RECOMMENDED PRACTICE
DNV-RP-F111

INTERFERENCE BETWEEN TRAWL GEAR AND PIPELINES

OCTOBER 2010

DET NORSKE VERITAS

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- Reinertsen Engineering
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CHANGES

- **General**

As of October 2010 all DNV service documents are primarily published electronically.

In order to ensure a practical transition from the "print" scheme to the "electronic" scheme, all documents having incorporated amendments and corrections more recent than the date of the latest printed issue, have been given the date October 2010.

An overview of DNV service documents, their update status and historical "amendments and corrections" may be found through http://www.dnv.com/resources/rules_standards/.

- **Main changes**

Since the previous edition (October 2006), this document has been amended, most recently in April 2009. All changes have been incorporated and a new date (October 2010) has been given as explained under "General".

CONTENTS

1. General

1.1 Introduction

Fishing activities such as bottom trawling shall be considered for offshore pipelines for two main reasons:

— possible hazard and inconvenience to the fishermen in case of trawl gear hooking to the pipeline, and
— possible hazard to the integrity of the pipeline due to loads from the trawl gear.

This Recommended Practice (RP) covers the aspects of pipeline integrity and not the potential hazard for fishermen in particular.

Equipment used for bottom trawling can expose a pipeline to substantial loads that may damage it. Such load is associated with the instantaneous impact and the subsequent pull-over as the trawl gear hits and is dragged over the pipeline. In addition, hooking of trawl equipment may impose considerable loading to the pipeline.

Typical trawl gears are illustrated in Figures 1-1 to 1-3.

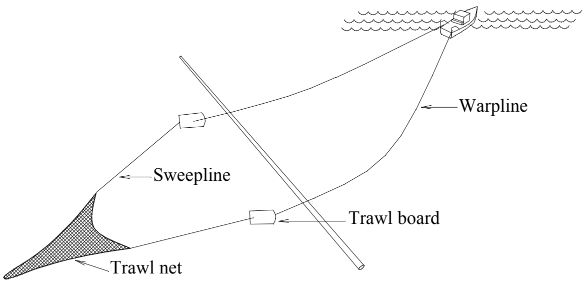

Figure 1-1
Typical otter trawl gear crossing a pipeline

Figure 1-1 shows a typical otter trawl. The otter trawl board holds the trawl net open by hydrodynamic forces. Such trawl boards are dragged along the seabed and may represent a hazard to the pipeline.

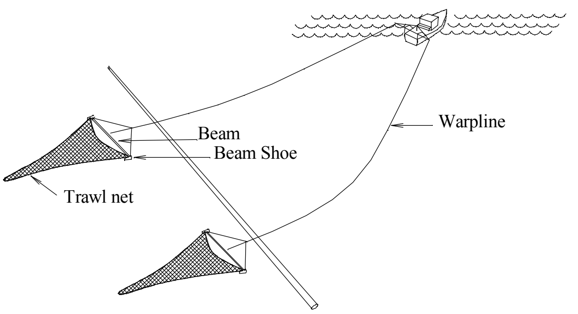

Figure 1-2
Typical beam trawl gear crossing a pipeline

In beam trawling, a transverse steel beam is used to keep the net open as shown in Figure 1-2. Beam shoes are mounted at each end of the beam and represent a substantial hazard to pipelines due to their sharp edges and large kinetic energy.

In twin trawling the clump weight shown in Figure 1-3 has a mass typically in the range of 2 to 9 tonnes, and can cause larger impact energy and pull-over loads than trawl boards. Several designs are used, ranging from a clump of chain to spherical or cylindrical rollers. Twin trawling with clump weight is currently not used for industrial trawling, and is hence only relevant in consumption trawl areas.

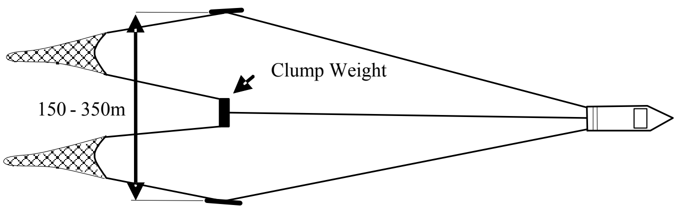

Figure 1-3
Typical twin trawling with clump-weight.

Traditionally, pipelines are protected against trawl impact by coating, gravel or burial. As such protection is expensive; there is a need for improvement with respect to design methods and rules for trawl gear interference. This RP gives information on design methods such that unnecessary conservatism may be avoided. At the same time it intends to give a more uniform safety level for the potential failure modes.

1.2 Trawling aspects

The authority requirements with respect to interference between trawl gear and pipeline/ subsea structures vary from country to country. In the Norwegian sector, it is required that all subsea installations shall not unnecessarily or to an unreasonable extent impede or obstruct fishing activities, whereas in other countries the authorities allow non-overtrawlable structures (i.e. by applying safety zones and restricted areas on maps, or by using guard vessels).

Subsea installations attract fish, and hence fishing activity. A good dialog between the fishing and offshore industries is important in order to ensure safe and cost effective operation for all parties. Examples of elements important to communicate are:

— pipelines preferably to be routed outside fishing banks whenever practical, and thus, designers need important information about such;
— the offshore industry needs information on trawl equipment used, to design for appropriate loads and to reduce risk of hooking;
— new trawling equipment should be designed to minimize risk of hooking pipelines, subsea structures and other seabed obstructions; and
— development of new trawl equipment may have impact on existing pipeline designs.

Trawl velocity and pattern is mainly governed by fish movement pattern, sort of fish to catch (swimming speed), and economic speed of trawl vessels. Therefore, it is not likely that the trawling velocity will increase significantly in the future. Trawling for prawns is typically performed at 2 - 3 knots (1-1.5 m/s), whereas trawling for fish is performed at up to 5 - 6 knots (2.8 m/s average).

Presently (2005), the heaviest twin trawl equipment has a typical mass up to 9-10 tonnes and is used in the Barents Sea and outside Greenland - mainly trawling for prawn in areas without offshore activities. However, trawlers operating in these areas may also use the same heavy equipment in the North Sea or the Norwegian Sea (i.e. to avoid having two sets of equipment). The weight of the clump weights used is typically 60 - 70 % of the total weight of the trawl doors.

Trawling along a curved path may cause the trawl equipment path to be considerably different from the path of the vessel. Figure 1-4 illustrates a potential scenario where the trawl vessel turns around a 500 m radius safety zone and causes the trawl equipment to follow a path well within the restricted zone, [9]. It should be noted that trawling inside the safety zones is not allowed. However experience shows that this may occur and should be considered in the design.

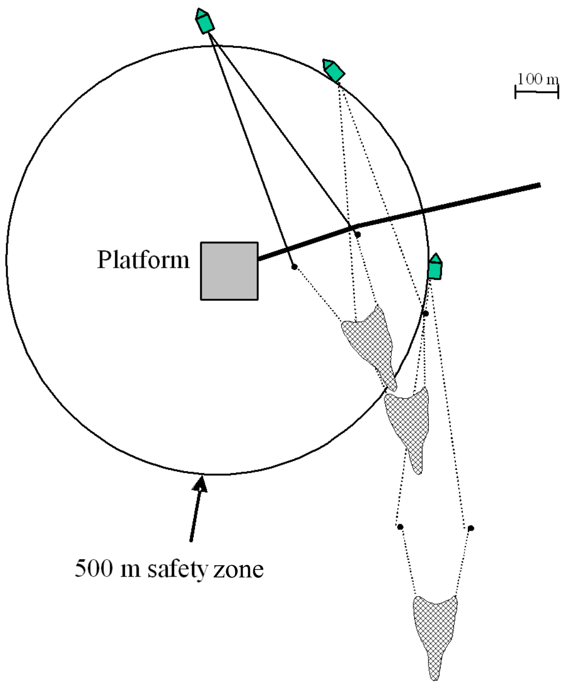

Figure 1-4
Possible trawl vessel and bottom trawl gear positions when fishing around platform safety zone.

Trawl interference with pipeline rock-berm and trenches as well as cuttings deposited during well drilling operations and left after removal of installations may represent considerable loading (and potential hooking) to trawl equipment. These aspects are not covered by this RP.

1.3 Scope and application

The objective of this RP is to provide rational criteria and guidance on design methods for pipelines subjected to interference from trawling gear; including the impact, pull-over and possible hooking phases. Design criteria are given as well as guidance on applicable calculation methods.

For pipelines subjected to global buckling, such as:

1) pipelines with release of effective, compressive axial force (buckling) prior to trawling, or
2) pipelines with release of effective, compressive axial force simultaneously with trawling, i.e. the trawl load triggers global buckling.

Global buckling pipeline response analyses is required in combination with the trawl load assessment. The global buckling analyses needs to include sensitivity studies of governing parameters such as pipe to soil interaction in accordance with DNV-RP-F110, to establish the proper functional load condition factor.

This document is applicable to rigid pipelines with outer steel diameters larger than 10" (i.e. the smallest pipe diameter tested in model tests have been used as basis for this RP). However, if measures are taken in the analyses to account for scaling effects outside of the model test validity range, the methodology reflected in this RP may still be applicable. Typically, this would involve special assessments of soil to pipe interaction factors (ref. Figure 3-3), global bending stiffness of pipeline and factors related to relative sizes between pipe and trawl equipment.

For pipelines with outer steel diameter less than 10", the soil reduction factors based on Figure 3-3 should conservatively be based on 300 mm outer diameter for impact load calculations.

Loads and load effects on flexible pipelines can be determined, provided relevant flexibility characteristics and acceptance criteria are specified.

Trawl pull-over and hooking may govern the acceptable free span lengths and gaps. These aspects are covered within this RP, while the effect of environmental loads on free spans is covered by DNV-RP-F105.

This document does not cover pipeline attachments such as anodes. However, it is envisaged that such equipment is designed for trawl loads both with respect to impact and pull-over including abrasion from trawl wire. Additionally, edges and protrusions and or bolts that may snag trawl nets need to be avoided.

Further, a methodology for qualifying possible DEH cable attached to the pipeline inside a protective structure is given in Appendix A.

This RP is intended for use on a world-wide basis. However, the collection of trawl gear data has been carried out for the North Sea and the Norwegian Sea. Data is given appropriate for otter, beam and twin trawling equipment in use in 2005 and expected for use in the near future in these areas.

The following design aspects are considered:

— coating damage due to impact
— pipe denting due to impact
— overstress due to pull-over or hooking.

This comprises the following topics:

— most critical trawl equipment
— frequency of trawl impacts
— effective impact energies to be absorbed by the coating and the pipe
— requirements to structural modelling
— recommendations for pull-over loads
— recommendations for lifting heights due to hooking
— acceptance criteria.

Figure 1-5 shows part of a flow chart for a typical pipeline design. After deciding on diameter, material, wall thickness, trenching and coating for weight and insulation, the trawling design is performed. It must be emphasised that the trawl pull-over assessment must be based on a realistic estimate of the effective axial force, and any changes due to sagging in spans, lateral buckling, end expansion, changes in operational conditions etc., must be properly accounted for. Unacceptable results from trawl impact, pull-over and/or hooking may change the sequence in this design flow chart (Figure 1-5) as it may have impact on coating and burial of the pipeline.

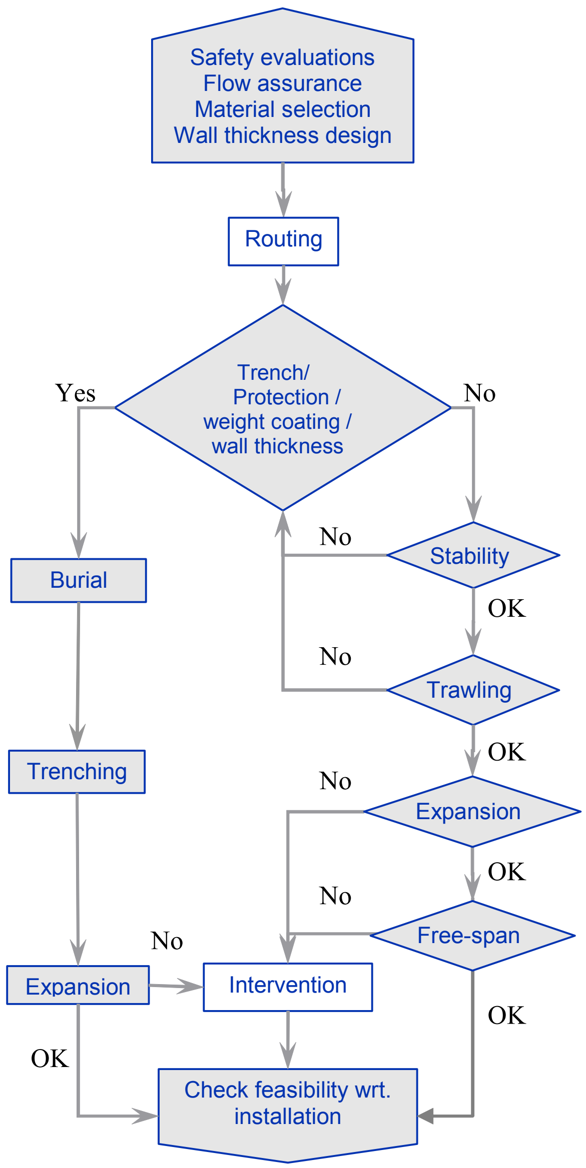

Figure 1-5
Flow chart for pipeline design

1.4 Limitations

This RP gives loads and load effects on pipelines due to trawl gear interference. These loads are related to the size, shape, velocity and mass of the trawling gear. This document is based on data for trawl equipment typically used in the North Sea and the Norwegian Sea up to 2005, however the methods may be used for other geometrically similar equipment as well.

The design criteria and associated set of partial safety factors are based on the assumption that load effects are obtained from a state-of-the-art FE-analysis or similar calculation method which includes the most important linear and possible non-linear effects of the considered pipeline section.

1.5 Relationship to other rules

This RP replaces the DNV Guideline number 13 issued in 1997, and is a supplement to and complies with the DNV-OS-F101. This document further relates to and harmonises with the DNV-RP-F110.

