Client

Wintershall Noordzee BV

Project

D12-B to D15-FA-1 Pipeline

Document

D12-B to D15-FA-1 Risk Assessment and dropped object analysis

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1. Introduction

1.1. Brief Description

Wintershall is planning to install a satellite platform D12-B in Block D12-A in the Dutch Sector of the North Sea. Export of the gas will be via a 10” pipeline to the D15-FA-1 platform. Platform D12-B will be operated by Wintershall and platform D15-FA-1 is operated by Neptune.

1.2. Document Scope of Work

The scope of this document includes the risk assessment for the 10” pipeline from D12-B to D15-FA-1. Also included is a risk analysis of objects dropped from either platform.

1.3. System of Units

All dimensions and calculations shall be documented using the International System of Units (SI) unless noted otherwise.

1.4. Abbreviations

BoD = Basis of Design

DWT = Dead weight tonnage

1.5. References

[1] Overheidsbeleid inzake de aanleg van offshore pijpleidingen voor het transport van olie en/of gas, letter to NOGEPA from the Dutch Ministery of Economic Affairs, dated 03 November 1987

[2] Risk analyses and burial requirements for Dutch Continental Shelf pipelines, D.Schaap a.o., 1987

[3] Eisen voor Stalen Transportleidingsystemen, NEN 3656 (Requirement for Steel Pipeline Transportation Systems)

[4] Veiligheidsanalyse voor zeeleidingen, Rijkswaterstaat Directie Noordzee

[5] Het scheepvaart verkeer op de Noordzee 1988-1998, gezien vanuit de lucht, Directie Noordzee van Rijkswaterstaat.

[6] Monitoring-nautische-veiligheid-2013-noordzee

[7] Beleidsnota Scheepvaartverkeer Noordzee “Op Koers”, no 17408-26, Ministerie van Verkeer en Waterstaat, Januari 1987

[8] Snelle reparatie Unocal-pijp volgens het boekje verlopen, Offshore Visie Magazine, Juni 1988

[9] Mooring Anchors, The society of Naval Architects and Marine Engineers Transactions, Vol 67, 1959

[10] Lloyd’s “Register of Ships”

[11] DNV RP-F107 - Risk Assessment of Pipeline Protection - October 2010

[12] DNV-RP-C204 – Design against accidental loads- November 2014

[13] 18004-60-RPT-01501-01-02 “Basis of Design”, Rev. 02, July 2018, ENERSEA BV

[14] 18004-60-RPT-05001-01-05 “Pipeline FEED design report” Rev. 05, March 2018, ENERSEA BV

2. Summary

This report presents the results of an assessment of the risks of failure of a pipeline from platform D12-A to platform D15-FA-1 because of ship traffic and objects falling from the platform and related activities at the spool piece area. The liquid release associated with pipeline puncture is the entire liquid presence in the pipeline.

Failure in this respect means damage to the pipeline resulting in leakage, which is considered class 3 damage [11]. The analysis is performed considering the potential damage stipulated by the following external hazards:

- Natural hazards (slope instability, seismic activity, severe storm, erosion)
- Corrosion
- Operational hazards (pressure, temperature)
- Third party damage (navigation, fishing)

As discussed in sections 6 and 7, all risk but the risk due to third party damage can be regarded as insignificant. Within the third-party damage, the following types of damage are considered

- Sinking of vessels.
- Dropping and dragging of anchors
- Damage by fishing gear

The risks from shipping traffic have been determined and quantified and have then been assessed according to the Dutch authority safety criteria [3]. The probability of damage leading to leakage as the result of a dropped and dragged anchor is provided in Table 1.

Table 1 Cumulative probability of leaks due to anchor drop and drag

Cover depth [m]	Probability leak anchor drop $x10^{-6}$	Probability leak anchor drag $x10^{-6}$	Total Probability of leak per $x10^{-6}$
0,0	0,21	0,11	0,33
0,2	0,14	0,08	0,21
0,4	0,08	0,07	0,15
0,6	0,06	0,07	0,13
0,8	0,05	0,07	0,12
1,0	0,00	0,06	0,07

The following can be concluded:

- The required minimum burial depth of 0.2 m stipulated by the Dutch authorities is sufficient to limit the probability of leakage to below 10^{-6} per year per kilometer of pipeline length, as described in section 7.
- Dropped objects from the platform crane will not result in critical damage to the spool if the rock cover height is larger than 0.41 m, as described in section 8.
- The amount of liquid released from a damaged pipeline is approximately 15 $m^{3.}$ The spillage, considering the position of the pipeline wrt to shore, is regarded acceptable.

The above conclusions are derived from the risk calculations presented in this report and the following assumptions and findings:

- A corrosion assessment should verify whether adequate internal corrosion allowance and external anti-corrosion coating are applied, such that the risk of leakage resulting from corrosion is negligible.
- Process control on the platforms eliminates operational hazards to the pipeline.
- The probability of pipeline damage due to sinking ships is negligible.

3. Dutch Authority Safety Criteria

The policy with regard to safety criteria for offshore pipelines is laid down in [1], effective 1987 and [3].

The Dutch Authorities require a minimum soil cover of 0.2 [m] for pipelines with a diameter smaller than 16-inch based on the maximum penetration depth of trawl gear into the sea bottom, consequently avoiding any contact between fishing gear and offshore pipelines. For areas denoted as shipping routes and anchor drop areas, a minimum cover depth of 0,6 [m] is required.

If natural sea bottom variations over the operational lifetime might occur, an appropriate extra cover is to be added to the minimum required cover.

In any case the following conditions must be fulfilled:

- The probability of pipeline damage due to third parties and resulting in a leak, should be less than $1.0x10^{-6}$ per km of pipeline per year;

Following from the established route, the pipeline distance of the D12-A to D15-FA-1 pipeline from shore is over 25 nautical miles. Consequently, the spillage of liquid hydrocarbons in case of a pipeline leak has a reduced impact wrt pipelines closer to shore.

4. Design data

All design data considered for risk and safety calculations for the pipeline in presented in the following subsections and have been extracted from the Basis of Design (Ref [13])

4.1. line Data

The basic pipeline design data considered in the analysis is presented in the tables below. Table 2 presents the data of the pipeline, while Table 3 presents the material properties of the steel used.

Table 2 Pipeline Data

Property	10" Pipeline D12-B to D15-FA
Product transported	Natural gas
Design life	Min. 30 years
Approx. length	11.8 [km]
Steel material grade	L360NB
Manufacturing process	HFIW Carbon steel
Pipe outside diameter	10" OD
Pipe outside diameter	273.1 [mm]
Wall thickness (WT)	12.7 [mm]
Wall thickness tolerance (wtt)	+5.5% / -5.5 %
Internal corrosion allowance (t_{cor})	3 [mm]
Anti-corrosion coating	Polyethylene
Anti-corrosion coating thickness	2.8 [mm]
Anti-corrosion coating density	900 [kg/m^3]
Concrete weight coating thickness	N/A
Minimum subsea hot bend radius	1.366 m (5D)

Table 3 Steel material properties

Property	Value
Material	L360NB
Density	7850 [kg/m$^{3]}$
Specified Minimum Yield Strength @20 °C	360 [MPa]
Specified Minimum Yield Strength @100 °C	304 [MPa]
Specified Minimum Yield Strength @65 °C	343.2 [MPa]
Specified Minimum Yield Strength @90 °C	315.2 [MPa]
Specified Minimum Tensile Strength	460 [MPa]
Young's modulus	2.07 x 10^{11} [Pa]
Poisson ratio	0.3 [-]
Thermal expansion coefficient	1.17 x 10^{-5} [m/m·°C]

4.2. Coordinate system

The parameters of the geodetic system to be used for horizontal position are listed in Table 4, the vertical position is given relative to the Lowest Astronomical Tide (LAT).

Table 4 Geodetic parameters

Item	Value
Datum	European Datum 1950 (ED50)
Projection	ED50 / UTM zone 31 N
Ellipsoid name	International 1924
Semi major axis	6 378 388 [m]
Inverse flattening	297.000
Central Meridian	03°00"00' E
Latitude of Origin	00°00"00' N
False Northing	0 [mN]
False Easting	500 000 [mE]
Scale Factor	0.9996

4.3. Route

The intended target boxes at the D12-B and D15-FA-1 platforms can be connected with straight pipeline along bearing of approximately 140 degrees from true North.

4.4. Seabed characteristics

The local sea floor consists of fine to medium sand, according to Ref [13]. This sand will be used to backfill the pipe trench and has the properties listed in Table 5.

Table 5 Soil properties

Property	Value
Soil type	Sand
Submerged Weight γ, [kN/m^3]	8.5
Angle of internal friction ϕ, [deg]	28

4.5. Dropped object classification

Classification of dropped objects is taken from table 3 DNV RP-F107 [11]:

Table 6 Overview object classification

No	Description	Weight in air (mT)	Typical objects
1	Flat/Long shaped	< 2	Drill collar/casing/scaffolding
2		2 – 8	Drill collar/casing
3		> 8	Drill riser, crane boom
4	Box/Round shaped	< 2	Container (food, spare parts), basket, crane block
5		2 – 8	Container (spare parts), basket, crane block
6		> 8	Container (equipment), basket
7	Box/round shaped	>> 8	Massive objects, e.g. BOP, pipe reel etc.

With the hydrodynamic properties as specified in Table 7.

Table 7 Overview hydrodynamic coefficients

No	Description	Drag (Cd)	Inertia (Ci)	Added Mass (Ca)
1,2,3	Slender shape	0.7 – 1.5	1.0	0.1 – 1.0
4,5,6,7	Box shaped	1.2 – 1.3	1.0	0.6 – 1.5
All	Misc. shapes	0.6 – 2.0	1.0	1.0 – 2.0

The crane on the D12-B platform has a boom of 22 m and a maximum lift capacity of 10 mT. Even though the crane reach does not pass directly overhead of the spool, objects falling to the sea floor can experience significant lateral drift. Therefore a risk assessment due to dropped objects has been performed.

Box shaped objects such as containers typically have a relatively large frontal area for its mass, resulting in a low impact velocity. The most probable objects to damage the spool are therefore pipe-shaped objects. A range of typical tubular objects and the relevant properties are listed in Table 8. The platform approach of both D15-FA and D12-B is provided in Appendix J, as can be seen, the crane can hardly reach over the spool, therefore the likelihood of occurrence seems very low, especially when considering the outreach is limited by the crane capacity for heavier objects.

Table 8 Dropped object pipe joint properties

Object	Unit	1	2	3	4	5
Outside diameter, OD	[m]	0.47	0.54	0.6	0.64	0.76
Mass object in air, M	[kg]	650	1038	1495	1765	3152
Length	[m]	0.74	0.85	0.95	1	1.2
Volume steel, V_{steel}	[m^3]	0.083	0.132	0.190	0.225	0.402
Steel cross area, Ac	[m^2]	0.112	0.156	0.200	0.225	0.335
Wall thickness, WT	[m]	0.076	0.092	0.106	0.112	0.140
Internal diameter, ID	[m]	0.318	0.357	0.387	0.416	0.480
Added mass, M_a	[kg]	84.9	135.5	195.2	230.5	411.6

4.6. Rock dump properties

The following properties are considered for the rock dump properties, as given in Table 9 following from [13]:

Table 9 Rock dump properties

Property	Value
Rock Density [kg/m3]	2650
Porosity [%]	30
Submerged Weight γ, [kN/m^3]	11.2
Angle of internal friction ϕ, [deg]	40

5. Hazards

5.1. Hazards

Submarine pipelines are subject to various hazards. They can be divided into the following categories:

- Natural hazards (slope instability, seismic activity, severe storm, erosion)
- Corrosion
- Operational hazards (pressure, temperature)
- Third party damage (navigation, fishing)

5.2. Classification of damage

The extent of damage due to third party hazards is divided in four classes varying in severity according [11], see Figure 1.

