The maxima of this function are tabulated below for x_t = 10 metre, k = 100, and a ship velocity of 12 knots.

Ship size (DWT)	Draught (metres)	Seabed soil	h_{GT} (metres)	z max. (metres)
50.000	12	clay	1,8	50
50.000	12	mud	3,8	350
150.000	17	mud	5,0	600

The nature of the input data is such that the accuracy of the results is no better than 50 percent. The safe pipeline separation in water depths of 8 to 12 metres should therefore be regarded as not less than 75 metres where the seabed is clay and 525 metres where the seabed is mud. The safe distance between the 12 and 17 metre depth contours, where mud prevails, must be regarded as not less than 900 metres.

5.2.4 Anchor Spread from Lay and Bury Barges

The spread of anchor positions perpendicular to the pipeline centreline typically extends from 100 m to 1,500 m. In order to avoid putting any restrictions on the lay and bury barge operations the distance between two pipelines should be either less than 100 m or more than 1,500 m. The spacings to be avoided are therefore those in the range of 100 to 1,500 m.

5.2.5 Navigational Considerations

From the point of view of the navigator of a vessel with machine failure, i.e.: a vessel considering dropping anchor, it is preferable that the two pipes either be located as close together as possible so that they can be regarded as a single crossing or alternatively be spaced several kilometers apart.

6. CONCLUSIONS

The example presented illustrates the role of safety analysis in development and modification of the engineering concept for a marine pipeline system crossing a navigational strait. It is shown that the systematic application of the calculation techniques developed in relation to the Danish Great Belt can aid the economic optimization of a capital project and at the same time establish confidence in the overall safety level.

7. REFERENCES

7.1 Special References

A. Colquhoun, R.S., and Thygesen, J.E., The Safety Analysis and Pipeline Protection Aspects of (the Danish) Gas Transmission System Marine Pipelines, Offshore Oil and Gas Pipeline Technology European Seminar, Basel, January 1982, Appendix A: Calculation of the Probability of Pipeline Damage due to Ship Anchoring following Machinery Failure (the Danish Great Belt).

B. Ibid, Appendix B: Calculation of the Probability of Pipeline Damage due to Ship Anchoring following Collision (the Danish Great Belt).

C. Ibid, Appendix C: Calculation of the Probability of Pipeline Damage due to Ship Grounding (the Danish Great Belt).

7.2 General References

1. "Pipeline Reliability" by Roger F. de la Mare, University of Bradford, and Øysten Andersen, Det norske Veritas (DnV Report No. 80-0572). August 1980.
2. "Sjöledning Danmark-Sverige - Haveriorsaker og risikobedömning" Asea-Atom, March 1979.
3. "Sikkerhetsanalyse for DONG's Sjøledningsprojekt", DnV Report No. 80-0129 dated 21st March, 1980. (Restricted).
4. "The Analysis of Traffic Accidents" by Yahei Fujü, Journal of Navigation 1971.
5. "The Probability of Vessel Collisions" by T. MacDuff, Ocean Industry Sept. 1974.
6. DHI Marine Pipelines, Technical Note ref. MPPO 30462, Damage due to Anchoring, 16th June 1980. (Restricted).
7. "Statistics of Tanker Casualties", International Association of Independent Tanker Owners (Intertanko), Oslo.
8. "On the possibility of modelling the spread and transport of oil at Sea", Danish Hydraulic Institute, September 1976. (Restricted).
9. Technical Note "Storebælt Crossing - Risk and Consequences of Tanker Grounding on Pipeline" DHI Marine Pipelines ref. MPPO 31189. (Restricted).
10. "Storebælt Crossing - Concept Proposal", DHI Marine Pipelines ref. MPPO 30720, Sept. 1980. (Restricted).
11. DnV report 78-574, Anchor and Anchoring Activity Hazard to the Ekofisk-Emden Pipeline. (Restricted).