The NORSOK standard "Subsea Production systems", U-001 gives requirements with respect to interference with trawl gear. Generally, this document is in accordance with the requirements given in the NORSOK standard. However, with regard to trawl impact, pull-over and hooking loads, this RP gives more precise and detailed estimates for the loads which may occur for pipelines while the NORSOK requirements refer to trawl loads on subsea structures.

In case of conflict between requirements of this RP and a referenced DNV Offshore Code, the requirements of the code with the latest revision date shall prevail.

Any conflict is intended to be removed in next revision of that document.

In case of conflict between requirements of this Offshore Code and a non DNV referenced document, the requirements of this Code shall prevail.

1.6 References

The latest revision of the following documents apply:

DNV Offshore standard
DNV-OS-F101 Submarine Pipeline Systems, Det Norske Veritas.

DNV Recommended Practice
DNV-RP-C205 Environmental Conditions and Environmental Loads, Det Norske Veritas.

DNV-RP-F105 Free Spanning Pipelines, Det Norske Veritas.

DNV-RP-F110 Global Buckling of Submarine Pipelines, Det Norske Veritas.

Other standards

NORSOK, Standard, "Subsea Production systems", U-001.

1.7 Trawl-pipeline interaction phases

When bottom trawl gear is towed across a pipeline, the interaction may conveniently be divided into two stages: *impact* and *pull-over*. As a special case *hooking* may occur.

- *Impact,* i.e. the initial impact phase when a trawl board, beam shoe or clump weight hits a pipeline. This phase typically lasts some hundredths of a second. It is mainly the local resistance of the pipe shell, including any protective coating and/ or attached electric cable protection structure that is mobilised to resist the impact force.
- *Pull-over*, i.e. the second phase where the trawl board, beam trawl or clump weight is pulled over the pipeline. This phase can last from about 1 second to some 10 seconds, dependent on the water depth, span height, and other factors. This will usually give a more global response of the pipeline.
- *Hooking*, i.e. a situation whereby the trawl equipment is "stuck" under the pipeline. This is a seldom occurring accidental situation where forces as large as the breaking strength of the warp line may be applied to the pipeline in extreme cases.

An overview of the design process for pipelines with respect to interference with trawl gear is shown in Figure 1-6. First, trawl equipment characteristics and frequency must be established. Then, analysis and design with respect to impact, pull-over and hooking is conducted. The impact energy to be used in testing of coated pipe sections is calculated. The effect of pull-over is found through global analysis. The capacity to resist possible hooking is checked by applying a certain lifting height.

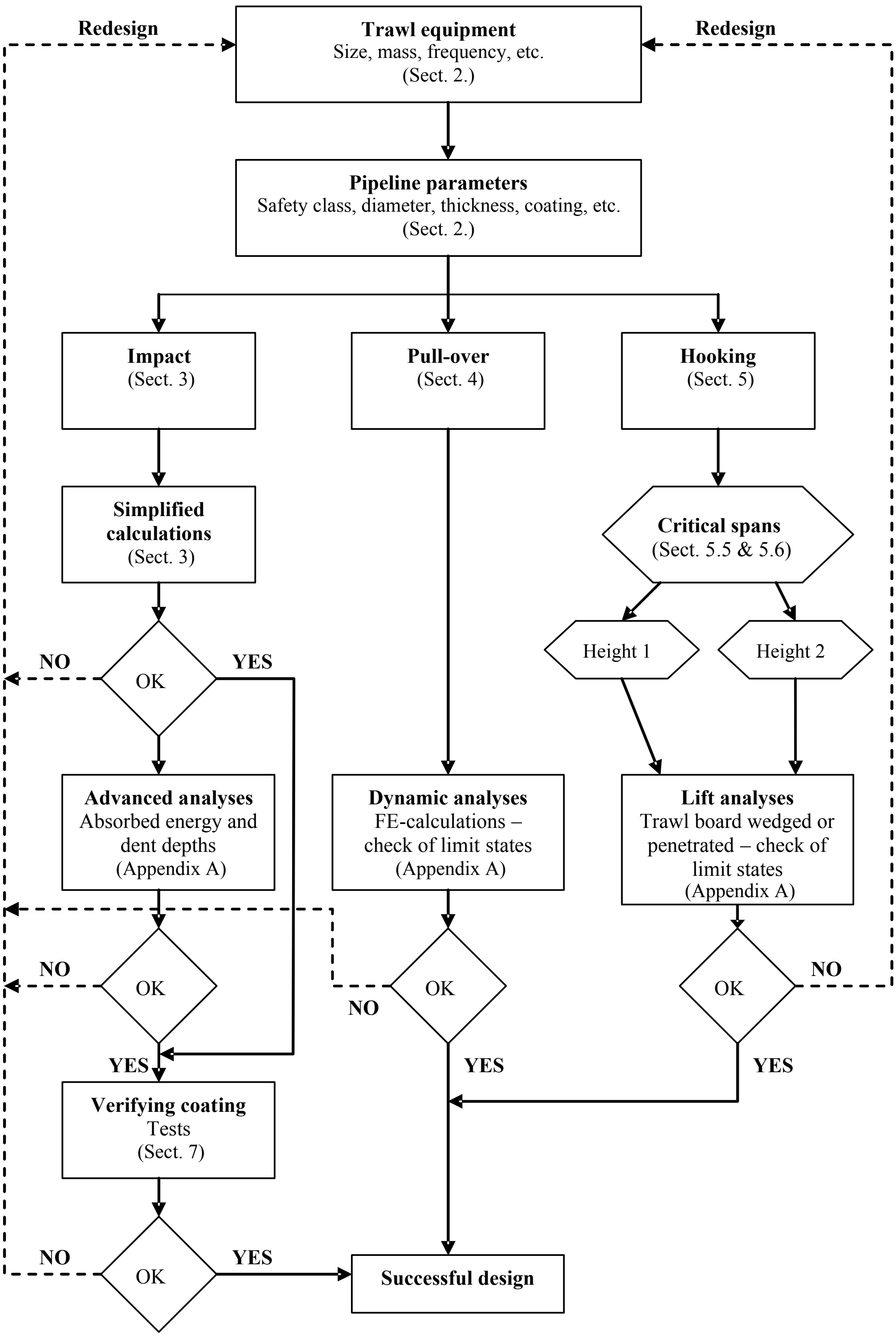

Figure 1-6
Overview of the design of pipelines with respect to interference with trawl gear.

1.8 Units

The international system of units (SI system) is applied throughout this document (e.g. length in meters, mass in kilograms, time in seconds and force in Newton).

1.9 Symbols and abbreviations

The following definitions apply:

A_{clump}	clump weight dimension, gap between roller and pipeline contact point (see Figure 4-1)
A_e	cross-sectional area of the steel pipe exposed to external pressure
A_i	cross-sectional area exposed to internal pressure
A_w	warp line cross-sectional area
B	half height of trawl board
C_b	coefficient of effective beam trawl mass during impact
C_F	coefficient of pull-over force
C_h	coefficient of effect of span height on impact velocity
C_T	coefficient for pull-over duration
d	water depth
D	steel pipe nominal outside diameter
E	Young's modulus
E_a	impact energy due to hydrodynamic added mass
E_{DEH}	impact energy absorbed locally by the DEH cable including protection structure
E_{loc}	impact energy absorbed locally by the pipe shell and coating
E_s	impact energy due to steel mass of trawl board, beam with shoe or clump weight
f_{imp}	trawl gear impact frequency
F_b	impact force due to trawl board bending action
F_{sh}	maximum impact force experienced by the pipe shell
f_T	trawl frequency per considered section, see Sec.6.4.
F_p	maximum pull-over force on pipe, horizontal direction
F_z	maximum pull-over force on pipe, vertical direction (note positive down)
f_y	yield stress to be used in design $f_y = (SMYS - f_{y,\,temp})\,\alpha_U$
$f_{y,\,temp}$	derating value due to the temperature of the yield stress
g	gravitational acceleration
$\overline{H}$	dimensionless height (= $(H_{sp} + OD/2+0.2)/B$)
h	trawl board height (=2B)
h'	dimensionless moment arm, to calculate clump weight pull-over load
H_a	height of attachment point of warp to beam trawl
H_{cr}	critical free span height for hooking
H_i	impact hammer pendulum height
H_l	lifting height during hooking
$H_{p,c}$	permanent dent depth (characteristic value)
H_{sp}	span height (pipeline to seabed gap)
H_t	dent depth (elastic and plastic)
I	trawl vessel density (annual mean no. of trawlers per unit seabed area)
k_b	out-of-plane stiffness of trawl board
k_{c1}	stiffness of protection cover for heating cables attached to the pipeline (when applicable)
k_{c2}	coating stiffness
k_{c3}	coating stiffness due to interaction effects between coating and steel pipe
k_i	in-plane stiffness of trawl board
k_{pb}	effective bending stiffness of pipe in impact calculation (time dependent)
k_{ps}	effective soil stiffness applied to pipe in impact calculation (time dependent)
k_s	local shell stiffness of steel pipe
k_w	stiffness of trawl warp
L	trawl board length, beam length or clump weight width
L_{clump}	distance from clump weight interaction point with pipeline to clump weight centre of gravity (See Figure 4-1)
L_w	warp line length
M_t	moment resulting from trawl pull-over load
M_{td}	design moment for resulting from trawl pull-over load
m_a	hydrodynamic added mass of trawl board or beam
m_h	mass of test impact hammer
m_t	steel mass of trawl gear
m_1	mass of test rig pipe support
m_2	mass of test rig floor
n_{cap}	capacity of coated pipe expressed as number of repeated impacts to failure
n_g	number of trawl boards, beam shoes or clump weights per trawl vessel
n_{mean}	mean number of impacts of coating before failure
N	axial force in pipe wall (true force) (tension is positive)
OD	overall outside diameter of pipeline, including coating
p_e	external pressure
p_i	characteristic internal pressure
R_{fa}	reduction factor for impact energy associated with hydrodynamic added mass
R_{fs}	reduction factor for impact energy associated with steel mass
S	effective axial force (tension is positive)
Su	soil undrained shear strength
t	pipe wall thickness (steel), $t = t_{nom} - t_{corr}$ (i.e. equivalent to t_2 in DNV-OS-F101)
t_{nom}	nominal thickness of the pipe (uncorroded)
t_{corr}	corrosion allowance
T_p	pull-over duration
V	tow velocity of trawler
α_e	proportion of pipeline length exposed to trawl interference (not buried or protected e.g. by rock cover)
α_U	Material strength factor, ref. DNV-OS-F101: $\alpha_U = 0.96$, except for pipeline material fulfilling supplementary requirements U, where $\alpha_U = 1.0$
δ_p	global deflection of pipe at point of trawl pull-over
γ_A	load effect factor, for trawl load classified as accidental ($\gamma_A = 1.0$)
γ_C	load condition factor, ref. DNV-OS-F101
γ_F	load effect factor, with the trawl load classified as a functional load
η	usage factor
φ	prevailing trawl direction relative to the pipeline perpendicular
ϕ	soil internal friction angle
σ	standard deviation for impact test results

DEH	Direct Electrical Heating
FE	finite element
ROV	remotely operated vehicle
RP	Recommended Practice
SCF	stress concentration factor
SMYS	specified minimum yield strength
Polymer	materials such as rubber and plastics
Characteristic load	the reference value of a load to be used in the determination of load effects
Load effect	effect of a single load or combination of loads on the equipment system, such as stress, strain, deformation, displacement, motion, etc.
Load effect factor	the partial safety factor by which the characteristic load effect is multiplied to obtain the design load effect.
Industrial trawling	catch for industrial production (e.g. oil, meal, animal food)
Consumption trawling	catch for food commerce

2. Trawl Design Data

2.1 Types of trawl gear

There are two main categories of bottom trawl gears of concern in the North Sea and the Norwegian Sea; conventional otter trawl gear, and beam trawl gear used in southern part of the North Sea. These differ in the way the trawl net is kept open:

— *Otter* trawls by use of trawl boards
— *Beam* trawls by use of transverse beams

In addition, the use of pair trawling by two ships and twin rig set-ups has developed in recent years. Such gear must be accounted for if heavy clump weights are used in order to force the trawl net down. The size and design of such clump weights varies.

Otter trawling in these areas is carried out with a range of ship sizes and types of gear. Typical types of ships and gear are:

— *Consumption* trawlers which have the largest equipment
— *Industrial* trawlers
— *Prawn* trawlers (operate in the deep water of the Norwegian trench and closer to the coast).

Various trawl board designs exist, however two major types, polyvalent / rectangular and V-shaped boards, are in common use. The polyvalent boards have generally been found to give the highest loads on pipelines. Figure 2-1 shows two typical trawl boards used in the North Sea and the Norwegian Sea. In recent years, trawl boards with spoilers have been developed, to improve the efficiency of the hydrodynamic force and thereby reduce drag forces and trawler fuel consumption.

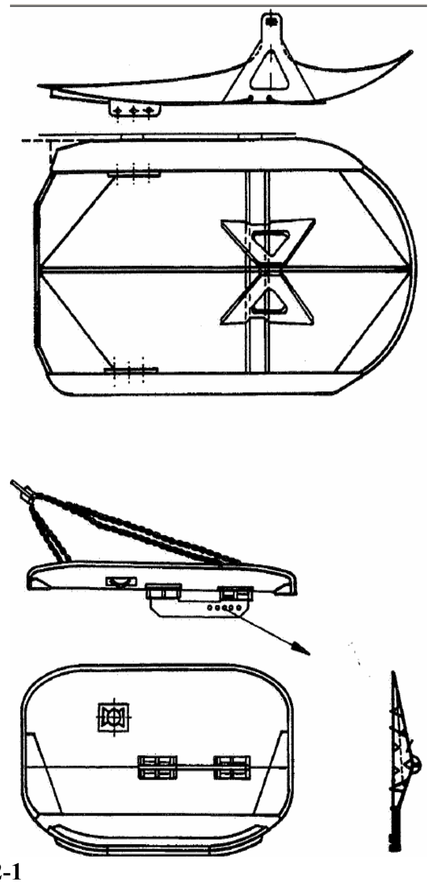

Figure 2-1
Typical Consumption trawl boards: Polyvalent (upper) and V-board (lower).