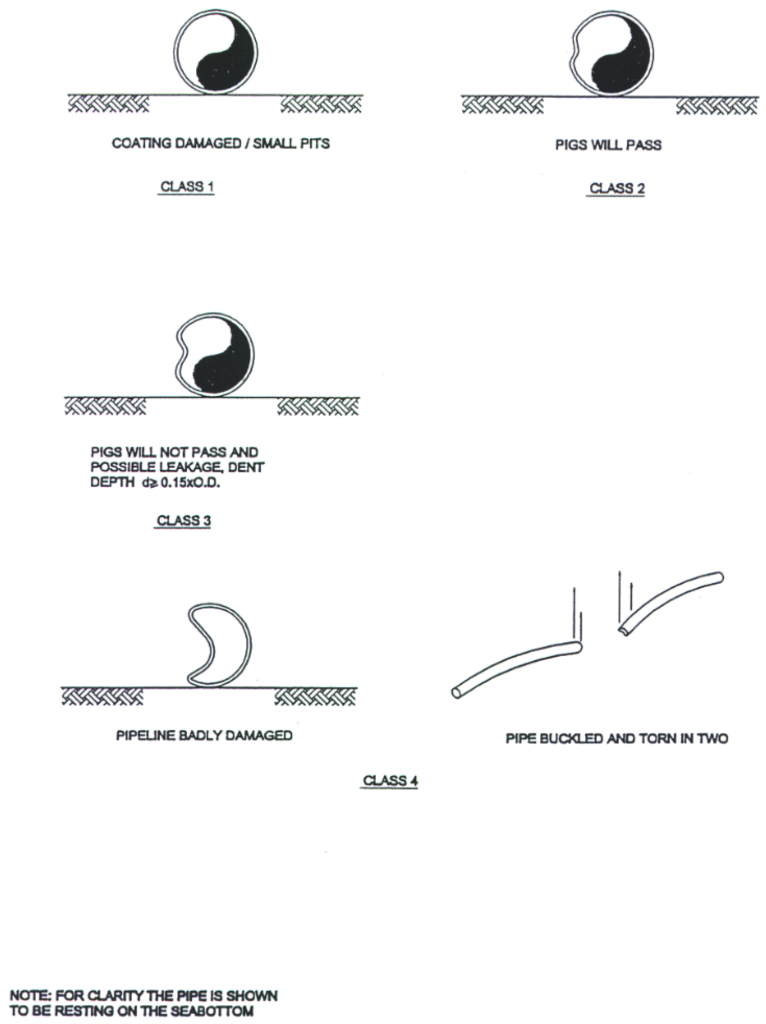


Figure 1 Damage classification

CLASS 1:

Damage to the coating system is denoted as class 1 damage. This type of damage is not serious on the short term, basically limited to damage to the pipeline coating. On the long term, it may have serious consequences such as over-stressing or fatigue due to spanning, forced corrosion due to simultaneous damage of the corrosion coating or loss of anodes and pits in the steel. Such deficiencies, however, will be discovered in time during routine inspections of the pipeline.

CLASS 2:

Small plastic deformations with dents up to 15% of the pipe diameter, 41 mm for the 10-inch pipeline under consideration for this project is denoted as class 2 damage.

Dents up to 10% of the pipe diameter (27.3 mm) are hard to detect and require a caliper pig for detecting. Gauging pigs will pass such dents without being deformed.

Dents up to 15% of the pipe diameter can be nominated as small plastic deformations but are certainly not an immediate jeopardy for the pipeline operation and will not lead to pipeline damage resulting in a leak.

CLASS 3:

Plastic deformations with dents more than 41 mm (15 percent of the pipe diameter for the 10-inch pipeline) is denoted as class 3 damage.

This type of damage becomes serious for the operator, as pigs may not any longer pass the damaged section. Moreover, the possibility of a leak in the pipeline due to damage cannot be excluded. A study from Rijkswaterstaat, Directie Noordzee specifies that for deformations more than 15% of the outside diameter the probability of damage resulting in a leak by dropping anchors is 1.0.[1]

CLASS 4:

Class 4 damage refers to large pipeline deformations and total rupture of the pipeline.

Obviously, Class 4 damage is more serious than Class 3 damage for both operator and controlling agency. The occurrence of a leak in the pipeline is very likely.

Objective of the risk assessment is to determine likelihood of occurrence of Class 3 damage due to third parties and the probability of pipeline damage resulting in a leak.

The safety of the pipeline shall be in accordance with the rules stipulated by the Dutch Authorities as discussed in section 3.

6. Risk Analysis Natural and Operational Hazards

Natural hazards to a pipeline are slope instability, seismic activity, severe storms, and erosion. Corrosion, (over) pressure and temperature effects are considered as operational hazards.

The pipeline will be directly trenched to a target depth giving a minimum cover of 0.2 [m] is required, as prescribed by the Dutch authorities [3].

The FEED design report [14] states that the seafloor along the route is flat and featureless, and there are no structures that are indicative of sediment transport. The probability of hazards occurring as the result of moving ripples or scour are therefore considered negligible. The area also contains no indications of seismic activity. Therefore natural hazard induced loads leading to pipeline damage have therefore been excluded from the risk assessment scope.

The probability of operational hazards, as the result of overpressure and overtemperatures, is reduced by ensuring that the process in the well completions and the platform are monitored and controlled by safety systems, such as pressure sensors, shut down valves and temperature indicators, which are used to prevent overtemperature/ over pressure events.

The pipeline is externally protected against corrosion by means of a coating system and cathodic protection system. Next to the coating system, also a cathodic protection system is designed as part of the pipeline design and should provide protection of the pipeline for the given design life.

In case degradation of the pipeline protective systems occurs, this should be noticed during maintenance surveys, followed by maintenance actions to repair possible damaged areas.

7. Risk analysis third party damage

7.1. General

Potential damage to the pipeline by marine traffic can be caused by the following hazards:

- Damage due to the fishing gear
- Damage to deck cargo and containers going overboard
- Dropped anchors
- Dragging by the anchor
- Sinking of vessels

At spools close to the pipeline, dropped objects from the platform crane might cause damage, which is assessed as well, as provided in section 8.

Based on section 5 the damage to the pipeline can be classified as minor damage if the resulting dent in the pipe wall is smaller than 15% of the outer diameter.

The possible hazards and consequent damages leading to class 3 damage will be analyzed in the this section. The analysis has been carried out to examine the resistance of the sand cover as protection measure.

7.2. Risk analysis fishing gear impact

Investigations on the interaction of trawl beams and pipelines have demonstrated that pipelines with a diameter of 16-inch or above are not significantly damaged in case of contact with trawl beams. On the other hand, trawler beams and nets are not damaged when passing an on-bottom pipeline.

It has been noticed that despite a warning system, trawler beams hit pipelines. The damage however was limited to scratches in the coating, which could ultimately lead to class 1 damage (corrosion). Pipeline denting or leakage caused by beam trawling over unburied pipelines has not occurred so far.

In case of pipeline trenching with backfill, the pipe will only be exposed to bottom trawl fishing gear if a span occurs due to natural sea bottom variations. In this case, however, the pipeline will be buried at least 0.2m below to sea floor to comply with appropriate regulations. The exposure to bottom-fishing gear is therefore insignificant.

7.3. Risk analysis deck cargo and containers going overboard

The probability of damage resulting from cargo going overboard depends mostly on the kinetic energy of the dropped object and the size of the contact area. As the weight of the cargo/container relative to its size is limited, certainly when compared to the properties of an anchor, it is assumed that the probability of a leakage is below the acceptable threshold.

7.4. Risk analysis navigation

7.4.1. Shipping traffic

The Dutch sector of the North Sea is an area of intensive sea traffic. Most of the ships follow the assigned shipping lanes. The area between these lanes are also used by smaller merchant vessels and fishing boats. Figure 2 shows the position of the blocks D12 and D15 with respect to the shipping lanes. From Figure 3 it can be determined that traffic intensity at this location is low with a maximum of 3 ships per 1000 km2.

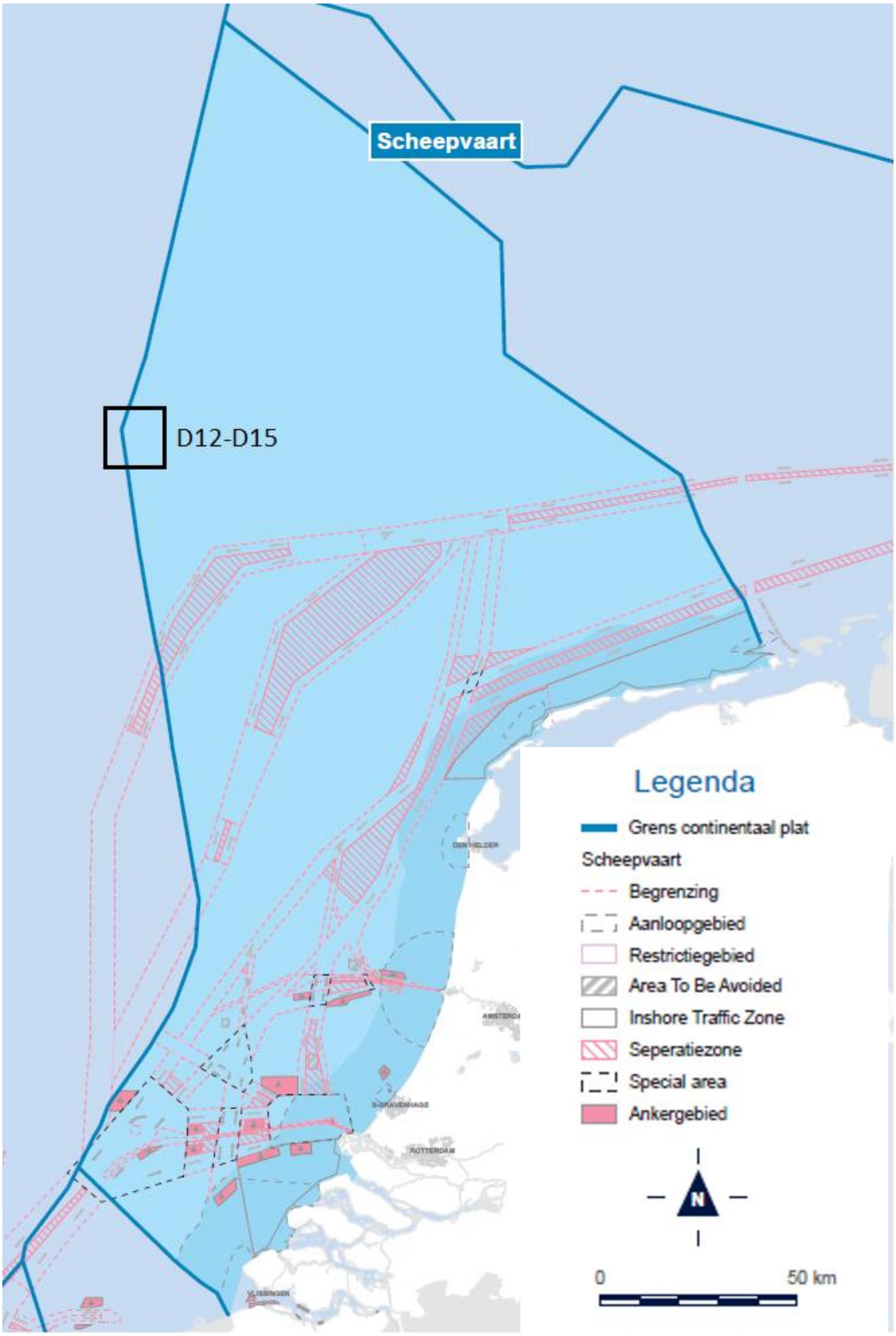


Figure 2 Situation D12-D15 blocks wrt shipping lanes

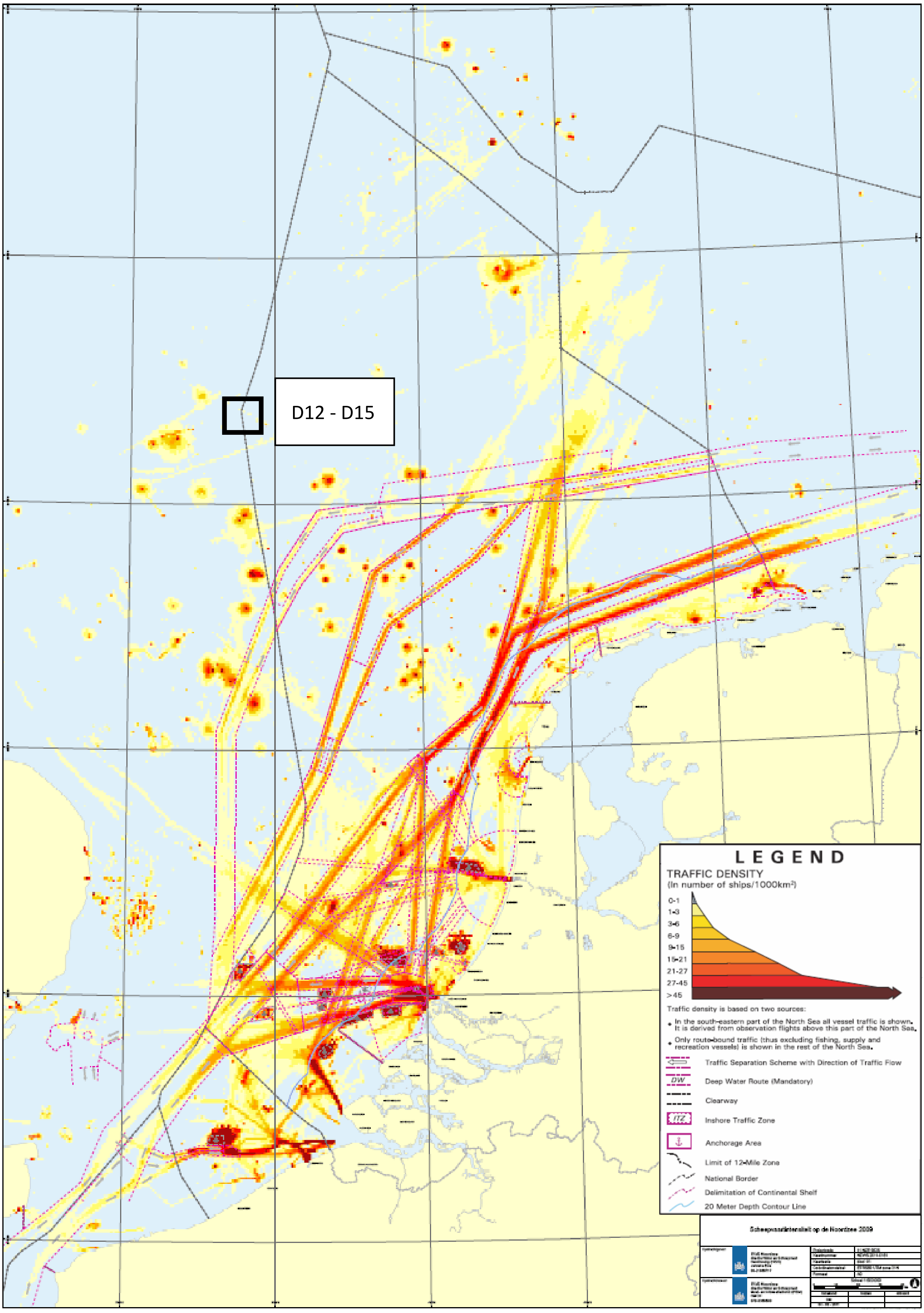


Figure 3 Marine traffic density in North Sea

A distribution of the various types of vessels that cross the pipeline is given in [10]. The shipping traffic varies from small vessels (fishing, general cargo, etc.) to tankers and bulk carriers. The composition of shipping incidents in the Dutch sector of the North Sea per vessel type is presented in Table 10. Table 11 shows the number of incidents per location of the Dutch sector.

Table 10 Traffic in the Dutch sector of the North Sea involved in a shipping incident

	Year	Number of shipping incidents							
Activity	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Inland shipping	2	2		3	2	1	2	2	2	16
Recreational	5	11	7	6	50	29	36	42	46	232
Fishing	17	16	11	14	27	30	29	29	40	213
Work / ferry services	2	4	3	6	7	4	5	13	7	51
Open sea shipping	17	22	16	20	22	20	23	56	74	270
Other	1	2	3		1	5	4	18	18	52
Total	44	57	40	49	109	89	99	160	187	834

Table 11 Shipping incident per location in the Dutch sector

	Year	Number of shipping incidents							
Area / year	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
North of Netherlands	1	3	6	7	37	22	28	22	27	153
West/North of Netherlands	1	1								2
West/South of Netherlands					3			1		4
Sea and Delta	4	14	20	27	46	57	56	48	74	346
Total	6	18	26	34	86	79	84	71	101	505

Approximately 67 percent of the merchant vessels have a Dead Weight Tonnage of less than 10,000 DWT. Fishing and recreation vessels also have a tonnage less than 10,000 DWT [6]. The remaining category, work/construction vessels, may have a tonnage greater than 10,000 DWT. It is assumed that 25% of those vessels are larger than 10,000 DWT. Some 2.6% of the merchant vessels are larger than 100,000 DWT. [5]

The distribution of vessels in percentages with respect to their Dead Weight Tonnage (DWT) category is presented in Table 12

Table 12 Composition of traffic and tonnage

Vessel size	Percentage
DWT ≤ 3.000	74.0
3.000 < DWT ≤ 10.000	6.3
10.000 < DWT ≤ 100.000	18.2
DWT > 100.000	1.5
Total	100.0

It is assumed that the composition of the ship traffic crossing the pipeline is similar to the traffic composition valid for the entire Dutch sector of the North Sea.

The information regarding the number of accidents and emergency situations of the period between 2004 and 2012 is derived from statistical data based presented in Table 13, ref. [6]. There has been a single case of a sunken ship in the period between 2004 and 2012. The number of fishing + shipping + ferries total in the sea and delta area is calculated to be 346 * (534/834) = 221,5 incidents between 2004 and 2012, or 24.6 incident per year.

Table 13 Accidents and emergency situations (2004-2012)

Incident	Number of incidents	
	2004-2012	per year
Total 2004 – 2012: Sea en delta	346	38,4
Number fishing + shipping + Ferries total Netherlands	534	59,3
Total number of shipping incidents	834	93
Number fishing + shipping + Ferries total sea and Delta	221,5	24,6
Sinking	1,0	0,1

The composition of traffic involved in the accidents and emergency situations is indicated in Table 14

Table 14 Traffic composition involved in accidents

Vessel type	Percentage
General cargo	52.1
Tankers	26.3
Bulk carriers	5.1
Fishing vessels	7.9
Others	8.6
Total	100.0

The risk that a vessel will be involved in an accident or will face an emergency depends on the distance sailed by a vessel. The cumulative distance sailed per year is approximately 21.6 million nautical miles, ref. [6].

The hazards for pipeline damage caused by navigation may be distinguished in hazards due to dropping and dragging anchors as well as sinking ships. Foundering is not relevant due to the local water depth of 28.6 to 40.0 meters.

7.4.2. Sinking ships

The fact that sinking ships are a potential danger to the pipeline was demonstrated by the Swedish ferry "Venca Gorthan", which sank in February 1988 and damaged Unocal's Q1 oil pipeline [8]. The damaged section had to be by passed and was re-commissioned four weeks after the incident.

It should be noted that the amount of oil leaked from the pipeline due to this accident was insignificant. In view of this the pipeline damage could be assumed as less severe than Class 3 damage and as such should not be considered as a serious type of damage by the controlling agency. The damage itself corresponds to Class 4 damage, as the pipeline had experienced large deformations and the operator had to shut down the pipeline for remedial action.

In the occurrence of such pipeline damage possible losses of liquid hydrocarbons cannot be excluded. Therefore, the damage to sinking ships must be considered.

The average number of sinking ships is 1 per 9 years according [6] and the total distance sailed by ships of 21.6 x 10^6 nautical miles, the frequency of ships sinking, as presented in Table 13. Consequently, the probability that a ship will sink is equal to $P_{accidental}$ = 5.14 x 10^{-9} per sailed nautical mile.

Approximately 85% of all sunken ships had a DWT of less than 500. Taking 500 DWT as an average, the characteristic length of the ships is 50 m. The critical corridor in which a vessel can sink and hit the pipeline is 100 m wide, with the pipeline in the center.

The course of a ship in an emergency has a random orientation, not all the ships which sink in the critical corridor, will hit the pipeline. Only a fraction of $1/\pi$ of the ships sinking in the critical area will hit the pipeline.

As stated section 7.4.1, a shipping density of 3 ships per 1000 km² is assumed within area of the North Sea where the pipeline will be placed.

The average sailing speed is 8.9 nautical miles per hour, this means that an average vessel will sail 24 x 365 x 8.9 = 77964 nautical miles per year. The sailed distance (L_s) within the area of 1000 km² is therefore equal to the number of nautical miles per year multiplied by the shipping density:

$$L_s = 77964 \quad \cdot 3 = 2.34 \cdot 10^5 \; nm$$

The distance sailed in the critical pipeline corridor of 100 m per km pipeline length equal to

$$L_c = L_s \frac{0.1}{1000} = 23.4 \; nm$$

The probability of sinking ships on the pipeline (P_s) is equal to the frequency of sinking ships, $P_{accidental}$, multiplied by the sailed nautical miles in the critical pipeline corridor L_c.

Consequently $P_s = P_{accidental} \cdot L_c = 5.14 \cdot 10^{-9} \cdot 23.4 = 1.20 \cdot 10^{-7}$ accidents per km per year in the critical pipeline corridor due to sinking ships. Taking the random directionality into account, the probability of a sinking ship on top of the pipeline is $\frac{P_S}{\pi} = 3.83 \cdot 10^{-8}$ per km per year.

When a ship sinks, it will eventually come to rest on the seabed. If this mishap occurs just above the pipeline, it would depend on the local strength of the shell of the ship whether the pipeline would be dented or damaged with leakage.

Due to the relatively low vertical velocity of the sinking ship when hitting the pipeline, one can consider the loading on the pipeline as quasi static. The kinetic energy carried by a sinking ship of 3000 DWT (74% of the vessels) is in the order of 6 kJ per m². The plastic energy capacity of the pipeline is 4.3 kJ according to section

7.4.3.2, for a dent of 15% of the outside diameter. A sunken ship will likely provide a more even load distribution. To penetrate 0.2 m cover approximately 30 kJ of kinetic energy per m² contact area is required. It is likely that the energy of the sinking ship will dissipate into the soil cover before the pipeline is hit.

When left on the seabed, wrecks are known to dig themselves in due to scour. In this respect, the cover on top of the pipeline will not completely prevent damage but will result in postponing the damage.

Due to the low probability of a ship sinking above the pipeline, further investigations into the dynamics of ship wreck impacting the buried pipeline will not be performed.

7.4.3. Dropping and dragging anchors

7.4.3.1. Accidents due to dropping and dragging anchors

Dropping anchors near the pipeline poses a risk, as it can potentially hit and damage the pipeline.

Anchoring of work boats outside platform areas is not expected to be hazardous to the pipeline as the crews of such vessels are always fully aware of obstacles in their work sector and anchoring is consequently carefully planned. Furthermore, anchoring of a workboat is often done with assistance of a special anchor vessel.

Reasons for anchoring can be divided in two groups, including:

- Regular anchoring, to await the boarding of a pilot or permission for entering the harbor, waiting for further sailing orders of the owner or for cleaning and maintenance.
- Emergency anchoring, following an accident such as fire, engine failure or collision.

In case of regular anchoring, a ship's captain will inspect his sea charts, avoid obstacles and preferably choose an area assigned for anchoring. For that reason, regular anchoring is not considered to be a risk factor for the safe operation of a pipeline.

In the event of an emergency it may be expected that most of the ship's captains will inspect their sea charts before dropping an anchor. In addition, many captains prefer not to anchor at all in emergency situations. However, it cannot entirely be ruled out that some of them decide to drop an anchor impulsively. Following this reasoning, it is assumed in this study that in 25 percent of emergency situations, anchors are dropped without prior inspection of the sea charts. In such case, the anchors are considered to be dropped at random; some of them will land in the vicinity of the pipeline and may create a critical situation for the pipeline.

The probability of anchor drops or dragging of the anchor near the pipeline is a function of the following factors:

- The chance that a ship faces an emergency.
- The width of the corridor, wherein anchor drop or drag becomes a risk factor for the pipeline.
- The length of the hazardous zone, this being a function of the angle between vessels' course and pipeline.
- Traffic density and composition in the identified region.
- Critical ship DWT causing Class 3 damage in the case of drop/drag.

The traffic density/composition and the chance that a ship faces an emergency is a function of the registered accidents and emergency situations ref.[6]) and listed in in section 7.4.1.

The probability that a vessel will be involved in an accident or will face an emergency depends on the distance sailed by a vessel. Using the data presented in ref. [6], the cumulative distance sailed per day by all vessels is determined being 21.6 million nautical miles.

Considering the total number of ships involved minus the ships running aground as shown in Table 13 the frequency of an accident or emergency is:

$P_{accidental} = \frac{24.6-0.1}{21.6 \cdot 10^6} = 1.13 \cdot 10^{-6}$ accidents per sailed nautical mile per year.

The maximum dragging distance of an anchor depends on the type, mass, and the soil conditions. For smaller anchors in sand the dragging distance is less than 10 m, for heavier anchors it is 10–15 m. In this study, the critical corridor is taken as 20 m (10 m each side of the pipeline) for all anchors.

When the anchor is dropped in the inner part of the critical zone it will hit the pipeline directly. The width of this anchor drop sector is a function of the anchor width. The width of a large anchor is taken as 2.5 m (see also Appendix A for anchor sizes) resulting in a sector width for anchor drop of 5.0 m.