The size of the trawl board mainly depends on the type of trawl net being used. No depth dependency for trawl board sizes and velocities has been found. It is rather the type and quantity of fish which governs the trawl type and thereby the board size and trawling velocity.

A typical beam trawl shoe and its components are shown in Figure 2-2. Beam trawls are developed to catch various species of flat fish. They are mainly used on flat, sandy seabed in shallow waters in the southern parts of the North Sea.

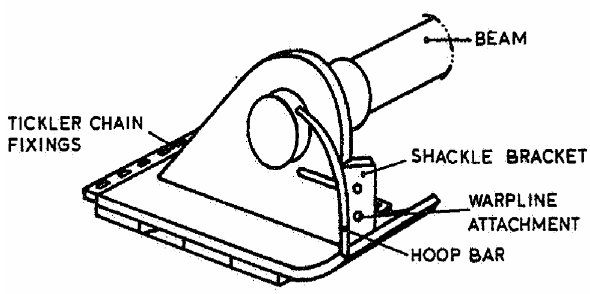

Figure 2-2
Typical outline of a beam trawl shoe

Typical clump weights are shown in Figure 2-3 and Figure 2-4.

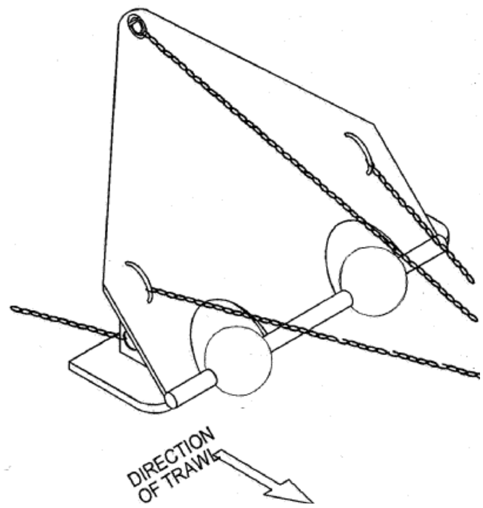

Figure 2-3
Typical clump weight (Bobbin type)

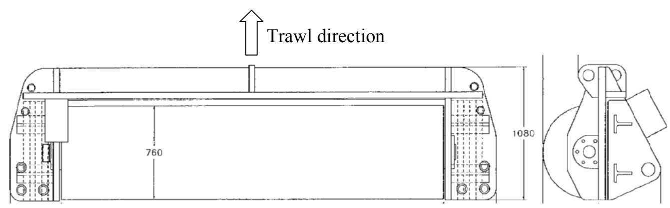

Figure 2-4
Typical clump weight (Roller type)

2.2 Basic data requirements

Before calculating the load and load effects of the pipeline some basic data with respect to expected trawling along the pipeline route has to be established. These shall include, but not be limited to, data along the route for:

— trawling category (i.e. industrial or consumption trawling with otter, beam trawl gear, or pair / twin trawling with clump weight)
— trawling equipment in use (type, shape, size, mass, trawling speeds)
— expected frequency of trawl gear crossing over the pipeline; and

— expected or possible developments or changes in the foreseen trawling equipment or frequency (e.g. new equipment, larger vessels, increased frequency, etc.).

The route should be divided into subsections categorised in a suitable manner with respect to the above factors.

Data shall be obtained from the relevant authorities. The design process shall ensure that the collected data are relevant and up to date.

If development of trawl equipment deviates from design assumptions, the need for reanalyses to account for these (e.g. trawl equipment type, mass, velocity and frequency) has to be considered.

2.3 Most critical trawl gear

It should be observed; when considering the most critical trawling equipment, velocities, impact frequencies and area of application; that these parameters are subject to change. As an example, the largest trawl board in the North Sea and the Norwegian Sea has increased from about 1 500 kg in the late 70's and 80's to 4 000 kg in 2005. In the Barents Sea trawl boards up to 6 000 kg are currently being used.

Development of fishing technology may open new areas for fishing, while international and national laws and regulations may introduce changes in fishing activity in certain areas. It is therefore essential to establish relevant data for trawl equipment and to assess possible future development and its impact on trawl-pipeline interaction.

Table 2-1 lists the appropriate data for the largest trawl boards, beam trawls and clump weights in use in the North Sea and the Norwegian Sea in 2005. However, the following area specific trawl data needs to be investigated for each project:

— the types and maximum size of trawl gear normally used in the area
— future trends (new types, mass, velocity and shape)
— the trawling frequency in the area.

Table 2-1 Data for largest trawl gears in use in the North Sea and the Norwegian Sea in 2005

	Consumption	*Industrial*	*Beam*	*Clump weight*
Mass [kg]	4 500	5 000	5 500	9 000
Dimension Lxh [m]	4.5 × 3.5	4.9 × 3.8	17.0 2)	1)
Trawl velocity [m/s]	2.8	1.8	3.4	2.8

1) Typical dimension of the largest clump weights of 9 tonnes are L = 4 m wide (i.e. length of roller) by 0.76 meter diameter cross section. For smaller size roller type clump weights (i.e. 3 500 to 6 000 kg), the width L is typically 3.2 m, whereas the roller diameter is unchanged.

2) Beam trawl length (i.e. distance between outside of each shoe)

2.4 Trawl gear impact frequency

Due to evolution of fishing equipment and change in fishing stocks, the trawling frequency may change significantly during the lifetime of the pipeline. The following aspects should be addressed to obtain a good estimate of the frequency of interference (hereafter termed the trawl gear impact frequency) between the pipeline and trawl gear:

— fishing vessel density in the relevant area
— prevailing trawling direction relative to the pipeline
— distribution of different trawl equipment and sizes

If this information is not available, the highest frequency class according to Section 6 shall be used.

An estimate of the trawl gear impact frequency, f_{imp}, is:

$$f_{imp} = n_g \cdot I \cdot V \cdot \alpha_e \cdot \cos\varphi \qquad (2.1)$$

where n_g is the number of trawl boards, beam shoes or clump weight for each vessel, I is the expected trawler density (i.e. annual mean number of trawlers per unit seabed area), V is the trawling velocity, α_e is the proportion of the pipeline length exposed to trawl loads, and φ is angle of the prevailing trawling direction relative to the pipeline perpendicular. If sufficient information is available a distribution function for the trawling directions can be applied instead of the $\cos\varphi$ term. φ applied in Eq. (2.1) should not be taken larger than $75°$.

3. Impact

3.1 Introduction

The impact loads are associated with the transfer of kinetic energy from the impacting trawl board, beam shoe or clump weight to the pipe, its coating, possibly DEH cable protection structures and the soil. Generally the time of energy transfer is so short that most of the energy transferred is absorbed as local deformations. For smaller diameter pipelines some energy is also absorbed by global deformation of the pipe and in the soil.

The impact assessment covers the following main steps:

— calculate the impact energy level the system will absorb from considered trawl gear interference, as basis for the impact test specifications
— calculate the pipe steel wall capacity with respect to specified denting acceptance criterion.

The methods included here are based on the theoretical work presented in [1] and [4].

3.2 Impact energy

The impact direction and the amount of energy transferred to the pipe coating depend in general on the shape of the front of the trawl board, clump weight or beam shoe, on the pipe diameter and span height and on the direction of travel relative to the pipeline.

The impact energy constitutes *effective* masses with an *effective* velocity. The total effective mass consists of the steel mass of the board/beam/clump and the hydrodynamic added mass, including mass of entrained water. The effective velocity may be taken as the towing velocity component normal to the pipeline.

The effective masses and velocity may be obtained through simulation of the trawl gear-pipeline interaction. Alternatively Table 3-1 gives design data which can be applied if no more detailed information is available. It is emphasised that trawl gear data differs per location, and may change in future. Therefore, area specific trawl data that accounts for future development should be established.

3.3 Energy dissipation

The kinetic energy of the trawl gear may partly or entirely be dissipated during the impact by:

— deformation of trawl equipment
— deformation of protection cover for attached heating cables etc.
— deformation of coatings (i.e. corrosion-, weight-, thermal insulation- and / or field joint coating)
— elastic deformation and possibly plastic denting of pipe steel wall
— global deflection of the pipeline, including soil friction effects; and / or
— deformation of soil.

Each of these elements needs to be represented by equivalent characteristics (spring stiffness, mass etc.), when applying the advanced impact assessment method given in Appendix A. The spring characteristic should be based on tests or equivalent analysis to establish the representative load displacement characteristics - including nonlinear effects. For cable protection covers, the load / displacement level at which load is transferred directly to the cable needs to be accounted for.

The impact energy assessment gives the total energy that the considered system will absorb, which is used as basis for the energy level to be applied in the impact testing. Elements with low stiffness, such as field joint coatings and cable protection covers may increase the total energy absorbed by the pipeline, although the energy absorbed by the pipe steel wall may decrease.

Table 3-1 Design parameters for trawl gear impact

Parameters		*Consumption*		*Industrial*	*Beam*	*Clump weight*
Shape of board		*Polyvalent & rectangular*	V-board			
Direction of impact φ	deg	45	18	0	0	0
Effective impact velocity:	m/s	2.8 C_h 1)	2.8 C_h 1)	1.8 C_h 1)	3.4	2.8
Steel mass: m_t	kg	4500	4500	5000	5500	9000
In plane stiffness: k_i	MN/m	500	500	500		4200 2)
Bending board stiffness: k_b	MN/m	10	10	10		
Hydrodynamic added mass: m_a	kg	2.14 m_t	1.60 m_t	2.90 m_t 5) 2.14 m_t	1500 4)	3140 3) 4)

1) The factor C_h is given by Figure 3-1.

2) The largest clump weights used per 2005 are the "roller type", see Figure 2-4. The specified clump weight stiffness is conservatively based on the stiffness of the corner plate. Alternatively, more advanced dynamic analyses with less conservatism can be performed, accounting for flexibility of the clump weight structure absorbing some amount of energy (if available), and considering the two scenarios, see Figure 3-2:

   a) Base case: Trawl direction normal to the pipeline, single point impact at mid-span of clump weight. Effective clump weight mass is equal to the total steel mass.

   b) For locations with prevailing trawl direction inclined to the pipeline, impact energies may be distributed into two frequency classes, one normal to the pipeline and one oblique to the pipeline axis. The latter implies impact at clump weight corner, causing in-plane rotation of the clump weight. Effective clump weight mass may then be approximated as ½ the total steel mass. For impact directions oblique to the pipeline, the velocity component normal to the pipeline may be used.

3) Based on sea water volume of roller cylinder (diameter 0.76 m, and length 3.14 m), calculated in accordance with DNV-RP-C205. Factor to account for seabed proximity is taken as 2.29 and reduction factor to account for length of cylinder is 0.8. Note, for reference an equivalent clump weight of mass of 6 000 kg has an estimated hydrodynamic added mass and mass of entrained water of 2 890 kg (i.e. based on roller diameter 0.76 m, length 2.34 m, and mass of entrained water of 890 kg).

4) Includes mass of water entrained in the hollow section. For the 9 000 kg clump weights, the mass of the entrained water estimated as 465 kg (ref. manufacturer). For an equivalent 6 000 kg clump weight, the mass of the entrained water is specified as 890 kg.

5) For V-boards up to 1 500 kg mass, hydrodynamic mass to be taken as 2.9 m_t, for larger polyvalent boards 2.14 m_t may be assumed.

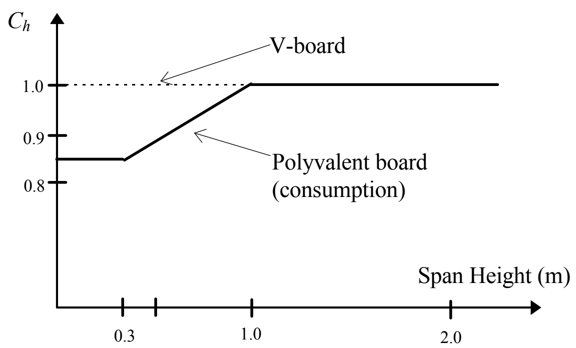

Figure 3-1
C_h coefficient for effect of span height on impact velocity

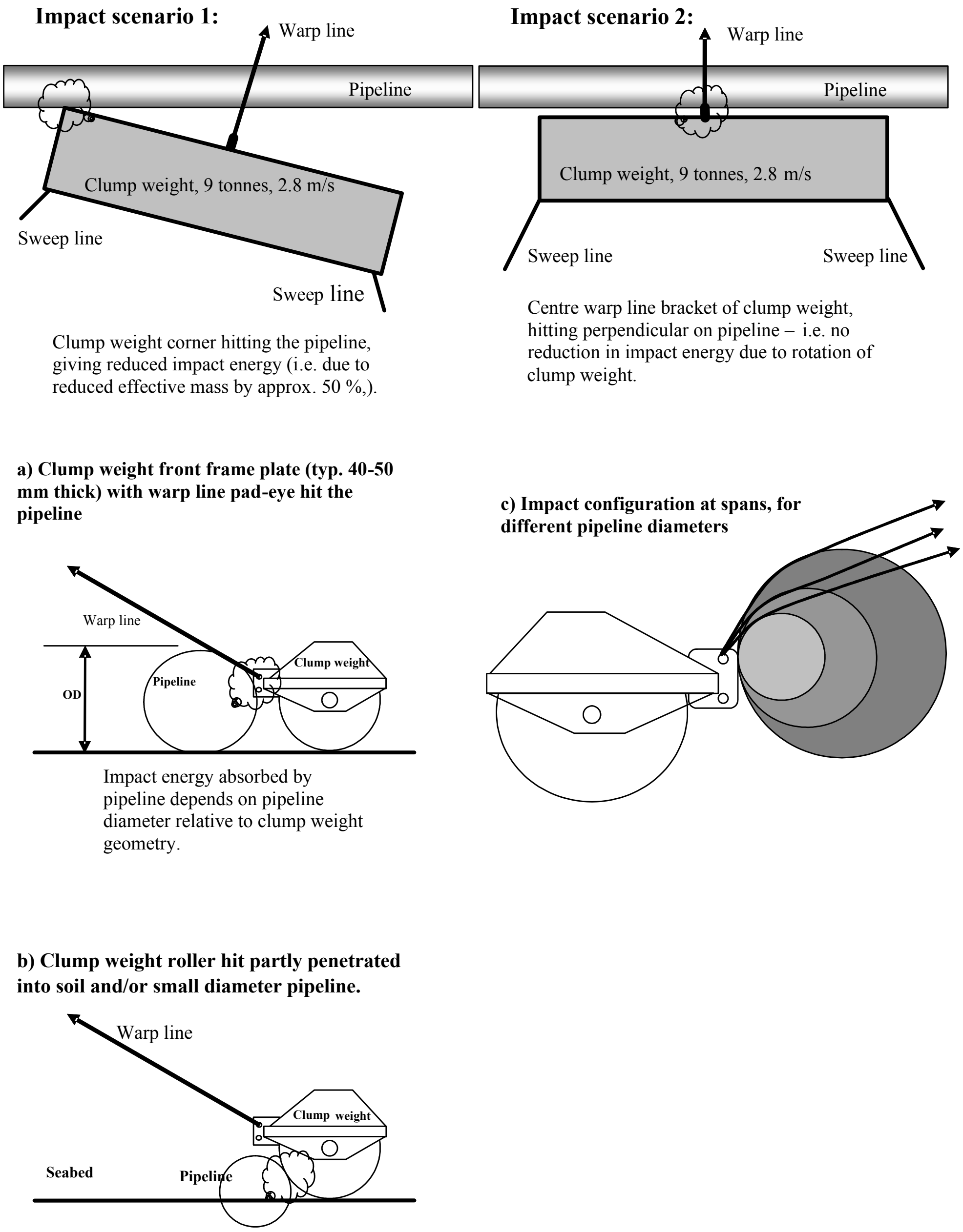

Figure 3-2
Relevant clump weight impact configurations

3.4 Simplified response calculations

3.4.1 General

The impact assessment methodology given in the following applies for steel pipelines (i.e. bare pipes, painted pipes and pipes with thin corrosion coating and / or with concrete coating). For other configurations (e.g. pipeline with other coatings, or pipelines with piggy-back electrical cable with protection structure) special assessments are required, see Appendix A.