The probability that an anchor, when dropped in the critical zone, will directly fall on top of the pipe is therefore 5/20. Consequently, the probability that dropping an anchor in the critical zone will result in anchor drag towards the pipeline is 15/20.

The frequency of accidents per year occurring in the critical zone is calculated as follows:

It is assumed that in 25 percent of the events that an accident occurs, an anchor will be dropped without first consulting any charts, as discussed above. Furthermore, it was shown that the probability that a dropped anchor within in the critical zone directly hits the pipeline is 5/20. The frequency directly hitting the pipeline per km per year can thus be calculated.

The direction of the dragging anchor is variable and the portion of dropped anchors that are dragged towards the pipeline is accounted by multiplying the total number by a factor 1/π.

The distance sailed per year in the critical pipeline corridor of 20 m per km pipeline length is equal to:

$L_c = L_s \frac{0.02}{1000} = 4.68\, nm$

The probability of an accident due to emergency anchoring P_{anchor} per km per year in the corridor is equal to the probability of accidents per sailed nautical mile P multiplied by the sailed nautical miles per year in the corridor L_c and apply the factors 0.25 and 5/20 to account for the probability of anchor drop and anchors directly falling on the pipe:

$P_{anchor} = P_{accidental} \cdot L_c \cdot \frac{5}{20} \cdot 0.25 = 3.32 \cdot 10^{-7}$ anchors falling on the pipeline per kilometer per year.

The probability of an accident due to dragging anchors P_{drag} outside the shipping lane is equal to the probability of emergency anchoring multiplied by 15/20 accounting for the anchor drag length of 15 m relative to the length of the critical area 20 m. Further factors of 1/π and 0.25 are applied to account for the directionality and the probability of anchoring.

$P_{drag} = P_{anchor} \cdot \frac{15}{20} \cdot \frac{1}{\pi} \cdot 0.25 = 3.17 \cdot 10^{-7}$ accidents per km of pipe per year due to dragging anchors

7.4.3.2. Damage due to dropping and dragging anchors

Not all anchors dropped or dragged in the critical zone will result in leakage. There are two major factors contributing to this. First is the absorption of energy by the soil covering the pipeline, second is the allowable deformation of the pipeline before leakage occurs.

An anchor dropped from a ship first penetrates vertically into the seabed. The depth of penetration depends on the weight and shape of the anchor and characteristics of the seabed soils.

As the ship continues to move after the anchor has reached the seabed, the anchor chain tightens and pulls the anchor over until it reaches a horizontal position on the seabed. From this position the flukes gradually work down into the soil until the body of the anchor is either partly or wholly embedded in the seabed and the anchor attains its maximum holding power.

To represent the entire range of anchors with masses of respectively 1000 kg, 5000 kg, 10000 kg, and 15000 kg have been considered in this study. Typical anchor parameters are given in Appendices A, C and D. Based on published test results an average drag distance of 10 m has been selected as appropriate for the sizes of anchors considered. [9]

The passive soil resistance determines the maximum holding power of an anchor. When this holding power is exceeded, some anchors drag horizontally through the soil, while others rotate and will break out and dig in again. When an anchor attains its maximum holding power at the end of dragging, it also has embedded a certain depth below the sea bottom.

A pipeline, which is resting in or on the seabed, is hit by an anchor either vertically when the anchor is dropped on top of it, or horizontally when the anchor is dragged towards the side of the pipeline.

Both types of loading deform the pipeline differently and are discussed below.

Damage due to anchor drop

The kinetic energy of the falling anchor is absorbed by the soil and by deformation of the pipeline. To visualize the plastic deformation energy, the model in Appendix B is used.

The energy required for plastic deformation is a function of the pipeline characteristics and extent of deformation in accordance with equation:

$E_p = 2\,\sigma_t\, t_{EOL}^2\, \delta\, \sqrt{2}$, in which:

$t_{EOL} = (1 - wtt) \cdot wt - t_{cor}$, where

- t_{EOL} is the wall thickness of the pipeline at the end of life;
- wtt is the wall thickness tolerance, as defined in Table 2**;**
- t_{cor} is the internal corrosion allowance, as defined in Table 2**;**
- δ is 15% of the pipeline OD, so 41 [mm];

For the given material properties and wall thickness, provided in Table 2 and Table 3. This leads to a plastic energy of 4.32 [kJ].

The maximum allowable deformation (δ) is 15 % of the pipeline diameter, further deformation is associated with leakage. To establish the impact velocity of the anchor it is necessary to determine the impact velocity of the anchor when it reaches the seabed. During its descend to the sea floor, the anchor is subjected to the forces of gravity and drag. Drag can be computed from:

$$F_d = \frac{1}{2}\rho V^2 C_d A$$

If the anchor is released from sufficient height, drag and gravity will be in balance at a certain speed of descend, known as terminal velocity. Terminal velocity can be calculated from:

$v_T = \sqrt{\frac{2 \cdot g \cdot (m - V \cdot \rho_{water})}{\rho_{water} \cdot C_d \cdot A}}$, in which:

- m is the dropped object;
- g is the gravitational constant;
- V is the volume of the object (the volume of the displaced water);
- ρ_{water} is the sea water density, 1025 [kg/m^3] as given in [11];
- Cd is the drag coefficient, which is a function of the dropped object shape;
- A is the projected area of the object in the flow direction;
- v_T is the terminal velocity;

The kinetic energy of the anchor is computed from

$E_k = 0.5(M + M_a) \cdot v_T^2$

With the added mass given by

$m_a = \rho_{water} \cdot V \cdot C_a$, in which:

- C_a is the added mass coefficient, which is a function of the object shape;

The calculation of the kinetic energy as a function of the anchor mass is provided in Appendix G.

The absorption of energy (E_{pen}) by the seabed can be derived with the Brinch-Hansen method for the soil bearing capacity

$$E_{pen} = \int_0^{d_p} F(y)dy$$

Where:

y is the penetration depth [m]

d_p is the depth of the soil cover above the top of the pipeline [m]

$F(y)$ is the soil bearing capacity at a certain depth [N], given by:

$$F(y) = A \cdot \left(c\, N_c\, S_C\, D_c + q_0\, N_q\, S_q\, D_q + 0.5\, \gamma\, B\, N_\gamma\, S_\gamma\, D_\gamma\right)$$

Where:

A is the frontal area of the anchor [m^2]

c is the cohesion of the soil [N/m^2], for the project under consideration $c = 0$ (ref. [13])

q_0 is the overburden load at depth y [N/m^2], $q_0 = \gamma\, g\, y$

γ is the submerged density of the soil [kg/m^3], as given in Table 5 and Table 9

ϕ is the angle of soil internal friction [deg], as given in Table 5 and Table 9

B is the width of the anchor frontal area [m]

L is the length of the anchor frontal area [m]

N, S and D are dimensionless factors related to the soil bearing capacity, shape of the frontal area, and the depth respectively

$$N_c = \frac{N_q - 1}{\tan\phi}$$

$$S_c = 1 + 0.2\frac{B}{L}$$

$$D_c = 1 + 0.4\,\mathrm{atan}\frac{y}{B}$$

$$N_q = e^{\pi\tan\phi}\tan^2\left(45 + \frac{\phi}{2}\right)$$

$$S_q = 1 + \sin\phi\frac{B}{L}$$

$$D_q = 1 + 2\tan\phi\ (1 - \sin\phi)^2\,\mathrm{atan}\frac{y}{B}$$

$$N_\gamma = 2\left(N_q - 1\right)\tan\phi$$

$$S_\gamma = 1 - 0.4\frac{B}{L}$$

$$D_\gamma = 1$$

Damage will be beyond the 15 % acceptable deformation when:

$$E_k - E_{pen} > E_p$$

Appendix A shows a relation between anchor mass and the frontal area of the anchor.

The calculated absorption energy as a function of the cover depth is provided in Appendix G.

Using a representative set of anchor masses, a relation between anchor mass and the required minimum soil cover was established, as presented in Figure 4.

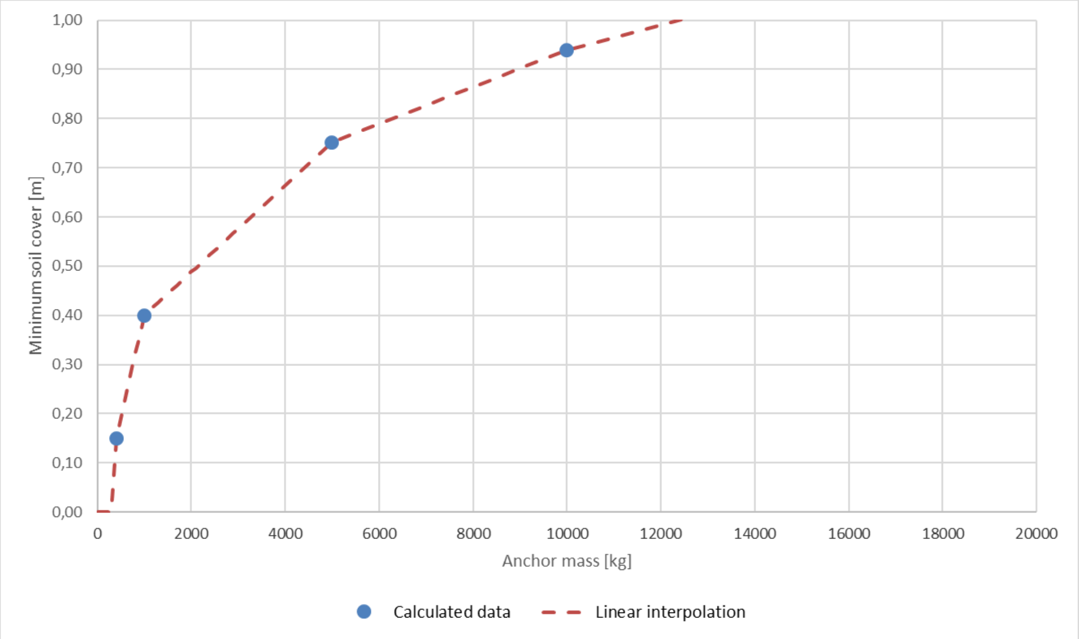


Figure 4 Required minimum soil cover as function of anchor mass

Damage due to anchor drag

If the pipeline is hit by a dragging anchor, it first experiences an impact load, followed by a sustained load when the anchor hooks behind the pipeline and the anchor chain/cable is straightened.

The impact loading and its consequence for the pipeline can be found from the results above. It is logical to expect that the velocity of the dragged anchor is very low and of the same order as the surface current velocity, which keeps the ship without engine power moving. With an anchor drag velocity of 1 m/s the effect of the impact load is negligible due to the anchor velocity at the time of a direct drop.

For that reason, the pipeline damage assessment following an anchor drag is only done for the second phase of loading, when the anchor hooks and starts to drag the pipeline. The ultimate load to which the pipeline is exposed is assumed to be equal to the design load of the anchor chain.

The hooking load is counteracting the wave and wind load on the vessel, which is floating around. A safety factor of 2 to 3 for the anchor chain is usually applied to the anchor maximum holding force. Therefore, in the following analysis the ultimate load to which the pipeline is exposed was taken to be half of the breaking strength of the anchor chain.

If a pipeline has sufficient cover it is possible that the dragging anchor will not reach it. This cover depth is equal to the depth of anchor embedment after being dragged minus half of the pipe diameter, as an anchor which hits the pipe on its top half will be dragged over the pipeline without causing any serious damage.

The depth of penetration or embedment as a function of the anchor size is illustrated in Appendix D. This relationship is valid for sandy soils like those found along the considered pipeline route. The following minimum cover depths in

Table 15 can be considered to protect the pipeline against any form of damage to anchor drag.

Table 15 Safe pipeline cover against anchor drag

Anchor mass	Cover depth
[kg]	[m]
1000	0.85
5000	1.30
10000	1.75
13500	1.95

To investigate the uniformly supported pipeline exposed to a concentrated load, a mechanical model is selected based on the following assumptions:

- The pipeline is supported by soil which will yield, and therefore, the soil resistance equals the ultimate soil resistance.
- Three plastic hinges represent the deflection pattern of the pipeline.
- The maximum load capacity of the pipeline is reached when the stress level in the fully plastic cross section reaches the breaking strength of steel.

Appendix E shows a schematic presentation of the mechanical model. Based on the above assumptions, the maximum load capacity can be determined by considering an energy balance.

The ultimate load bearing capacity due to energy absorbed by the plastic hinges and soil is equal to:

$$F = 4\sqrt{M_p R}$$

Where:

M_p is the plastic moment [Nm], $M_p = D^2\, t\, \sigma_t$

D is the outside pipe diameter [m]

t is the pipe wall thickness at end of life [m]

σ_t is tensile strength of steel [N/m^2]

R is the resistance of the soil behind the pipe [N/m], $R = \gamma\, g\, z\, N_q\, D$

z is the depth of the centerline of the pipe

γ is the submerged density of the soil [kg/m^3], as given in Table 5 and Table 9

$$N_q = e^{\pi \tan\phi} \tan^2\left(45 + \frac{\phi}{2}\right)$$

The maximum anchor drag force to which the pipeline will be exposed is taken to be half of the breaking strength of the chain. According to Lloyd's register of Shipping, the mass of an anchor is related to the link breaking strength of the anchor chain. Appendix F shows a plot of this relationship.

The tension force in the chain is equal to the anchor drag force plus drag of the chain itself on the sea floor and the gravity component up to the ship anchor chain attachment point. To account for these forces the following approximate linear relation is used:

$$T = K \cdot F$$

The factor K depends on whether the pipeline is buried or not, and on the type of anchor considered. For anchors used on merchant vessels, K = 1.1 for an unburied pipeline and K = 1.3 for a buried pipeline. For this project a buried pipeline is considered.

7.4.3.3. Probability of damage due to anchor drop and drag

Accounting for the associated vessel Dead Weight Tonnage (DWT), the probability of a dropped anchor resulting in unacceptable damage has been determined. The distribution of marine traffic split into the four groups as discussed earlier in this chapter has been utilized to establish this probability (in percentage) according to:

$P(d) = 100 - \frac{DWT}{3000} P_{0,group1}$; valid for DWT<3,000 mT

$P(d) = 100 - \frac{DWT-3000}{7000} P_{0,group2} - P_{0,group1}$; valid for 3,000 mT < DWT < 10,000 mT

$P(d) = 100 - \frac{DWT-10000}{100000} P_{0,group3} - P_{0,group1} - P_{0,group2}$; valid for 10,000 mT < DWT < 100,000 mT

$P(d) = P_{0,group4}$; valid for DWT >100,000 mT

Dropped anchors

The DWT of the ships which anchors can cause Class 3 damage when directly dropped on top of the pipeline were calculated in section 7.4.3.2, see Figure 4. For the associated DWT ranges, the percentage of a group which causes damage by a dropped anchor can be determined, as given in Table 16.

Table 16 Percentage of group which causes damage by anchor drop

Anchor weight	Associated DWT	% when M<3000	% when 3000< M<10000	% when 10000<M <100000	% when M>100000	Total %
300,0	1430,1	64,7	0,0	0,0	0,0	64,7
500,0	2398,4	40,8	0,0	0,0	0,0	40,8
900,0	4870,3	0,0	24,3	0,0	0,0	24,3
3000,0	15482,9	0,0	0,0	18,6	0,0	18,6
6000,0	33777,6	0,0	0,0	14,9	0,0	14,9
12000,0	83976,6	0,0	0,0	4,7	0,0	4,7

Following the relation between anchor mass and DWT, as provided in Appendix C, the leak probability can be determined for anchor drops, as provided in Table 17.

Table 17 Probability of a leak as a function of the critical anchor mass and cover depth

Cover depth [m]	Critical anchor mass [kg]	Critical DWT [mT]	Traffic > Crit.DWT [%]	Probability of leak $X10^{-6}$
0,0	300,0	1430,1	64,7%	0,21
0,2	500,0	2398,4	40,8%	0,14
0,4	1000,0	4870,3	24,3%	0,08
0,6	3000,0	15482,9	18,6%	0,06
0,8	6000,0	33777,6	14,9%	0,05
1,0	12000,0	83976,6	4,7%	0,02

Dragged anchors

The DWT of the ships which anchors can cause Class 3 damage when directly dragged towards the pipeline were calculated in section 7.4.3.2, see Figure 4. For the associated DWT ranges, the percentage of a group which causes damage by a dropped anchor can be determined, as given in Table 18. The relevant properties calculated for anchor drag, can be found in Appendix H.

Table 18 Percentage of group which causes damage by dragged anchor

Anchor weight	Associated DWT	% when M<3000	% when 3000< M<10000	% when 10000<M <100000	% when M>100000	Total %
541	2597	35,9	0,0	0,0	0,0	35,9
906	4400	0,0	24,7	0,0	0,0	24,7
1212	5939	0,0	23,4	0,0	0,0	23,4
1476	7293	0,0	22,1	0,0	0,0	22,1
1725	8585	0,0	21,0	0,0	0,0	21,0
1961	9824	0,0	19,9	0,0	0,0	19,9
2174	10960	0,0	0,0	19,5	0,0	19,5
2381	12076	0,0	0,0	19,3	0,0	19,3
2580	13157	0,0	0,0	19,1	0,0	19,1
2771	14206	0,0	0,0	18,8	0,0	18,8
2958	15247	0,0	0,0	18,6	0,0	18,6

Table 19 Consequences of anchor drag

Cover Depth [m]	Critical anchor mass [m]	Critical DWT [mT]	Traffic > Crit. DWT [%]	Probability of leak X10^{-6}
0	541	2597	35,9%	0,11
0.2	906	4400	24,7%	0,08
0.4	1212	5939	23,4%	0,07
0.6	1476	7293	22,1%	0,07
0.8	1725	8585	21,0%	0,07
1.0	1961	9824	19,9%	0,06

7.4.4. Pipeline damage probability of a leak

The probability of pipeline damage due to fishing activities and containers and cargo overboard can be excluded. Likewise, the probability of pipeline damage due to sinking ships is negligible.

The probability of damage resulting in leakage is the summation of the probabilities of leakage due to dropping and dragging anchors is presented in Table 20

Table 20 Cumulative probability of leaks due to anchor drop and drag

Cover depth [m]	Probability of leak: anchor drop x10^{-6}	Probability of leak: anchor drag x10^{-6}	Total Probability of leak: (anchor drop + anchor drag) x10^{-6}
0,0	0,21	0,11	0,33
0,2	0,14	0,08	0,21
0,4	0,08	0,07	0,15
0,6	0,06	0,07	0,13
0,8	0,05	0,07	0,12
1,0	0,00	0,06	0,07

The probability leading to class 3 damage smaller is less than $1*10^{-6}$, thus based on anchor drop and drag, the minimum required cover of 0.2 [m] is sufficient.

8. Dropped object analysis

This section describes the used methodology for determining the impact energy due to the dropped objects and the amount of energy absorbed by the rock dump as a function of its height. This approach excludes probabilistic data and is merely a comparison between impact energy of the dropped object and absorbed energy by the cover layer. It is assumed that the spool has the same properties as the pipeline, as a result the same acceptable amount of plastic deformation energy has been used.

The required height of the rock dump near the platforms and tie-in, to withstand the impact energy generated by dropped objects because of crane handling from and on(to) the platform/supply vessel (containers, equipment, pipes etc.), is determined following DNV-RP-F107 [11].

8.1. Dropped object impact energy

Calculation of the kinetic energy (E_k) of a dropped object is performed using the same method as described in section 7.4.3.

As discussed in chapter 4.5, the most likely objects to damage the pipeline are tubular objects such as pipe elements.

Using the data on typical dropped objects as presented in Table 8, the terminal velocity and kinetic energy upon impact are calculated and the results are presented in Table 21. The maximum drop height (Hd) in air is estimated not to exceed 50 [m].

The impact velocity at sea level can be determined using section 4 of ref. [12]:

$$v_{i,a} = \sqrt{2 \times g \times Hd}$$

The characteristic water depth is determine using 4 of ref. [12]:

$$sc = \frac{M + Ma}{\rho_w \; * \; C_d \; * \; A_p}$$

Knowing the minimum water depth of 28 [m], (s) and having determined the characteristic distance (s_c) and terminal velocity (v_t) for a specific object, the actual impact subsea velocity (v) and thus the impact energy can be calculated using above given Figure 5.

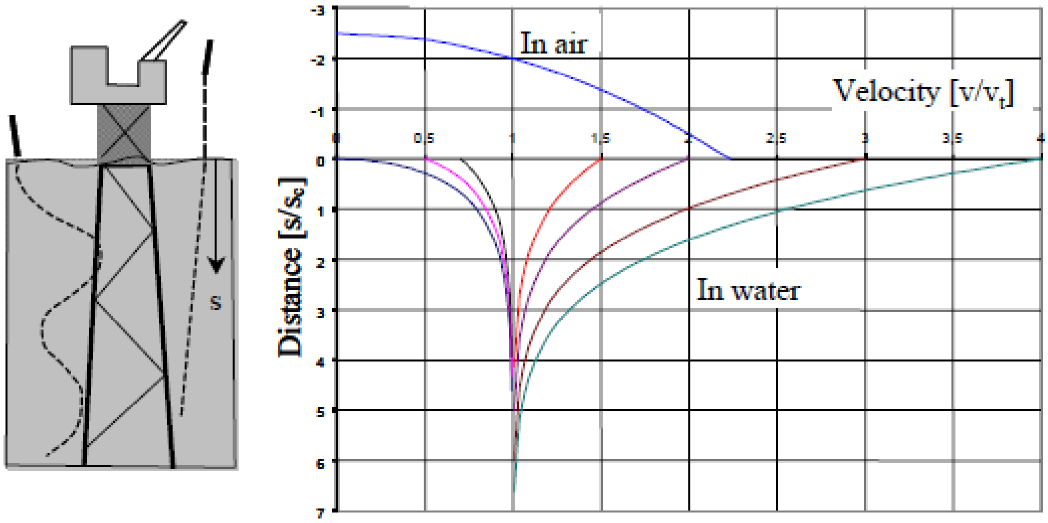


Figure 5 Velocity profile for objects falling in water [12]

Table 21 Kinetic impact energies for design dropped objects

Object	Unit	1	2	3	4	5
Impact vi,a at waterline	[m/s]	31.3	31.3	31.3	31.3	31.3
drop distance in air, Sa	[m]	50	50	50	50	50
drop distance in sea, S	[m]	28	28	28	28	28
Terminal velocity in water, vt	[m/s]	8.98	9.62	10.17	10.43	11.43
Characteristic distance, sc	[m]	8.1	4.2	4.9	5.0	6.4
vi,a/vt_air	[-]	3.49	3.26	3.08	3.00	2.74
s/sc	[-]	8.13	6.72	5.76	5.55	4.38
vi/vt_water	[-]	1.1	1.1	1.1	1.2	1.1
vi	[m/s]	9.9	10.6	11.2	12.5	12.6
Kinetic impact energy, Ek	[kJ]	35.8	65.7	105.8	156.4	281.7

8.2. Rock dump energy capacity

The properties of the rock dump as presented in Table 9 are used as input for the dropped object calculation.

The bearing force which can be taken by the rock dump is once again evaluated according the Brinch-Hansen method elaborated in section 7.4.3, denoted as F(y).

The energy absorption capacity of a rock dump is defined by:

$$E_p = \mathrm{p} \cdot g \cdot \left\{\frac{1}{2} \cdot (B_r + B_o) \cdot \frac{1}{2} (L_r + L_o) \cdot h\right\}$$

Whereas,

Br, Lr = breadth/length influence zone rock dump at top of pipe (see eq. 5.14 & 5.15)

$$Br = Bo + 2 \cdot h \cdot \tan(90 - \varphi)$$

$$Lr = Lo + 2 \cdot h \cdot \tan(90 - \varphi)$$

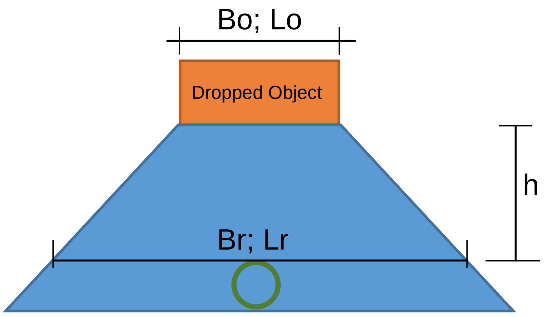


Figure 6 Rock dump geometric annotations

Where both Br and Lr are calculated are calculated per object, based on the rock dump properties as provided in section 4.6 and the pipe diameter, which is equal to Bo and Lo.

Cylindrical objects will find a stable falling orientation in a horizontal position. As the longest object considered is 1.2 m in length and the width of the rock cover is typically 2 meters, it is assumed that the object contacts the rock cover along its full length. The contact area is then equal to the outer diameter times the length.

The absorption energy calculated for the objects dropped on the and 10" for both the rock dump and the spool is presented Table 22, where the maximum value for the rock dump cover is highlighted. The absorption energy of the spool is identical to the absorption energy of the pipeline (Ep = 4.32 [kJ]), as calculated in section 7.4.3.2. For the calculation of the governing dropped object absorption energy of the rock dump, see Appendix I.