The following simple, conservative method may be used to calculate the energy absorbed by the pipe locally, assuming that the pipe deforms locally by indentation, and that all the impact energy is absorbed through such a deformation. Correction factors for energy absorbed by global pipeline deformation and in the soil may be found (ref. R_{fs} and R_{fa}) in Figure 3-3. Alternatively, the pipeline response may be assessed through more advanced analyses, as described in Appendix A.

3.4.2 Trawl board

The impact energy associated with the steel mass of the trawl board is:

$$E_s = R_{fs} \cdot \tfrac{1}{2} m_t (C_h \cdot V)^2 \qquad (3.1)$$

where m_t is the trawl board steel mass. R_{fs} is a reduction factor depending on the outer pipe diameter and given in Figure 3-3 for bare steel pipes and pipes coated with concrete. For softer coatings, e.g. polymers, R_{fs} should be assessed but can conservatively be set to 1.0.
C_h is span height correction factor for the effective pull-over velocity, see Figure 3-1.

Guidance note:

For pipelines with outer diameter less than 300 mm, the reduction factors given in Figure 3-3 for 300 mm could conservatively be used, unless otherwise documented.

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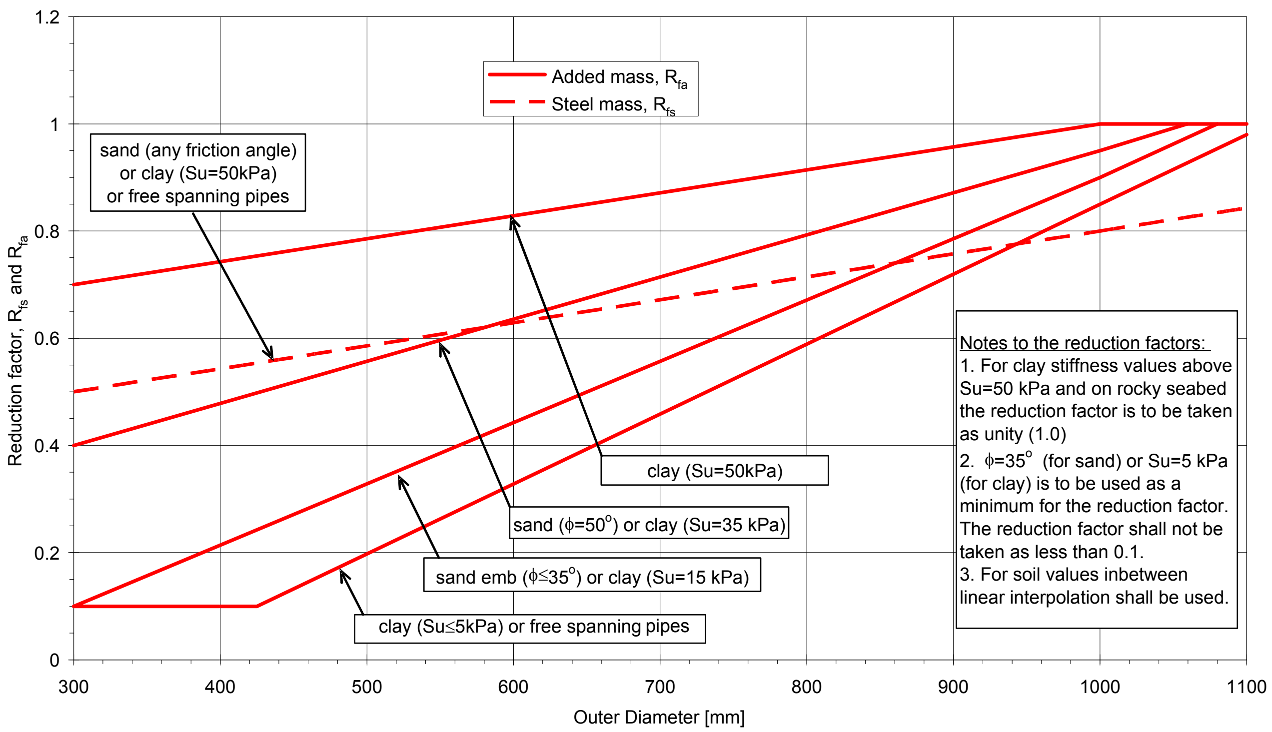

Figure 3-3
Reduction factors for concrete coated and bare steel pipes.

The main contribution of the hydrodynamic added mass is in the direction perpendicular to the board and is activated through lateral bending of the board. The impact force associated with the hydrodynamic added mass of the trawl board may be estimated as:

$$F_b = C_h \cdot V \cdot \sqrt{m_a \cdot k_b} \tag{3.2}$$

The associated impact energy from added mass of the trawl board is:

$$E_a = R_{fa} \cdot \frac{2(F_b)^3}{75 \cdot f_y^{\,2} \cdot t^3} \le \tfrac{1}{2} m_a (C_h \cdot V)^2 \tag{3.3}$$

where:

$$f_y = (SMYS - f_{y,\,temp}) \quad \alpha_U \tag{3.4}$$

where m_a is the trawl board added mass, t the steel wall thickness (i.e. to be taken as the nominal wall thickness minus the corrosion allowance) and k_b the lateral bending stiffness of the board. α_U is the material strength factor, ref. DNV-OS-F101. $f_{y,temp}$ is the temperature derating value of the yield stress.

α_U = 0.96, except for pipeline material fulfilling supplementary requirements U, where α_U = 1.0.

R_{fa} is a reduction factor depending on the pipe diameter and the soil type which is given by Figure 3-3 for bare steel pipes and pipes coated with concrete. For softer coatings, e.g. polymers, R_{fa} should be assessed but can conservatively be set to 1.0.

Guidance note:

The pipe wall thickness to be applied is $t = t_{nom} - t_{corr}$, however if more detailed knowledge on corrosion mechanism exists, e.g. that corrosion is limited to grooves at 6 and/ or 12 o'clock position and is concluded to cause minor reduction in trawl load capacity, applying $t = t_{nom}$ may be acceptable.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Appropriate parameters are given in Table 3-1. Eq. (3.5) is conservatively based on a relationship between the impact force and associated indentation of the pipe representative for a bare steel pipe:

$$F_{sh} = 5 \cdot f_y \cdot t^{\frac{3}{2}} \cdot H_t^{\frac{1}{2}} \tag{3.5}$$

Here, F_{sh} is the impact force experienced by the pipe shell and H_t is the dent depth (i.e. both elastic and permanent).

A conservative estimate of the kinetic energy absorbed by local deformations of the coating and the pipe wall is found by taking the maximum of E_s and E_a:

$$E_{loc} = \max \begin{Bmatrix} E_s \\ E_a \end{Bmatrix} \tag{3.6}$$

3.4.3 Beam trawl

For beam trawls, the impact energy absorbed by the pipe and its coating may be calculated as:

$$E_{loc} = R_{fs} \cdot \tfrac{1}{2} C_b (m_t + m_a) \cdot V^2 \tag{3.7}$$

where C_b is a factor taking into account the effective mass and may conservatively be set equal to 0.5 if a more precise estimate is not available. m_t is the steel mass of the beam trawl inclusive shoes, and m_a is the hydrodynamic added mass including the mass of water entrained in the hollow beam.

3.4.4 Clump weights

For clump weights, the total absorbed energy can be calculated as:

$$E_{loc} = R_{fs} \cdot \tfrac{1}{2} (m_t + m_a) \cdot V^2 \tag{3.8}$$

where m_t is the dry steel weight of the clump weight, and m_a is the hydrodynamic added mass including the mass of water entrained in the hollow sections.

The added mass can be estimated as the mass of the displaced sea water volume, multiplied by a factor 2.29 for proximity to sea bed and a factor 0.8 for limited length, according to DNV-RP-C205. The mass of entrained water is given in Table 3-1.

The effective impact mass ($m_t + m_a$), the local stiffness and the in-plane stiffness of the clump weight depend on impact configuration as shown in Figure 3-2. The clump weight mass and stiffness given in Table 3-1 are conservative. Less conservative values may be adopted based on dynamic simulations or tests of actual configuration.

Two impact scenarios are considered relevant for clump weights (see Figure 3-2):

- Trawl direction normal to the pipeline, with the clump weight hitting with its total mass at centre of the clump weight. Typically, the warp line pad-eye protrudes causing a single point contact. If there are no protrusions, the impact load transfer will be distributed over a larger area and hence becomes less critical.
- Trawl direction at an inclined angle to the pipeline, with the corner of the clump weight hitting the pipeline. The impact energy will be reduced from rotation of the clump weight.
- For scenarios where the pipeline interferes with the roller directly (e.g. for partly buried and / or smaller diameter pipelines, see Figure 3-2 b) the clump weight will roll over and cause smaller loads to the pipeline, than for interference with the structural frame of the clump weight as illustrated in Figure 3-2 a and c.

The governing impact scenario depends on type of clump weight, relative height of clump weight versus pipeline diameter, trawl direction, span height etc.

The clump weight impact specification given in Table 3-1 are based on conservative estimates. Less conservative values may be adopted, if documented by representative tests or dynamic simulations.

3.4.5 Pipe shell indentation

If no detailed relationship between the impact force and associated indentation of the steel pipe wall is available, the permanent indentation of the pipe shell caused by the impact may be estimated as:

$$H_{p,c} = \left(\frac{F_{sh}}{5 \cdot f_y \cdot t^{3/2}}\right)^2 - \left(\frac{F_{sh} \cdot \sqrt{0.005 \cdot D}}{5 \cdot f_y \cdot t^{3/2}}\right) \quad (3.9)$$

where $H_{p,c}$ is the estimated permanent plastic dent depth and:

$$F_{sh} = (\tfrac{75}{2} E_{loc} \cdot f_y{}^2 \cdot t^3)^{1/3} \quad (3.10)$$

Eq. (3.9) and (3.10) are valid for bare steel pipes. Pipes with thick polymer coating will in general be subjected to smaller impact loads but absorb more energy. The latter is caused by the significant energy absorption in the coating. Therefore, the above simplified approach may give non-conservative results for such coatings, and the advanced method given in Appendix A should be applied. Similar comments apply to DEH cable protection structures.

This simplified analysis will lead to increasingly conservative results for smaller and lighter pipes. In this case the advanced assessment (Appendix A) is recommended.

4. Pull-over

4.1 Introduction

Pull-over analysis deals with the global response of the pipeline as the trawl gear is pulled/ forced to cross over the pipe. During this phase, the pipeline may be subjected to relatively large horizontal (lateral) and vertical forces.

The pull-over calculation procedure for trawl boards is based on both experimental [3, 5, 6] and theoretical work [7, 8], the basis for beam trawls is tests [1, 2], while the basis for the clump weights is established as part of specific field development projects in the Norwegian Sea.

4.2 Structural modelling

The structural behaviour of the pipeline during pull-over shall be evaluated by modelling a sufficiently large part of the pipeline, the seabed and other supports and performing a structural dynamic analysis by applying the pull-over load (static analysis is likely to be non-conservative).

The most critical position for trawl pull-over depends on:

- length, height and shoulder supports of free spans;
- effective axial force;
- lateral curvature of the pipeline; and
- lateral or axial supports or restraints.

The pull-over load for trawl boards and clump weights shall be applied as a single point load while the pull-over load for beam trawls may be applied as two concentrated loads at a distance equal to the width of the trawl beam and with half the pull-over force at each position.

All relevant non-linear effects shall be taken into account in the analysis of trawl gear pull-over. These may be, but not restricted to:

- buckling effects caused by effective axial force;
- large displacements including geometrical stiffness;
- soil resistance; and
- non-linear material behaviour

The effective axial force must be accounted for:

$$S = N - p_i A_i + p_e A_e \quad (4.1)$$

where p_i and p_e denote the internal and external pressures and A_i and A_e the corresponding cross-section areas of the steel pipe exposed to internal and external pressure, respectively. For more details, see DNV-OS-F101.

The boundary conditions at the ends of the pipeline model shall be sufficient to represent the pipe-soil interaction and the continuity of the whole pipeline length. In case of buckling it is important to model a sufficient length of the pipeline (anchor length) or by alternative boundary conditions allow the buckled section to be exposed to the potential axial feed-in.