Table 22 Absorption energy Ep for the design dropped objects for the 10" spool

Object	Unit	1	2	3	4	5
$h_{,critical}$	[m]	0.22	0.27	0.31	0.37	0.41
Bearing capacity, p(h)	[tonnes/m^2]	41.8	50.4	57.8	66.2	75.3
Absorption energy Rock dump, (Epd)	[kJ]	31.5	61.4	101.4	152.1	277.3
Absorption energy Rock spool, (Eps)	[kJ]	4.32	4.32	4.32	4.32	4.32

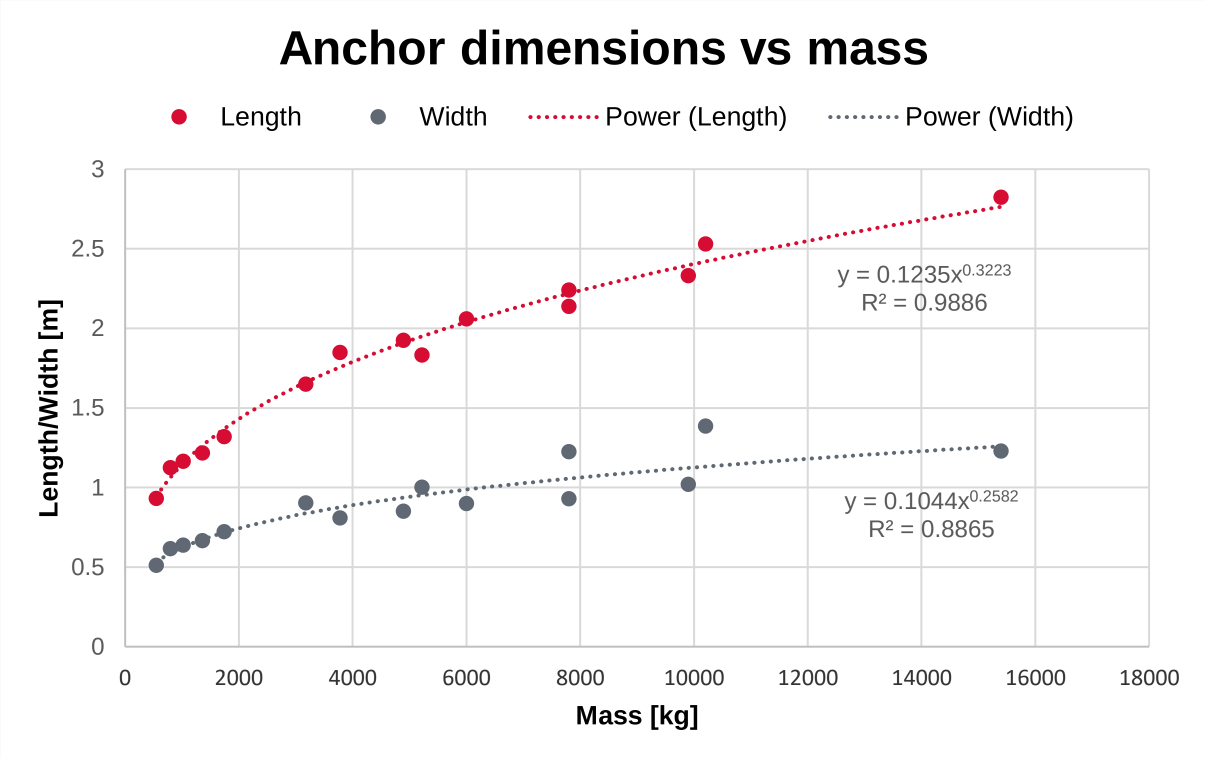
As can be seen, object 5 is most critical regarding the required rock dump height, which should be more than 0.41 m.

9. Liquid Hydrocarbon Spillage

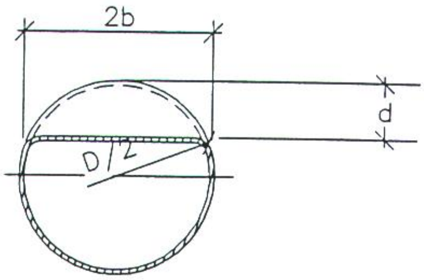
In case of rupture of the pipe, a part of its liquid contents might be spilled. The distance to the shore is over 25 [miles]. According [13], the maximum liquid hold-up in the pipeline is approximately 15 [m^3]. Considering the relatively large distance to shore and the relatively small volume of liquid hold-up, the maximum spillage which could occur is considered acceptable.

A. Anchor size determination

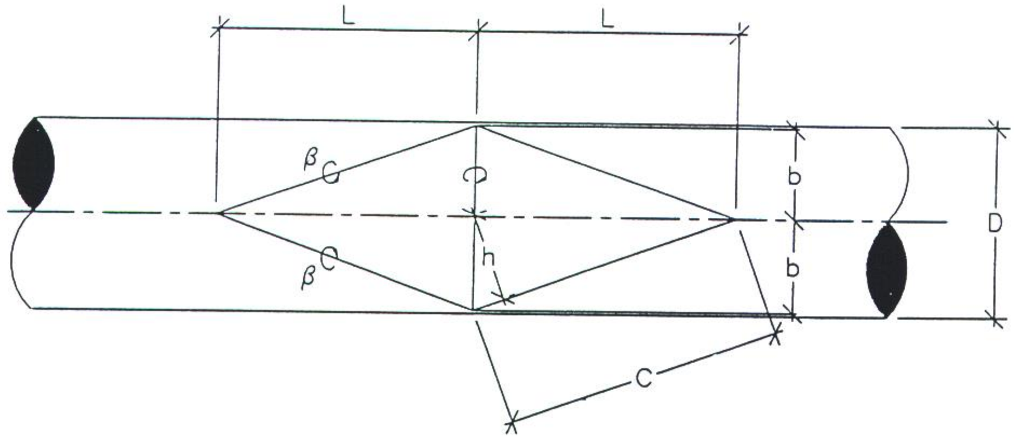
Data was gathered on several types of anchor configurations (stockless and Baldt) in a mass range of 550 to 15400 kg. The length and width dimension projected to the oncoming flow during the descend to the sea floor were obtained. A polynomial curve has been fitted through the data and this was used to estimate the dimensions of an anchor for which only the mass was specified.