Due to erosion/scouring, free spans may develop over time and change the pipe-soil interaction. This must be accounted for in the analysis/modelling of trawl pull-over.

4.3 Pull-over loads for trawl boards and beam trawls

Pull-over loads may be assessed through model tests or numerical simulations. Alternatively, if the flexibility of potential free-spans is not dominating, the method given below may be used for 10" to 40" pipelines.

The maximum horizontal force applied to the pipe, F_p, is given by:

Trawl boards:

$$F_p = C_F \cdot V(m_t k_w)^{1/2} \quad (4.2)$$

Beam trawls:

$$F_p = C_F \cdot V\left[(m_t + m_a) \cdot k_w\right]^{1/2} \quad (4.3)$$

where k_w is the warp line stiffness and V the trawling velocity. m_t is the steel mass of board or beam with shoes, and m_a is the hydrodynamic added mass and mass of entrained water. The empirical coefficient C_F is a function of trawl gear type and some geometrical parameters characterising the trawl-pipeline interaction.

For trawl boards this coefficient is:

For polyvalent and rectangular boards:

$$C_F = 8.0 \cdot (1 - e^{-0.8 \cdot \overline{H}}) \quad (4.4)$$

For V-shaped boards:

$$C_F = 5.8 \cdot (1 - e^{-1.1 \cdot \overline{H}}) \quad (4.5)$$

and $\overline{H}$ is a dimensionless height:

$$\overline{H} = \frac{H_{sp} + OD/2 + 0.2}{B} \quad (4.6)$$

Here, H_{sp} is the span height (negative for partly buried and trenched pipelines), OD the pipe outer diameter including coating and B is half the trawl board height. The span height should represent a conservative estimate to account for uncertainties (e.g. survey inaccuracy).

Trawl loads on trenched or partly buried pipelines have not been covered by the model tests used as the basis for this RP. For partly buried and or trenched pipelines, this may be simulated by specifying a negative span height, H_{sp}, in the pull-over load calculations.

For beam trawls:

With hoop bars:

$$C_F = \begin{cases} 4.0 & OD/H_a < 2 \\ 6.0 - OD/H_a \quad \text{for} & 2 < OD/H_a < 3 \\ 3.0 & OD/H_a > 3 \end{cases} \quad (4.7)$$

Without hoop bars:

$$C_F = \begin{cases} 5.0 & OD/H_a < 2 \\ 8.0 - 1.5 OD/H_a \quad \text{for} & 2 < OD/H_a < 3 \\ 3.5 & OD/H_a > 3 \end{cases} \quad (4.8)$$

C_F shall be taken as for beam trawls without hoop bars if it is not assured that all beam trawls in the relevant area have such bars installed. If no better information is available, the attachment point of the warp line, H_a, may be set to 0.2 meters.

The warp stiffness, k_w, is estimated as $k_w = EA_w/L_w$, where EA_w is the axial stiffness of the warp and L_w its length. If no better information is available, the warp stiffness of one single wire (typically 32-38 mm diameter) may be calculated as:

$$k_w = \frac{3.5 \cdot 10^7}{L_w} \quad \text{[N/m]} \quad (4.9)$$

where L_w is the length of the warp line in meters. Typically, the warp line length is 2.5 to 3.5 times the water depth. The wire length is relatively longer in shallow water (i.e. 2.5 times is for deep water applications). It should be considered that two or three 32 mm diameter wires are commonly used as warp lines for beam trawls.

The warp line stiffness given above is based on the assumption of a straight wire between the bottom trawl gear and the vessel. In case of a catenary shaped warp line, the stiffness will be lower which again will cause a lower pull-over force. In case such a reduced stiffness shall be applied, the weight of the wire, the warp line force and the drag load caused by combination of trawling velocity and current have to be accounted for.

For trawl boards the maximum vertical force acting in the downward direction can be estimated as:

Polyvalent and rectangular boards:

$$F_z = F_p(0.2 + 0.8 \cdot e^{-2.5 \cdot \overline{H}}) \quad (4.10)$$

V-shaped boards:

$$F_z = \tfrac{1}{2} F_p \quad (4.11)$$

This downward acting force may be assumed to have the same force-time history as the corresponding horizontal force.

The pull-over forces given by Eq. (4.2) to (4.11) are valid for one trawl board while for beam trawls these equations give the total pull-over force from both beam shoes.

4.4 Pull-over loads for clump weights

As for trawl boards and beam trawls the pull-over loads may be assessed through model tests or numerical simulation. Alternatively, if the flexibility of potential free-spans is not dominating, the method given below may be used for pipes of 10" to 40" diameter (i.e. range of dimensions used in the model tests to derive pull-over loads from clump weights) as long as the clump weight is of the sphere/bobbin or roller type.

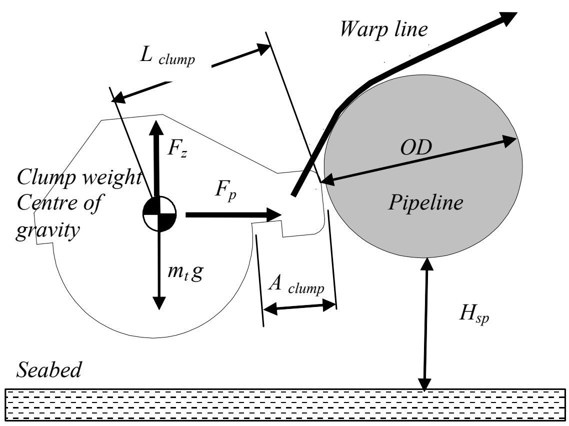

Figure 4-1
Clump weight interaction with pipeline

The estimate for the maximum horizontal pipeline pull-over force from clump weights is given below:

$$F_p = 3.9 \cdot m_t \cdot g \cdot \left(1 - e^{-1.8 \cdot h'}\right) \cdot \left(\frac{OD}{L_{clump}}\right)^{-0.65} \quad (4.12)$$

$$h' = \left(H_{sp} + OD\right) / L_{clump} \quad (4.13)$$

where (see Figure 4-1) OD is the outer diameter of pipe including coating, and L_{clump} is the distance from reaction point to centre of gravity of the clump weight, m_t is the steel mass and g is the gravitational acceleration.

The distance from the reaction point to the centre of gravity of the clump weight can be taken as:

$$L_{clump} = 0.7 \quad [m] \quad \text{- roller type} \quad (4.14)$$

$$L_{clump} = 0.55 \quad [m] \quad \text{- sphere/bobbin type} \quad (4.15)$$

Note that L_{clump} is constant, and not to be scaled for other sizes of clump weights, unless more specific data is available.

Further, the model tests are base on roller type clump weight drum diameter of 0.76 m. To account for larger drum diameters, this may be approximated by linear scaling:

Roller type clump weight:

$$L_{clump} = 0.7 \cdot \frac{0.5 \cdot D_{drum} + A_{clump}}{0.5 \cdot 0.76 + 0.32} \quad [m] \quad (4.16)$$

Bobbin type clump weight:

$$L_{clump} = 0.55 \cdot \frac{0.5 \cdot D_{drum} + A_{clump}}{0.5 \cdot 0.53 + 0.28} \quad [m] \quad (4.17)$$

where 0.32 and 0.28 are the un-scaled lengths. A_{clump}, for the roller- and bobbin type clump weights respectively (see Figure 4-1), whereas D_{drum} and A_{clump} represents the new dimensions for the clump weight with larger drum/ sphere diameter.

The maximum upward (vertical) pull-over force for clump weights is estimated by:

$$F_z = 0.3F_p - 0.4 \cdot m_t \cdot g \quad (4.18)$$

While the maximum downward force (i.e. negative sign) becomes:

$$F_z = 0.1F_p - 1.1 \cdot m_t \cdot g \quad (4.19)$$

In each case it should be considered if the upward or the downward force will give the most critical load combination.

4.5 Pull-over duration Trawl boards and beam trawls

The force-time history of the horizontal and vertical force applied to the pipe is shown in Figures 4-2 and 4-3 for trawl boards and beam trawls, respectively.

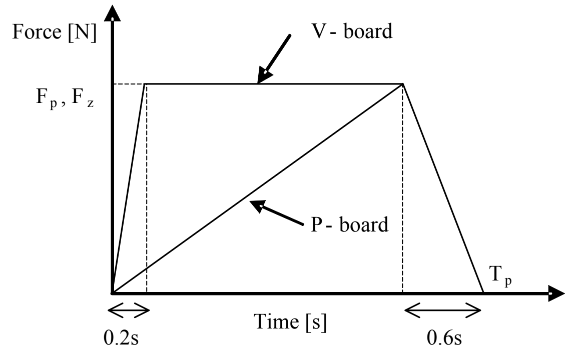

Figure 4-2
Sketch of force-time history for otter trawl board pull-over force on pipeline. (Applies for both lateral and vertical pull-over forces, F_p and F_z).

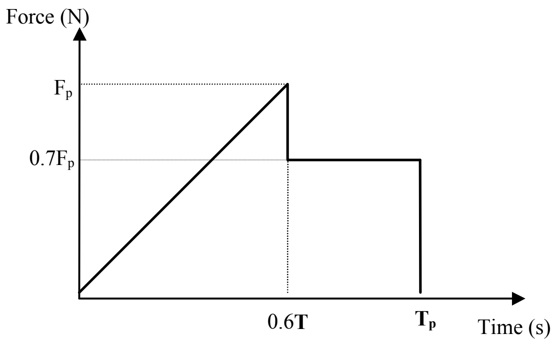

Figure 4-3
Sketch of force-time history for beam trawl pull-over force on pipeline

The total pull-over time, T_p, is given by:

$$T_p = C_T \cdot C_F \left(m_t / k_w\right)^{1/2} + \delta_p / V \quad (4.20)$$

Note that the same coefficient, C_F, is used as for the forces and is given by Eq. (4.4) to (4.8).

δ_p is the displacement of the pipe at the point of interaction which is unknown prior to response simulations. Therefore, the value of δ_p/V must be assumed (e.g. as $C_T\,C_F\,(m_t/k_w)^{1/2}/10$) and may be corrected after response simulations in some sort of iterative approach. However, the response has normally been shown to be rather insensitive to realistic values of δ_p.

The coefficient for the pull-over duration, C_T, is given as:

$$C_T = 2.0 \quad \text{- trawl boards} \quad (4.21)$$

$$C_T = 1.5 \quad \text{- beam trawls} \quad (4.22)$$

The fall time for trawl boards may be taken as 0.6 seconds, unless the total pull-over time given by Eq. (4.20) is less than this, in which case the fall time should be equal to the total time but still allowing for some force build-up say 0.1 second.

Care should be taken in case of very short pull-over durations. A sensitivity check with respect to the duration is recommended, especially if the duration is close to half the natural vibration period of a span.

4.6 Pull-over duration - clump weight

The model tests shows that the clump weight can be represented as a quasi-static load, and dynamic loading effects are not significant during the pull-over. First the clump weight stops in the collision, then the warp line is tightened until the clump weight is rotated over the pipeline. However, the pipeline response may be dynamic, e.g. if global buckling is triggered. Thus, the following parameters are governing for the pull-over duration.

— trawl velocity
— pipeline induced movement at interaction
— warp line stiffness
— clump mass

The pull-over duration of a bobbin and roller type clump weight can be calculated as:

$$T_p = F_p/(k_w \cdot V) + \delta_p/V \qquad (4.23)$$

where, as for trawl boards and beam trawls, δ_p is the displacement of the pipe at the point of interaction which is unknown prior to response simulations. Therefore, the value of δ_p/V must be assumed (e.g. $\delta_p/V = 0.1F_p/(k_w \cdot V)$) and may be corrected after response simulations in some sort of iterative approach.

The force-time history of the pull-over force for clump weights is shown in Figure 4-4 below.

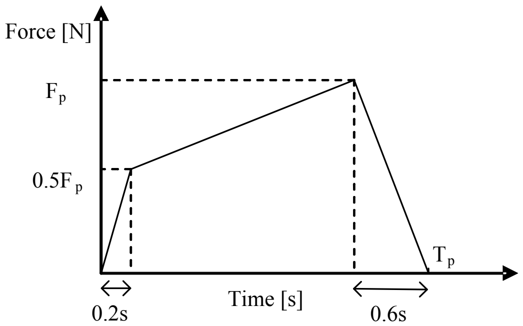

Figure 4-4
Sketch of force-time history for clump weight pull-over force on pipeline (Applies for both lateral and vertical pull-over forces, F_p and F_z).

4.7 Response calculations

Inertia forces reduce global response but may cause localisation of bending, such that it is uncertain whether neglecting inertia will be conservative or not. Therefore it is recommended to conduct the pull-over analyses as dynamic analyses.

Pipeline deflection and resulting bending moment from pull-over loads depend on axial and lateral soil resistance:

— a lower bound axial friction is conservative with respect to pipeline displacement
— a lower bound lateral soil resistance may be conservative with respect to bending moment from the pull-over force alone, but may be non-conservative if the displacement is dominated by the compressive axial force in the pipeline.

A sensitivity study needs to be performed, analysing the pipeline response from pull-over loads considering both upper- and lower bound lateral soil resistance, combined with the lower bound axial friction. The global analysis needs to include sensitivity studies of governing parameters such as pipe to soil interaction, to establish the proper functional load condition factor.

The soil resistance applied in the structural model shall take into account the short duration of the pull-over load.

In case of pipeline sections exposed to global buckling due to temperature and/or pressure loads, trawl pull-over may trigger lateral buckling, and reference is made to the design methodology and design criteria in DNV-RP-F110.

The pull-over analysis shall consider effects from subsequent trawl pull-over considering the deformed shape from a previous pull-over and the most critical direction for subsequent crossings. The number of subsequent pull-over events shall consider the expected number of trawl gear interactions over the design life for the relevant section.

5. Hooking

5.1 Introduction

Trawl gear hooking of pipelines, such that the trawl gear gets stuck, is a rarely occurring event. As an example there were reported a total of 7 events of trawling gear hooking on the Norwegian Continental Shelf related to pipelines from 2000 to 2003.

In this context, hooking is defined as the condition where the trawl gear is wedged under the pipeline, the trawler is forced to stop, back up, and attempt to free the gear by winch in the warp line (usually lift directly up).

The most likely scenarios for hooking, according to observation from small scale and field tests are:

— a de-stabilised trawl board (dragged on its back along the seabed) approaches a pipeline on the seabed or a free spanning pipeline with a small gap. The trawl board may dig under the pipeline and get hooked.
— the crossing angle with the pipeline is less than 45° and the pipeline is free spanning. The warp line lifts the trawl board off the seabed, it slides along the pipeline, becomes de-stabilised, turns over and slides underneath the pipeline until it gets wedged at the span shoulder.

For this reason free spans represent an increased risk of hooking. However, even for pipelines resting on the seabed, hooking cannot be ignored. A trawl-board may become unstable and partly penetrate underneath the pipeline. Such a scenario is most likely when the board is towed in a direction almost parallel to the pipeline or there are several pipelines or other seabed obstructions in the area. A typical hooking scenario at a free span is illustrated in Figure 5-1.

The typical response of trawlers experiencing hooking can be described as:

— Initially the trawler moves with a constant velocity. The tension from the warp lines onto the drum of the trawl winches is relatively even. Brakes lock the trawl winch drum. The brakes are pre-set to avoid damage to the trawl in case it gets fastened.
— If the trawl gear hooks the pipeline, the winch starts paying out with the pre-set tension governed by the brakes.
— The trawler reduces/reverses the propulsive force.
— The trawler tries to unfasten the equipment by pulling with the winch power from different directions.
— If this does not work, the trawler may haul the warp lines and pull until something breaks or the gear comes loose. This is provided that the winch has sufficient power or structural strength and brake power if the ship motion is used for jerking. The jerking can be caused by wave action or by propulsion.

This implies that the pipeline structural integrity has to be considered for large hooking loads in different directions. Usually the most extreme load will be vertical lifting until the trawl gear is loose or the capacity of the lifting wire is reached.

Two hooking conditions are considered:

Part penetration: where a part of the considered trawl gear components (trawl board, clump weight or beam) is stuck underneath the pipeline. For trawl boards this may occur for all span heights, also for pipelines resting on the seabed, while for clump weights and beam trawl a certain minimum span gap is required.

Wedged is defined as the condition when the trawl gear components have crossed under the pipe in a free span and is stuck at the opposite side of the pipeline with the warp line under the pipe. This is considered as a scenario with a very low likelihood and is only relevant for trawl boards. A certain critical span height is required for this to happen.

5.2 Structural model

The integrity of the pipeline when exposed to hooking is performed by static finite element analyses, lifting the pipeline at the hooking point to the critical height in accordance with Section 5.5 and 5.6. The element type, pipeline model length and boundary conditions requirements are the same as specified in Section 4.2.

5.3 Snagging

As for subsea structures it must be ensured that no protruding components or details exists that parts of the trawl gear such as the ground rope of trawl net can snag on. Examples may be bolted flanges, Tees, valves, etc. These need to be protected / covered in order to avoid large snagging loads and in order to be overtrawlable.

5.4 Critical span height

Trawl boards may become wedged for a free span height exceeding:

$$H_{cr} = 0.7B \quad \text{- trawl boards} \tag{5.1}$$

The critical span height with respect to board wedging is proportional to the board size. Hence, small boards are equally exposed to hooking as larger ones, they are more frequently used and give a smaller critical span height for wedging.

Part penetration is relevant for clump weights and beam trawls provided the span height exceeds:

$$H_{cr} = 0.7 \quad [\text{m}] \quad \text{- clump weights} \tag{5.2}$$

$$H_{cr} = 0.5 \quad [\text{m}] \quad \text{- beam trawls} \tag{5.3}$$

In case of beam trawling, span heights above the critical height are normally not allowed since hooking may lead to excessive loads due to the potential lever effect of the long beam.

Guidance note:
Rock dumping underneath the pipeline has been used to reduce the span height below the critical value to mitigate potential wedging. It is assumed that the rock berm must have a certain width related to the length of the trawl board to give the intended effect.

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5.5 Part penetration

If the maximum span height is below the critical height given in Section 5.4, the pipeline should be analysed for a static lifting height H_l, possibly limited by the maximum warp force (Section 5.7). H_l may be estimated as:

$$H_l = 0.7B - 0.3 \cdot OD \quad \text{- trawl boards} \tag{5.4}$$

$$H_l = 0.2L \quad \text{- clump weights} \tag{5.5}$$

In the lifting height expression for trawl boards above, the distance from the front to the first warp line attachment point should be used as "*B*", if this distance is larger.

If detailed dimensions about the trawl boards used in the area are not known, use of half the trawl board height, *B*, is assumed adequate.

The lifting height expression for clump weights is a ratio of the clump weight width, *L*.

For beam trawls, span heights exceeding critical height is not allowed (ref. Section 5.4), and lift height from part penetration is hence not relevant.

5.6 Wedged

If the maximum span height exceeds the critical height given in Section 5.4, the pipeline should be analysed for an increase in static lifting height of:

$$H_l = B \tag{5.6}$$

5.7 Maximum warp line force

The maximum warp line pull may be limited by:

— the strength of the warp line
— the braking capacity of the winches
— the maximum winch power

The pipeline can be subjected to the maximum warp line force if the trawl gear does not loosen itself, e.g. by lifting the pipeline, before this force level is reached.

The breaking strength of a typical warp line is approximately 400 kN (32 mm diameter). However, double and triple warp wires (up to 3 × 38 mm diameter) are used for the heaviest trawl gears giving a total breaking strength of 800 - 1 200 kN.

Note that loads exceeding the winch power may be achieved by locating the trawler just over the point where the trawl gear is hooked, hauling the warp line until it forms a straight, vertical line, lock the winch and using wave motion and/or propulsion force to increase the warp line force.

5.8 Response calculations

The hooking response can be calculated by a static analysis applying the maximum lifting height as a prescribed displacement. The maximum warp line force may limit the relevant lifting force used in the analysis.

For calculation of the response during hooking relevant and conservative models shall be applied. If simpler methods are used, the conservatism in the results should be documented.

Assessment of hooking must consider the effect of any restraint including rock berms, tie-in points, subsea structures and other types of restraint.

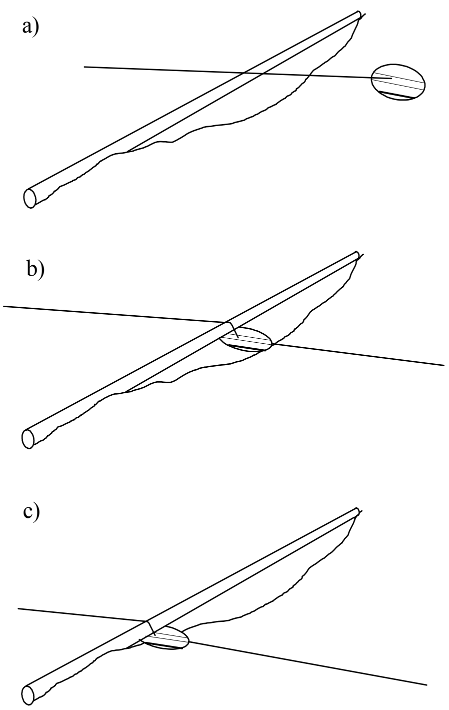

Figure 5-1
Sketch of typical hooking scenario in a free span

a) trawl board approaches pipeline span at a skew angle,

b) warp line comes in contact with pipeline and lifts board off seabed, board turns over

c) board slides along pipeline with its front underneath the pipe until stuck at the span shoulder.

6. Acceptance Criteria

6.1 General

The following specifies acceptance criteria for design or in operation assessments to prevent damage due to trawl interference. These criteria are based on DNV-OS-F101 wherein classification of safety classes is used to define acceptance criteria. In DNV-OS-F101, the pipeline loads are classified into different load categories to relate the load effect to different uncertainties and occurrences. Trawl loads are classified as an "Interference" load. The criteria are further differentiated with respect to the trawl gear impact frequency, f_{imp}.

If necessary data to calculate the impact frequency is lacking, the most critical frequency class given in Table 6-1 shall be selected.

Table 6-1 Frequency classes for trawl gear crossings

Frequency class	*Impact frequency, f_{imp} [/year /km]*
High	> 100
Medium	1-100
Low	< 1

For pipelines exposed to different types of trawl equipment with significant differences in mass and trawling frequency (e.g. trawling both with and without clump weights), qualification may be based on an acceptance criterion for each equipment type. Impact testing would then need to cover the total number of test blows of all equipment categories. The number of trawl equipment categories should be limited to three, to avoid unrealistic low frequency class per category.

6.2 Pipe shell - impact

An acceptable design against impact requires assurance against the following failure modes:

— *Denting:* The out-of-roundness due to a dent should not prevent safe operation of internal inspection vehicles.
— *Collapse:* The capacity against collapse shall be checked according to the collapse criterion in DNV-OS-F101 by using an ovality which corresponds to the dent depth. Such a failure mode will, however, mainly affect temporary phases with external overpressure, e.g. installation or loss of pressure. May also apply for shut-downs, when the fluid density is less than for the external sea water.
— *Fatigue:* The stress concentration caused by a dent shall be accounted for by a suitable SCF in fatigue calculations.

The maximum accepted ratio of permanent dent depth to the outer pipe steel diameter is:

$$H_{p,c} / D = 0.05\eta \qquad (6.1)$$

where $H_{p,c}$ is the characteristic permanent plastic dent depth and η is the usage factor.

The acceptable permanent dent sizes are given in Table 6-2. No notch or sharp indentations is permitted. This shall be ensured by the use of a coating which protects the steel pipe from direct contact with any sharp edged part of the trawl gear.

Table 6-2 Acceptable dent sizes relative to outer diameter

Frequency class	*Usage*	*Dent depth, H_{pc} [%] of D*
High (> 100)	0.0	0
Medium (1-100)	0.3	1.5
Low (< 1)	0.7	3.5

Note:
Acceptable dent depth also needs to comply with the requirements given in DNV-OS-F101.

The dent size shall be estimated by using the force-dent pipe shell relationship given in Section 4 or similar calculations using non-linear shell FE analysis as described in Appendix A. The dent size may also be measured during impact testing of the coated pipe.

The effect of dents on additional failure modes for fatigue and collapse shall be considered. Dents and especially dents with notches in the girth weld area may have a significant effect on the fatigue damage due to e.g. variations in the internal pressure.

6.3 Coating - impact

Coating is used for protection of the steel pipe in addition to possible weight increase and thermal insulation.

The protective coatings must be qualified by impact testing applying the following:

— The energy absorbed by the coated pipe shell shall be quantified based on the impact response calculations in Section 3 taking into account the efficiency of the test rig.
— The number of test impact blows shall consider the trawling frequency, see Table 6-3.

Table 6-3 Number of test impact blows within 0.5 metre length

Frequency class	*Impact frequency, f_{imp} [/year /km]*	*Blows*
High	> 100	8
Medium	1-100	4
Low	< 1	1

Note that the field joint coating must satisfy the same requirements as for the general coating because the impact frequency applies per unit length. The impact testing considers repeated testing within a single 0.5 m length. The probability of impact is equally distributed along each section of the pipeline. Hence, the probability of impact is equal for the 0.5 m long field joints as for the pipe joints.

The following functional requirements apply for the coating including the field joint coating:

— the pipeline steel material shall be protected against dents larger than acceptable
— the pipeline corrosion protection system shall remain intact, i.e. if damage to the corrosion coating exposing the steel is not acceptable, this must be compensated by conservative increase in cathodic protection
— acceptable weight loss shall be in accordance with the requirements for on-bottom stability of the pipeline.

Additional requirements valid for concrete coating:

— the inner reinforcement layer shall not be exposed
— large areas (typically 200 x 200 mm) of concrete spalling should be avoided. However, the acceptance criterion for acceptable spalling area is governed by cathodic protection requirements for pipeline and coating steel reinforcement, and requirements related to resulting submerged weight of the pipeline. Provided these acceptance requirements are met, larger spalling areas may be accepted.

Additional requirements valid for insulation coating:

— the insulation effect must not be degraded by trawl gear impacts.

6.4 Pull-over

The trawl pull-over load may cause a lateral displacement and associated bending of the pipeline. In combination with the compressive axial force, trawl pull-over may lead to rather large deflections and high utilisation of the pipeline steel material. Four scenarios are typically foreseen:

1) a pipeline with negligible effective axial force
2) a pipeline with release of effective, compressive axial force (postbuckling) prior to trawling
3) a pipeline with release of effective, compressive axial force simultaneously with trawling (i.e. the trawl load triggers the global buckling)
4) a free spanning pipeline.

Scenario 1 and 4 are covered within this RP. For scenarios 2 and 3, more detailed assessments are required to establish the proper functional load condition factor including sensitivity studies, analysing the pipeline response from pull-over loads considering both upper- and lower bound lateral soil resistance, combined with the lower bound axial friction.

Scenario 1 and 4 are covered within this RP, while scenarios 2 and 3 are covered by this RP in combination with DNV-RP-F110.

Figure 6-1 gives an overview of the safety factors to be applied to the trawl pull-over load effect.

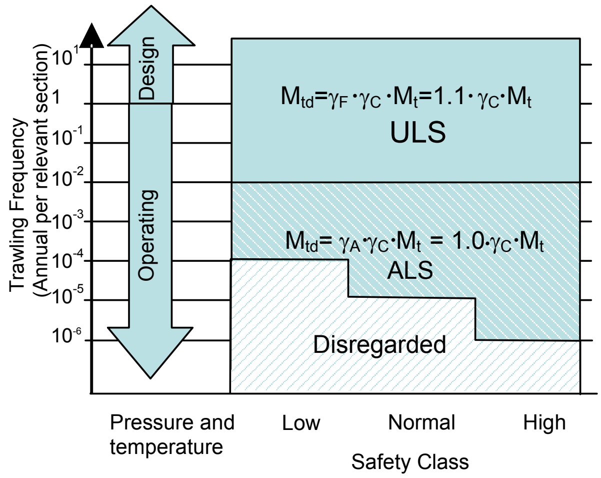

Figure 6-1
Trawl pull-over load effect factors.