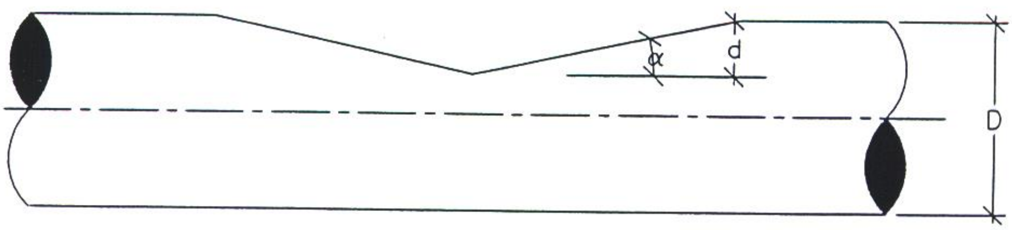
B. Plastic deformation model



A. PIPE CROSS-SECTION THROUGH DENT



B. PLAN VIEW OF SIMPLIFIED DENT SHAPE

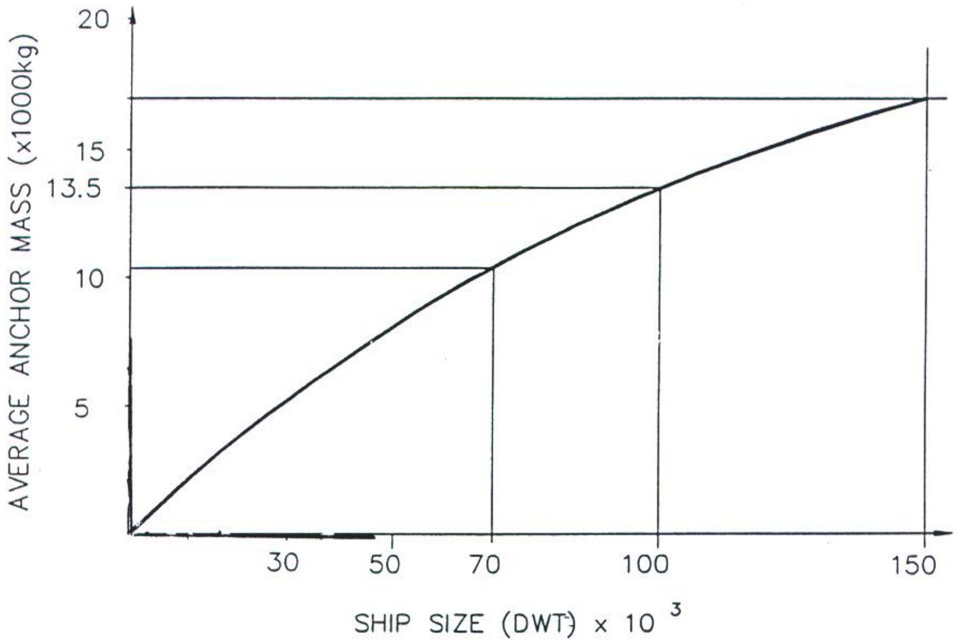


C. SIDE VIEW OF SIMPLIFIED DENT SHAPE

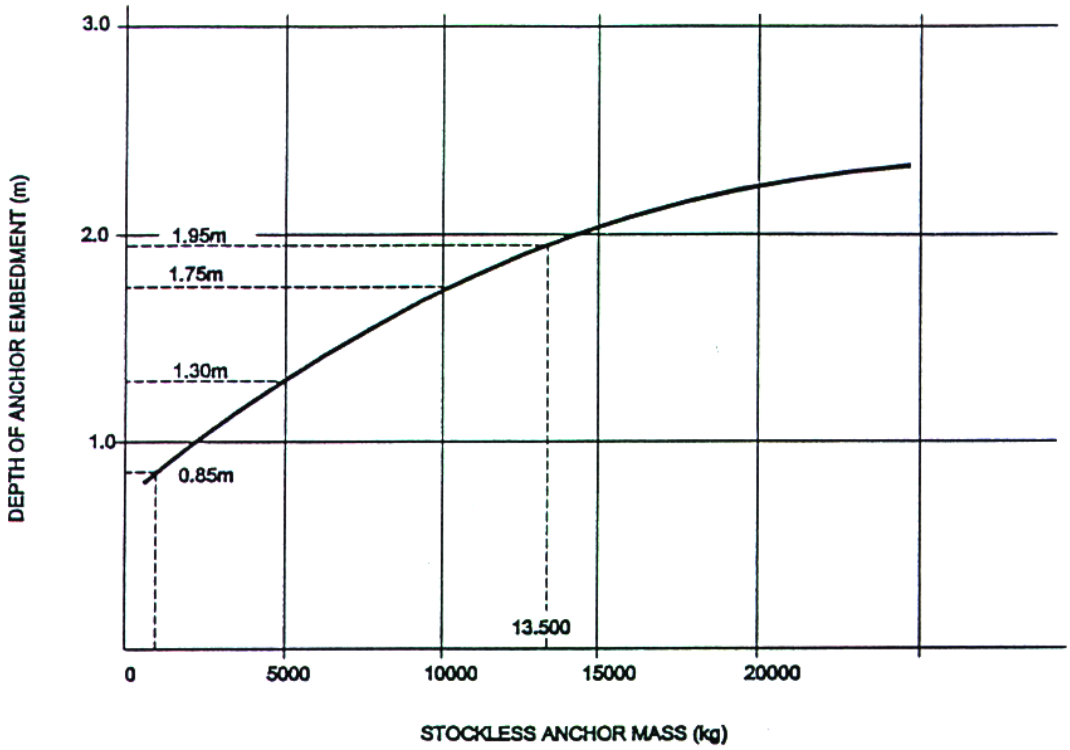
$\tan\alpha = d/L$

$\tan\beta = d/h$

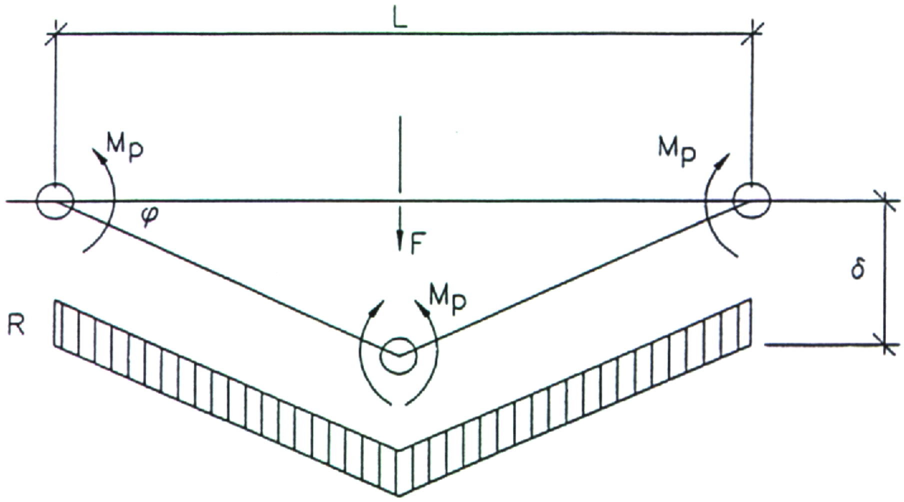
C. Ship size versus anchor mass



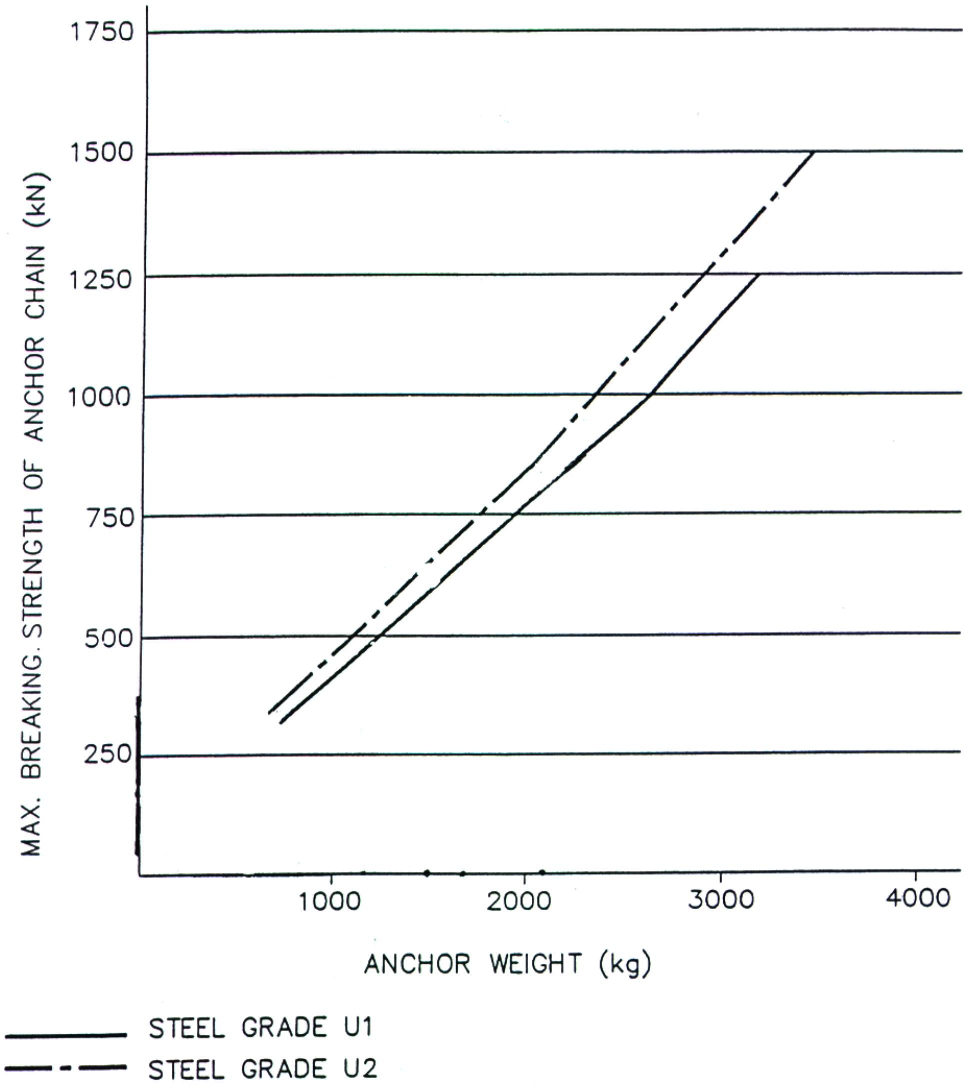
D. Penetration depths due to anchor drag versus anchor size



E. Mechanical model dragged pipeline



F. Anchor mass versus maximum breaking strength of anchor chain



SOURCE: LLOYD'S "REGISTER OF SHIPS"

G. Dropped anchor calculations

Table 23 Kinetic energy calculation per anchor mass group

Symbol	Description	unit	Anchor mass 1	Anchor mass 2	Anchor mass 3	Anchor mass 4	Anchor mass 5
g	grav. Acceleration	m/s^2	9,81	9,81	9,81	9,81	9,81
M	anchor mass	kg	400	1000	5000	10000	15000
w	width frontal	m	0,49	0,62	0,94	1,13	1,25
L	length frontal	m	0,85	1,14	1,92	2,40	2,74
A	anchor frontal area	m2	0,42	0,71	1,81	2,71	3,43
ρsteel	steel density	kg/m3	7850	7850,00	7850	7850	7850
ρwater	sea water density	kg/m3	1025	1025	1025	1025	102
Vanchor	anchor volume	m3	0,05	0,13	0,64	1,27	1,91
Cd	drag coefficient ASSUMED	[-]	0,80	0,80	0,80	0,80	0,80
vt	Terminal velocity	m/s	4,77	5,41	7,58	8,77	9,54
Ca	added mass coefficient		1,00	1,00	1,00	1,00	1,00
Ma	added mass	kg	52,23	130,57	652,87	1305,73	1958,60
Ek	kinetic energy total	J	5145	16534	162379	434332	772275
		kJ	5,1	16,5	162,4	434,3	772,3

Table 24 Calculation of the absorption energy as a function of the burial depth

Symbol	Description	unit	Anchor mass 1	Anchor mass 2	Anchor mass 3	Anchor mass 4	Anchor mass 5
A	Anchor frontal area	m^2	0,42	0,71	1,81	2,71	3,43
c	cohesion of soil	N/m2	0,00	0,00	0,00	0,00	0,00
g	submerged weight of soil	[N/m3]	8500	8500	8500	8500	8500
f	angle of soil internal friction	[rad]	0,49	0,49	0,49	0,49	0,49
		[deg]	28	28	28	28	28
B	Anchor width	[m]	0,49	0,71	1,81	2,71	3,43
L	Length of anchor	[m]	0,85	1,14	1,92	2,40	2,74
Nq	Bearing capacity factor	[-]	14,72	14,72	14,72	14,72	14,72
Nc	Bearing capacity factor	[-]	25,80	25,80	25,80	25,80	25,80
Sc	Shape factor	[-]	1,29	1,31	1,47	1,57	1,63
Ng	Bearing capacity factor	[-]	10,94	10,94	10,94	10,94	10,94
Sg	shape factor	[-]	0,77	0,77	0,77	0,77	0,77

Symbol	Description	unit	Anchor mass 1	Anchor mass 2	Anchor mass 3	Anchor mass 4	Anchor mass 5
Dg	depth factor	[-]	1,00	1,00	1,00	1,00	1,00
Sq	Shape factor	[-]	1,27	1,29	1,44	1,53	1,59
Dq	Depth factor (z=0,2m)	[-]	1,12	1,08	1,03	1,02	1,02
	Depth factor (z=0,4m)	[-]	1,20	1,15	1,07	1,04	1,03
	Depth factor (z=0.6m)	[-]	1,27	1,21	1,10	1,07	1,05
	Depth factor (z=0.8m)	[-]	1,31	1,25	1,12	1,09	1,07
	Depth factor (z=1,0m)	[-]	1,33	1,29	1,15	1,11	1,09
Z	penetration depth	[m]	0,20	0,20	0,20	0,20	0,20
	penetration depth	[m]	0,40	0,40	0,40	0,40	0,40
	penetration depth	[m]	0,60	0,60	0,60	0,60	0,60
	penetration depth	[m]	0,80	0,80	0,80	0,80	0,80
	penetration depth	[m]	1,00	1,00	1,00	1,00	1,00
qo	Overburden load at depth of D (z=0,2m)	[N/m2]	1700,0	1700,0	1700,0	1700,0	1700,0
	Overburden load at depth of D (z=0,4m)	[N/m2]	3400,0	3400,0	3400,0	3400,0	3400,0
	Overburden load at depth of D (z=0,6m)	[N/m2]	5100,0	5100,0	5100,0	5100,0	5100,0
	Overburden load at depth of D (z=0,8m)	[N/m2]	6800,0	6800,0	6800,0	6800,0	6800,0
	Overburden load at depth of D (z=1,0m)	[N/m2]	8500,0	8500,0	8500,0	8500,0	8500,0
Fy (z)	Force at sea bed (z=0,0m)	[N]	7,34E+03	1,81E+04	1,17E+05	2,62E+05	4,20E+05
	Force at depth D (z=0,2m)	[N]	2,22E+04	4,30E+04	1,85E+05	3,68E+05	5,59E+05
	Force at depth D (z=0,4m)	[N]	3,70E+04	6,79E+04	2,52E+05	4,74E+05	6,97E+05
	Force at depth D (z=0,6m)	[N]	5,18E+04	9,27E+04	3,20E+05	5,80E+05	8,35E+05
	Force at depth D (z=0,8m)	[N]	6,66E+04	1,18E+05	3,87E+05	6,86E+05	9,74E+05
	Force at depth D (z=1,0m)	[N]	8,14E+04	1,42E+05	4,55E+05	7,92E+05	1,11E+06
Epen (z)	kinetic energy absorbed (z=0.0m)	[kJ]	1,47	3,62	23,47	52,48	84,03
	kinetic energy absorbed (z=0.2m)	[kJ]	5,90	12,22	60,43	126,12	195,75
	kinetic energy absorbed (z=0.4m)	[kJ]	13,29	25,79	110,89	220,94	335,15
	kinetic energy absorbed (z=0.6m)	[kJ]	23,65	44,34	174,84	336,94	502,25
	kinetic energy absorbed (z=0.8m)	[kJ]	36,98	67,86	252,30	474,10	697,03

H. Anchor drag calculations

Table 25 Critical anchor weight as a function of the cover depth

Cover depth	z	z/D	Nq	Qu	R	Mp	F	F	T=K*F	Tbreaking (Tb = 2*T)	Anchor weight	Crit. DWT
[m]	[m]		fig 11	[N/m²]	[N/m]	[Nm]	[N]	[kN]	[kN]	[kN]	[kg], fig 12	[kg], fig 8
0,0	0,137	0,5	4,80	5565	1520	3,09E+05	8,67E+04	87	113	225	541	2597
0,2	0,337	1,2	5,46	15623	4267	3,09E+05	1,45E+05	145	189	377	906	4400
0,4	0,537	2,0	6,13	27947	7632	3,09E+05	1,94E+05	194	252	505	1212	5939
0,6	0,737	2,7	6,63	41489	11331	3,09E+05	2,37E+05	237	308	615	1476	7293
0,8	0,937	3,4	7,12	56661	15474	3,09E+05	2,76E+05	276	359	719	1725	8585
1,0	1,137	4,2	7,58	73189	19988	3,09E+05	3,14E+05	314	409	817	1961	9824

I. Dropped object analysis

Absorption energy (Ep) by rock dump

For falling pipes/solid weight blocks bearing capacity (p) at rock dump height can be determined using Brinch Hansen.

$$p(h) = (q_0 \cdot s_q \cdot N_q \cdot D_q + 1/2 \cdot s_\gamma \cdot \rho_{r,s} \cdot Bo \cdot N_\gamma \cdot D_\gamma)$$

h = rock dump height		0,41	m
Density rock material,		2650	kg/m3
porosity		0,3	-
Density rock material, subm.		1138	kg/m3
Angle of internal friction,	ρ_r	40	deg
		0,70	rad
	$\rho_{r,s}$		
Overburden pressure rock dump, qo @depth h	φ	468,41	kg/m2
Shape factor,		1,64	-
Soil bearing coefficient,	s_q	64,2	-
Depth factor, Dq	N_q	1,11	-
Shape factor,		0,6	-
Bo/Lo = width/length pipe @ impact = 1			
Breadth object, Bo		0,76	m
Length object, Lo	s_γ	0,76	m
Soil bearing coefficient,		79,5	-
Depth factor,		1	-
Bearing capacity, p	N_γ	75279	kg/m2
		75,3	tonne/m2
	D_γ		

Work done (Ep) by rock dump against impact energy of falling objects

Epd	p*A*h*g	277338	J
		277,34	kJ

J. Platform lay-out

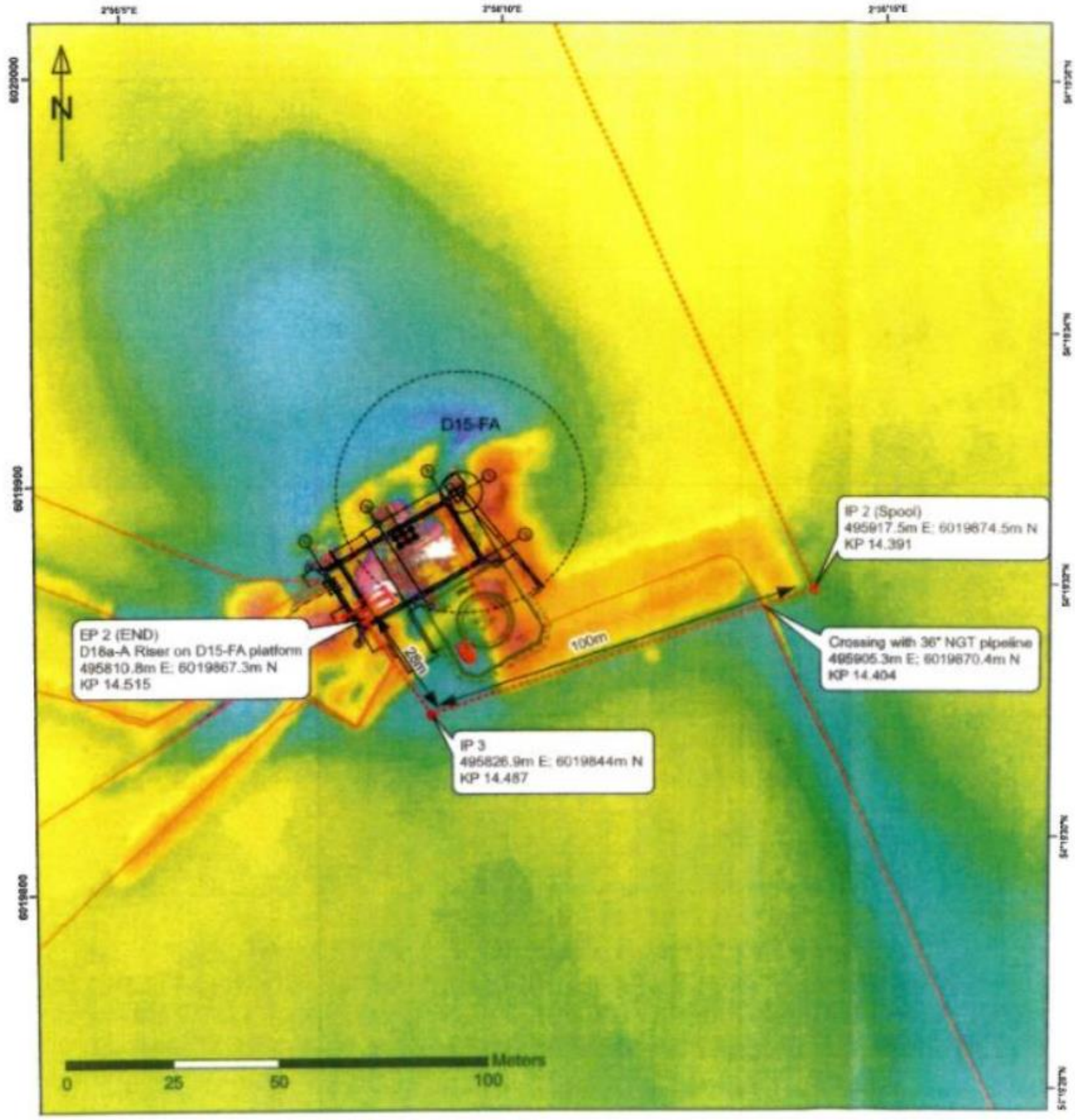


Figure 7 D15-FA crane reach vs pipeline platform

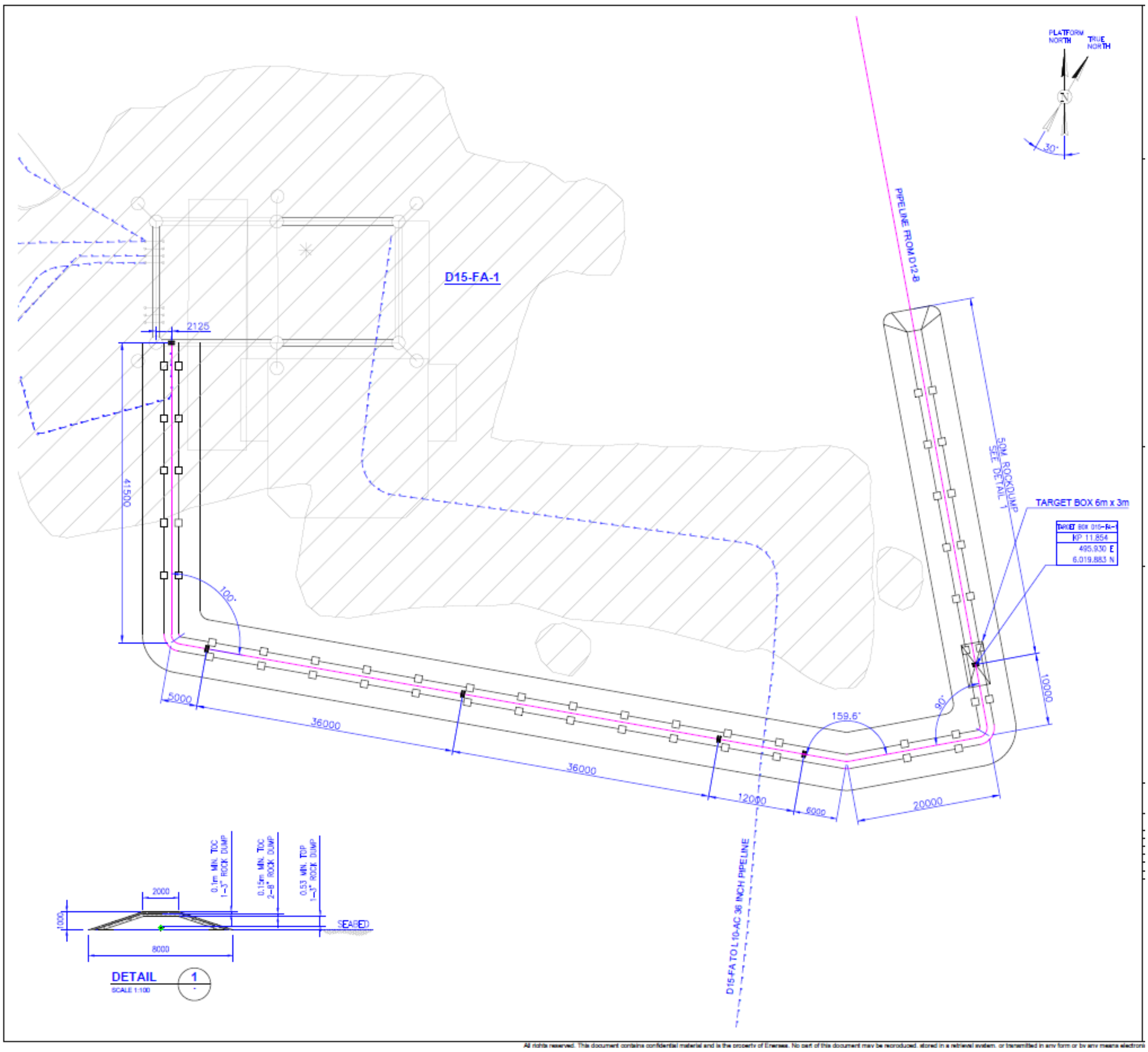


Figure 8 D15-FA platform approach

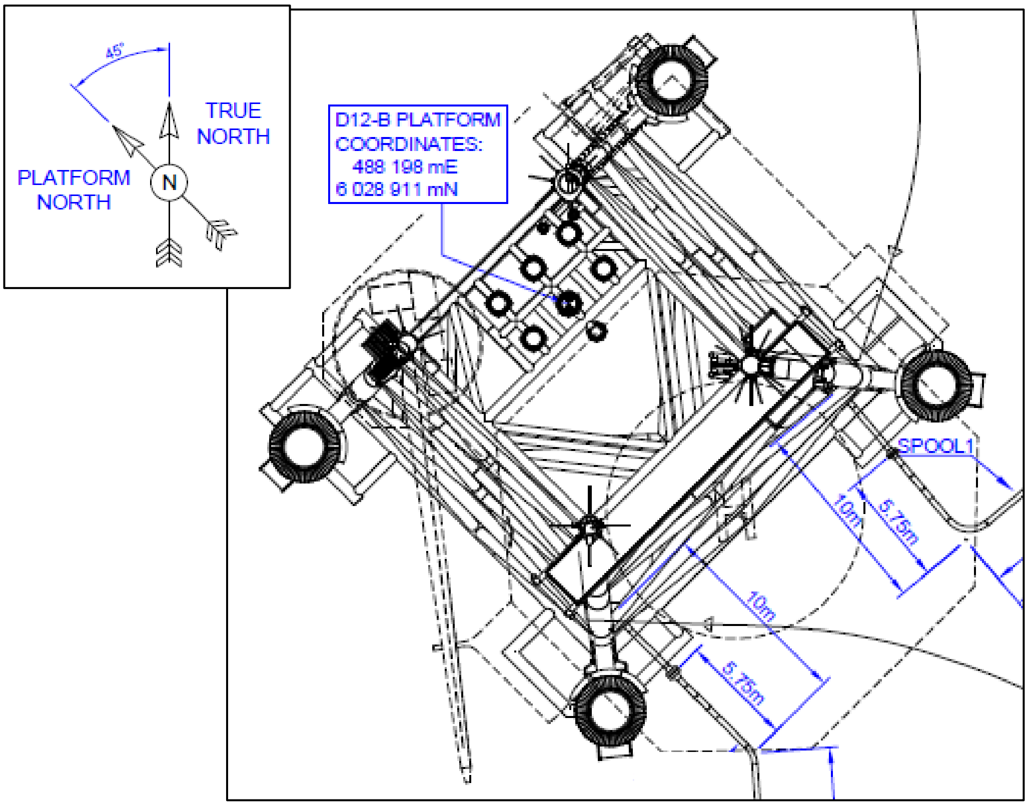


Figure 9 D12-B crane reach vs pipeline platform

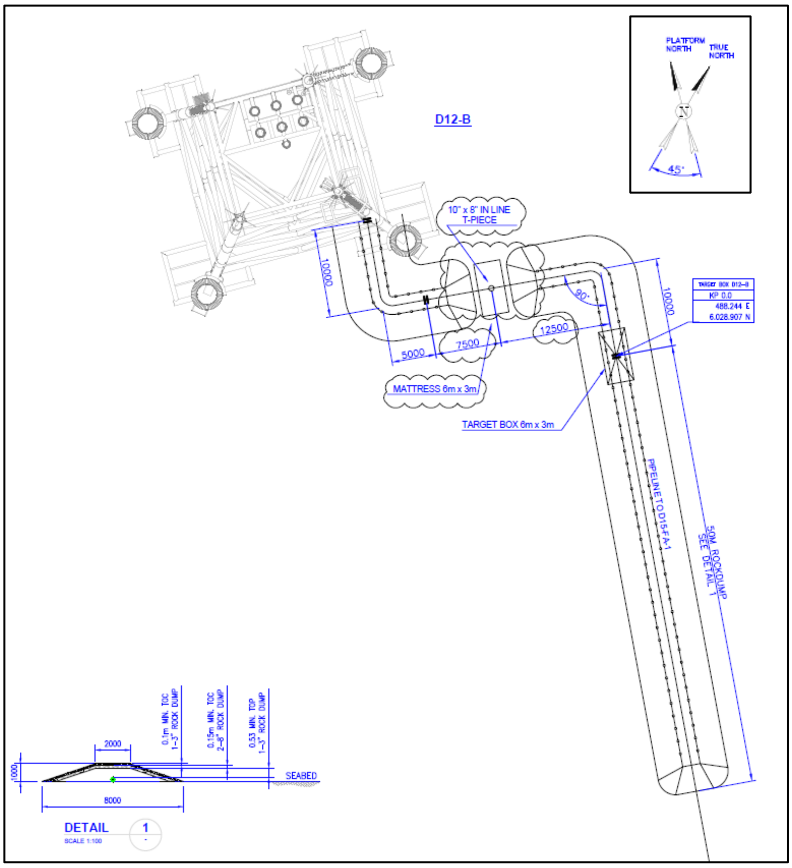


Figure 10 D12-B platform approach