Guidance note:

The annular trawling frequency threshold level where trawl pull-over loading may be disregarded is one order of magnitude below the acceptance criteria on total probability of failure, given in DNV-OS-F101. This is to account for that the considered pipeline section may be exposed to additional accidental loads than trawling.

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As noted from Figure 6-1, the trawl pull-over load is combined with the design functional load (i.e. local design pressure and temperature - i.e. not "maximum incidental pressure") for an annual trawling frequency per section larger than one.

For pipeline sections with annual trawling frequency of less than one, the pull-over interference load shall be combined with the local normal operating functional loads (i.e. not "Maximum Operating Loads", and based on appropriate temperature- and pressure profiles along the pipeline, to reflect the local functional load per considered section).

Further, for sections with annual trawling frequency of less than one, the trawl pull-over load may be reduced by a factor of 0.8 to account for the low probability that such low frequency trawling occurs with the combination of both the largest equipment, trawl direction perpendicular to the pipeline at maximum trawling velocity and at the most critical position. See Table 6-4.

Table 6-4 Trawl pull-over load factor for different trawl frequencies		
	$f_T > 1$	$f_T < 1$
Load factor	1.0	0.8
Note: this is a load factor to be applied directly on the pull-over load calculated according to equations given in Sec. 4 above (i.e. and not on the load effect referred in Figure 6-1).		

Note that the trawling frequency given in Figure 6-1 is not annual per kilometre as for the trawl impact frequency in Table 6-1 but annual per relevant section. This frequency is calculated according to Eq. (2.1) by considering section length instead of per km.

Section is here defined differently depending on pull-over scenario:

— pull-over response in the apex of a lateral buckle (post-buckling, scenario 2): The section length is taken as the length of the sum of buckles if more than one buckle is anticipated. The length of the relevant section is typically less than 100 meters per buckle.
— pull-over response of not buckled pipeline (pre-buckling

scenario 1 and scenario 3): section taken as the length of the entire pipeline (order of kilometres) or a pipeline stretch where trawl gear crossing frequency, effective axial force, soil resistance and other important parameters are more or less constant
— pull-over response in free-spans (scenario 4): section length taken as the sum of the span lengths.

The condition load effect factor defined in DNV-OS-F101, γ_C, may be used to account for different reasons, e.g. due to:

— uneven seabed
— pull-over with low probability of occurrence, and/or due to
— sensitivity analysis for buckling pipelines.

In case several γ_C are relevant simultaneously, they should be multiplied to account for all effects.

For free spans on uneven seabed the γ_C applies for the vertical load component of the trawl load. This is to account for uncertainty in gap height, span length, soil support stiffness and possible variations of these over time. The load condition factor for the vertical load component of the trawl load shall be taken as γ_C = 1.07, unless sensitivity studies on relevant parameters can justify a lower factor. The load condition factor for the horizontal component of the trawl load at free spans is γ_C = 1.0.

The following requirements shall be fulfilled to ensure safe operation of the pipeline during and after trawl pull-over:

— The trawl pull-over load effect shall be checked in combination with other load effects (e.g. from temperature, pipeline sagging, etc.).
— All relevant failure modes stated in DNV-OS-F101, i.e. local buckling, accumulated plastic strain, etc. shall be checked. The usage factors for these failure modes are given in DNV-OS-F101 for each safety class.
— In free-spans, the span length and the gap may change for different operating conditions. The trawl interference analyses should be performed for all relevant span configurations.
— A load effect factor equivalent to the functional load effect factor (γ_F = 1.1) shall be used for the pull-over interference load with an annual trawling frequency >10^{-2}. For occurrences less than once per hundred year, the pull-over interference load may be considered as an accidental load (γ_A = 1.0). In case of extremely infrequent trawling, the pull-over load effect can be disregarded, see Figure 6-1.
— Possible accumulation of damage, i.e. strain, due to subsequent trawling should be accounted for where applicable. The worst combination of subsequent trawling directions should be checked, i.e. all in the same direction or some in the opposite direction.

The effect of concrete coating bending stiffness should be considered, as localisation of bending may occur due to the discontinuity of stiffness in the field joints.

For pipelines exposed to different types of trawl equipment with significant differences in masses and trawling frequency (e.g. trawling both with and without clump weights), qualification may be performed for each of these - e.g. the pull-over load from equipment with low trawl frequencies may be considered combined with appropriate operating loads (i.e. pressure and temperature), whereas equipment with high trawl frequency should be combined with the design pressure and temperature.

6.5 Hooking

The following requirements shall be fulfilled for hooking loads:

— The trawl hooking load effect shall be checked in combination with other load effects where applicable (e.g. temperature effect loads, pipeline sagging, etc.).
— Due to the low probability of hooking, typical / normal operational values can be used for pressure and temperature.
— All relevant failure modes from DNV-OS-F101, i.e. local buckling, accumulated plastic strain etc. shall be checked. The usage factors for these failure modes are given in DNV-OS-F101 for each safety class.
— Hooking shall be regarded as an accidental limit state, thus the load effect factors for the hooking and other load effects shall be equal to unity, i.e. γA = 1.0.
— The hooking load effect shall be checked as a load controlled (LC) condition.

The effect of concrete coating should be considered, as the stiffening effect of the coating will lead to a longer lifted section, higher lifting forces and bending moments.

For the lowest trawl gear impact frequency class, hooking is assumed to have a very low probability (i.e. annual hooking frequency per pipeline of less than 10^{-4} to 10^{-5} per year) and can be neglected.

7. Coating Impact Testing

7.1 General

The following describes a method for qualification of the protective coating with respect to trawl impact. The method implies testing of coated pipe sections and covers the following items:

— specimens to be tested
— test equipment
— test procedures
— calibration of test equipment.

7.2 Specimens

Types: Coated pipes with relevant materials and dimensions.

Number of specimens per coating type:	minimum 3
Length of specimens:	minimum 2xOD

The coating shall be documented by specifying the coating type, possible reinforcement and the application procedure.

For quality control of the coating during production or application, samples should be tested when new batches of coating are applied. New batch is in this context defined as a batch for which a possible change in the production procedure can change the final mechanical properties.

Concrete coating shall have achieved its twenty-eight day strength before testing.

In case the coating is sensitive to temperature, the impact test shall be carried out both at maximum and minimum temperatures.

The effect of ageing during the design lifetime should be accounted for.

The field joint coating must satisfy the same requirements as for the general coating. Alternatively, documentation from previous tests on similar pipes may qualify the field joint coating material.

For pipelines with attached heating cable protection cover, this cover could be qualified by impact testing separately from the pipeline with coatings. The protection cover test should then be performed on rigid foundation, and include the heating cable. The test energy level needs to be derived from representative analyses, reflecting the tested configuration as illustrated by Figure 7-1.

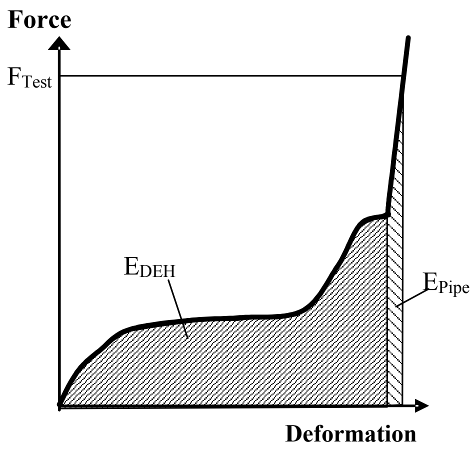

Figure 7-1
Typical load versus displacement plot for a pipeline with coating and attached DEH cable with protection structure

The following two impact test requirements apply for the DEH cable with protection structure attached to the considered pipe section:

1) Impact test energy level E_{Test} = E_{DEH} + E_{Pipe}. Alternatively, if the DEH cable with protection structure is tested separately from the pipe on a rigid foundation, the test energy may be limited to E_{Test} = E_{DEH}.
2) Minimum required impact force induced by the test hammer shall be F_{Test} (see Figure 7-1), to document that the system including cable sustains this load level without unacceptable damage.

   Alternatively, the load capacity can be documented by a static load versus deformation test.

   The value of the F_{Test} needs to be established based on representative analyses, as described in Appendix A.

The load versus deformation curve may vary for different protection structure designs, and needs to be established by tests for each type.

7.3 Test equipment

7.3.1 General

A typical test rig is shown in Figure 7-2.

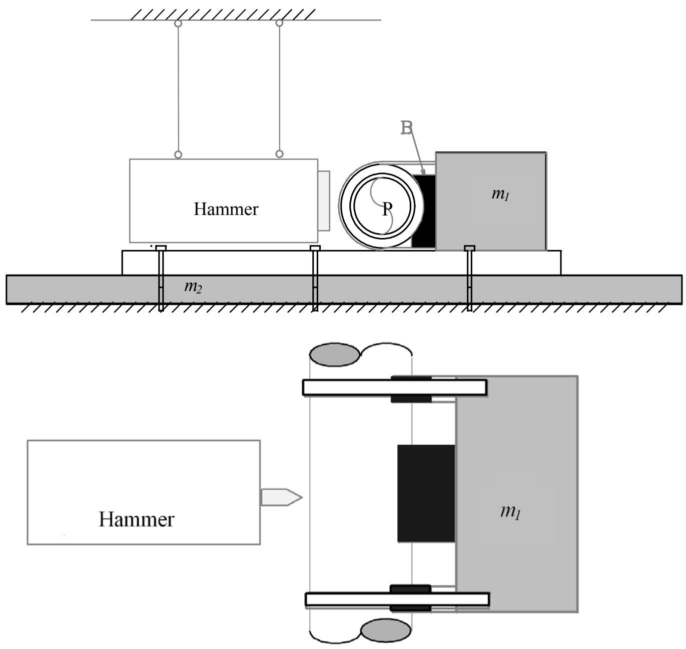

Figure 7-2
Typical test rig outline

The kinetic energy of the hammer is:

$$E_{kin} = m_h g H_i \tag{7.1}$$

where m_h is the mass of the hammer, g is the gravitational acceleration and H_i is the pendulum height.

7.3.2 Hammer

The mass of the hammer shall reflect the mass of the trawl equipment that the test is to represent.

The hammer shall be designed to accommodate the impact forces without significant flexing or permanent deformation.

The front of the hammer should ideally have a shape representative of the trawl equipment. Normally both trawl boards and beam trawls (with hoop bars) have rounded frontal shapes. Further, the structural frame of the largest clump weights is made from 40 - 50 mm plates.

A rectangular plate of 300 mm height and 50 mm width with a flat or half-round front may generally be used, see Figure 7-3.

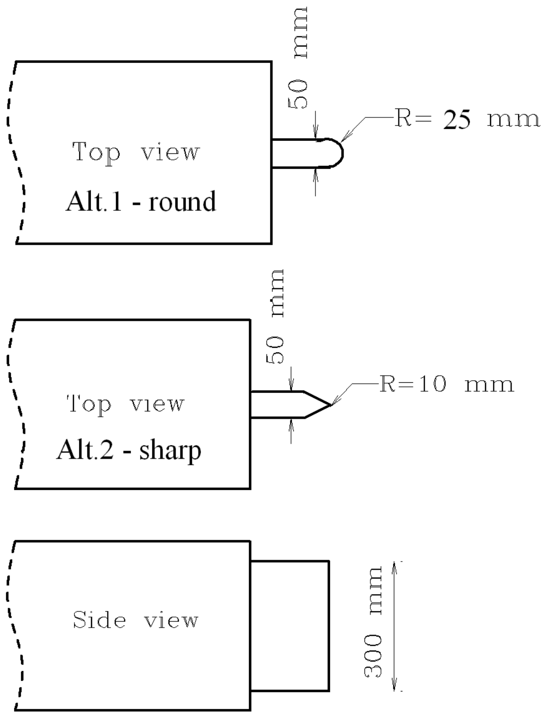

Figure 7-3
Hammer front shapes

However, due to damage and repair of the trawl gear, sharp edges may occur and should be considered. A rectangular plate of 300 mm height and 50 mm width with a conical shape and an edge radius of 10 mm may be used.

7.3.3 Pipe supports

The pipe support system should be adequately stiff and massive so that the energy is absorbed by the pipe and coating and not by the rig.

The mass of the supports should exceed 10 times the mass of the hammer.

The stiffness of the supports should exceed 10 times the initial shell stiffness of the pipe and/or the initial coating stiffness of the specimens to be tested.

Practical solutions to obtain this stiffness are:

— to mount a stiff mass behind the pipe in the impact direction (see Figure 7-2, mass m_1)
— to attach the rig to a massive floor (see Figure 7-2, mass m_2). The attachment to the floor must be designed to accommodate the maximum impact forces imposed by the hammer.

Brackets "B" between the pipe and the rig supports shall be "stiff" (steel) and give an even support of the pipe. The brackets shall extend over a length of at least 0.5*D* and a circumference of at least 30°. There shall be means to pre-tighten the specimens to the brackets and the rig.

The requirements for the pipe support as given above are valid for impact energies calculated according to the simplified method as given in Section 3 and the advanced method as described in Appendix A.

However, the impact energy to be applied in the tests may be calculated without the reduction factors as given in Section 3.

Then the pipe supports are allowed to be more flexible, e.g. a simple support span of 1-2 metres supported on wooden beams.

7.4 Test procedure

Determine:

— the test impact energy based on the qualification impact energy and the test rig efficiency factor
— the numbers of impacts required for each specimen, see Table 6-3.

Determination of impact resistance by repeated impact tests:

— repeat the testing until unacceptable damage according to Section 6.2 and 6.3 is detected. Each impact is performed at a location on the specimen as defined in Figure 7-4.

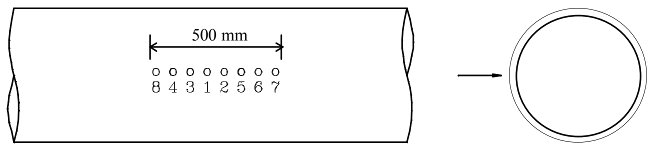

Figure 7-4
Positions for repeated impacts

— test several specimens and determine the impact capacity resistance by one of the following methods:

1) At least 3 impact tests on different pipes are performed. The capacity is set equal to the lowest number of impacts before unacceptable damage:

$$n_{cap} = \min(n_i) \quad i = 1,2,3 \qquad (7.2)$$

2) At least 6 impact tests on different pipes are performed. The mean and standard deviation for these tests are calculated and the characteristic impact capacity determined as:

$$n_{cap} = n_{mean} - \sigma \qquad (7.3)$$

Here n_{cap} is the capacity of the coated pipe in terms of number of impacts before failing, n_{mean} is the mean number determined in testing while σ is the standard deviation.

7.5 Test-rig calibration

Some of the kinetic energy will be absorbed by the flexibility of the rig and the pipe support system as the rig is not 100% efficient. Therefore, the impact energy applied in the tests shall take into account the efficiency of the rig.

The efficiency depends on the rig design and the design of the brackets or interference with the coating or pipe shell. The efficiency of the test rig may be calculated based on the mass and stiffness properties of the rig or estimated from dynamic measurements.

Hard concrete coated specimens, supported by solid steel, pretightened brackets as in Section 7.3 is considered to be practically 100 % efficient.

The efficiency of polymer coated specimens may be determined by aid of static or dynamic measurements. Alternatively the coating may be removed and the pipe supported as suggested in Section 7.3.

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APPENDIX A
ADVANCED IMPACT CALCULATION METHOD

A.1 Introduction

Physical effects that absorb kinetic energy during the trawl gear impact are:

- local deformation of the pipe steel wall
- local deformation of the coating
- local deformation of other elements that absorbs trawl impact energy (e.g. piggy-back heating cables inside protection structure)
- global pipe bending
- pipe inertia effects inclusive hydrodynamic added mass
- trawl board, beam or clump weight deformation
- friction between pipeline and soil
- soil deflections.

These effects may be included in an analysis model and a dynamic simulation performed to reduce the uncertainty and conservatism in the simplified approach.

Further, other pipeline configurations not covered by the simplified method (ref. Section 3) may be covered by analyses:

- flexibles
- pipelines with other coatings (e.g. polypropylene, polyethylene, field joint coatings)
- piggyback electrical cable strapped to the pipeline
- electrical cable protection structure

A.2 Analysis Model

Trawl boards

For trawl boards the effect of impact is split into two parts; one associated with the in-plane velocity of the steel mass of the board, and a second, which will generally occur some hundredths of a second later, caused by the hydrodynamic added mass acting through the flexural stiffness of the board.

Beam trawls

For beam trawls the in-plane deformation and stiffness of the beam is of importance. However, as the beam is spanning 10-20 metres, the effect of the mass of the beam and the shoe in the opposite end will gradually increase with time. Therefore, to represent the bending of the beam correctly it is recommended that the beam is modelled with beam elements and concentrated masses at each end to represent the beam shoes.

Clump weights

The clump weights used differ in shape and mass. However, the largest clump weights used in the North Sea and in the Norwegian Sea are the roller type. Two typical impact scenarios are illustrated in Figure 3-2. The following effects should be considered in an advance impact analyses with clump weights:

- Dynamic simulation, to calculate the input impact energy when the clump weight hits at one corner, to account for the induced rotation of the clump weight.
- Local stiffness of clump-weight, considering both impact at corner and impact at mid-span of clump weight. (Simple analyses give a stiffness of approximately 4200 MN/m for the corner plate, and 22 MN/m for a typical front frame beam before interfering with the drum, exposed to a single point load at mid-span).

Added mass of one clump weight can be calculated according to the methodology given in DNV-RP-C205. Typical mass of entrained water in clump weights are given in Table 3-1.

Analyses model assembly

The principles of the analysis model are shown in Figure A-1 for trawl boards. A similar model is applied for beam trawls and clump weights except that the lateral stiffness and the associated added mass are omitted. In addition the kinematics of beam/clump will cause a time dependent effective mass and stiffness that may be accounted for in an analysis.

Here:

- m_a and m_t are the hydrodynamic added mass and steel mass of the trawl gear
- k_b and k_i the out-of-plane and in-plane stiffness of the gear
- k_{c1} represent the stiffness of the protective cover for heating cable attached to the pipeline, when applicable
- k_{c2} is the stiffness of coating
- k_{c3} represents any possible effect it has on the steel shell stiffness by distributing the impact force over a larger area by shear deformations in the coating
- k_s is the local shell stiffness of the steel pipeline
- m_p is the effective mass of the pipe, including hydrodynamic added mass effects
- k_{pb} is the effective bending stiffness of the pipe
- k_{ps} is the effective soil stiffness acting on the pipe.

The effective masses and effective velocity to be applied in the dynamic analysis may be obtained from simulations of the trawl impact or from the simplified, conservative values given in Table 3-1.

The pipe mass, bending stiffness and soil resistance involved in the interaction all vary with time as more of the pipe adjacent to the interaction point is involved. This pipe and support sub-system may most conveniently be modelled as beam elements, see Figure A-2.

Note that the effective masses and impact velocity are based on an impact direction perpendicular to the pipe. Due to symmetry the problem may be reduced to a half model.

A sufficient length of the pipeline must be included in the structural model to avoid end effects influencing the results. A length of the half model in the order of $L/D = 50$ is found to be sufficient for a 16" pipeline. However, as the necessary length may vary with other factors as weight etc., it should be verified that the model has a sufficient length.

A.3 Trawl Board Stiffness

It should be noted that the shell stiffness of a pipeline would normally be in between the trawl board in-plane and bending stiffness. This implies that the impact energy associated with the in-plane steel mass will mainly be transferred to the pipe, while the impact energy associated with the added mass will partly be absorbed by flexing of the trawl board. The amount absorbed by the bending action of the trawl board depends on the relative stiffness between the pipe shell and the trawl board.

The trawl board stiffness k_b and k_i can be estimated through FE analyses, however the values given in Table 3-1 may be used for all trawl boards if no other information is available.

A.4 Pipe Shell Stiffness

If the pipe shell is not modelled directly, the coating and shell stiffness may be obtained from tests or separate analysis. These are applied as non-linear springs attached to the pipe beam model.

The shell stiffness must also account for the front shape of the trawl board or shoe, as the geometry of the contact area will significantly influence the relation between the contact force and the pipe indentation.

If no detailed information is available, the local stiffness of a concrete coated pipe may conservatively be approximated by the following relationship between the impact force and the indentation depth of a bare steel pipe:

$$F_{sh} = 5 \cdot f_y \cdot t^{\frac{3}{2}} \cdot H_t^{\frac{1}{2}} \qquad \text{A.1}$$

Here, F_{sh} is the impact force experienced by the pipe shell, t is the wall thickness and H_t is the dent depth. (i.e. both elastic and plastic).

The basic assumption for the above relationship between the contact force and the indentation is that the concrete coated pipe is stiffer than the steel shell. Thus, the estimated stiffness is lower than the real one and the calculated absorbed energy becomes larger. In this way the effect of the coating is conservatively neglected. For soft coatings this relationship may lead to a non-conservative result as the energy absorption becomes larger than for the bare steel pipe.

The energy absorbed locally by the steel pipe can be calculated directly from the maximum force obtained from the impact analysis as:

$$E_{ab} = \int F_{sh}(H_t)dH_t = \frac{2 \cdot F_{sh}^3}{75 \cdot f_y^2 \cdot t^3} \qquad \text{A.2}$$

A.5 Soil Stiffness

The soil stiffness, k_{ps}, is the effective stiffness which is to be determined dependent on the soil type. Analyses should be based on conservative values of the upper- and lower bound soil stiffness (i.e. with respect to pipeline response).

A.6 Masses

If the pipe shell is modelled by shell elements, the effect of the content and the hydrodynamic added mass can be accounted for as a smeared mass over the shell.

When calculating the hydrodynamic added mass of the pipeline, the span height over the seabed shall be accounted for by appropriate methods as e.g. in DNV-RP-F105.

A.7 DEH cable with protection structure

The stiffness of the DEH cable protection structure, with the electric cable located inside, may be obtained from tests, providing non-linear effects such as when the protection structure is fully deformed and in contact with the electric cable.

The stiffness of the DEH cable with protection structure may be affected by different combinations of impact velocities, mass, and water filling of the protection structure. The test programme to establish this stiffness should reflect these parameters. For systems where the stiffness is sensitive to the impact velocity, the applied test impact velocity needs to comply with the established trawl velocity of the considered area.

The non-linear spring representing the DEH cable with protection structure is included in the analysis model at the impact location, as shown by spring stiffness k_{c1}, in Figure A-1.

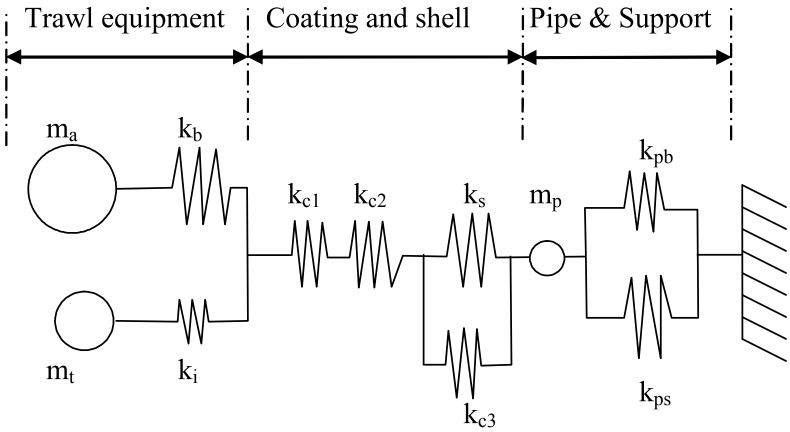


Figure A-1
Principles of the analysis model for trawl gear impacting a pipeline. Note, the hydrodynamic added mass for trawl boards is applied through the out-of-plane stiffness, whereas for clump-weights the added mass is added directly to the mass of the clump weight (i.e. for clump weights, the total mass equal (m_a + m_t), and associated stiffness equal k_i).

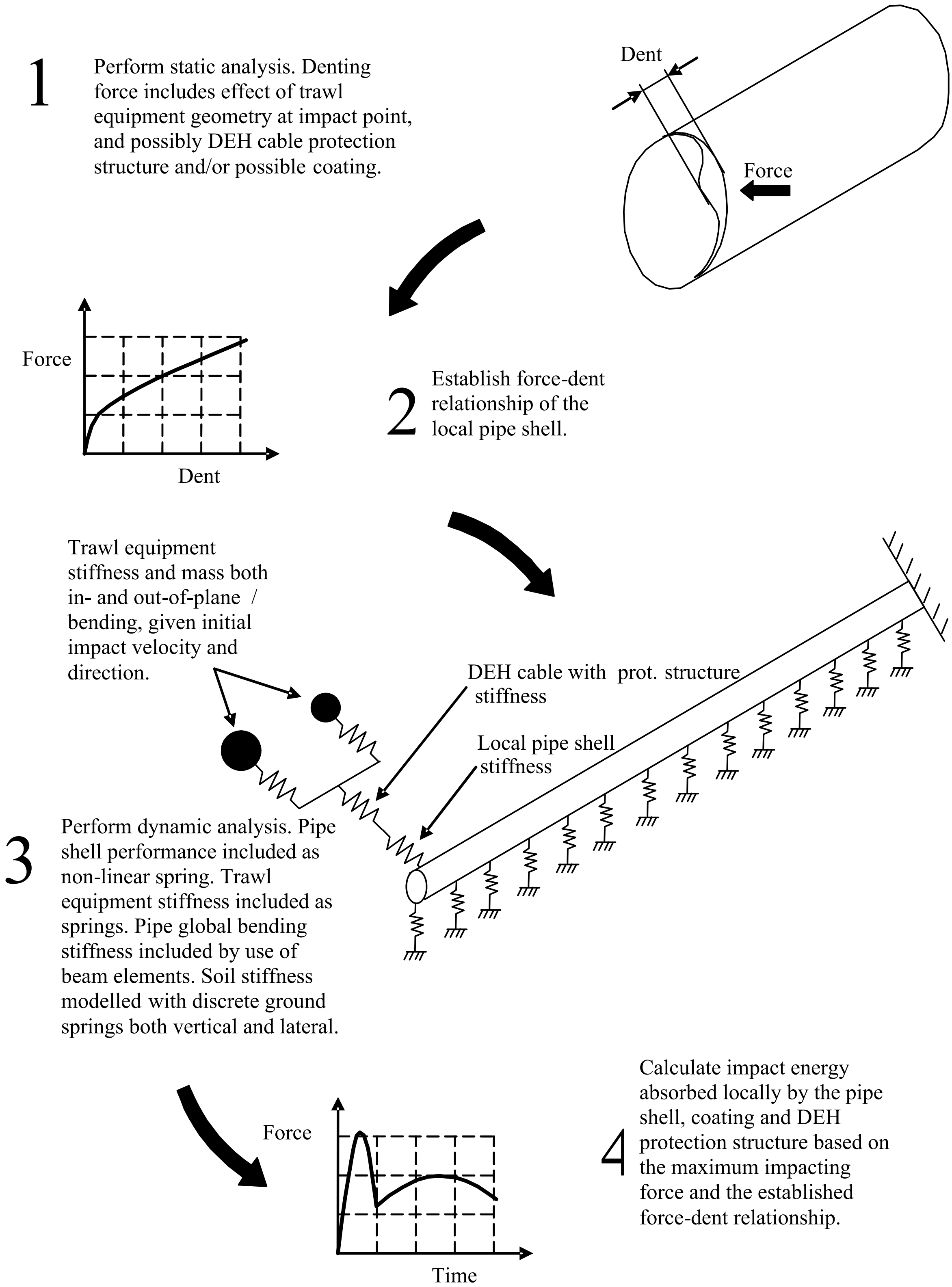


Figure A-2
Typical scheme for simulation of the impact process

APPENDIX B
EXAMPLE

Design basis

As an example a 13 km 14" pipeline is chosen to demonstrate the use of the RP.

Pipeline dimensions and material (general)

Pipeline dimensions		
Outer diameter, D	: 356	mm
Wall thickness, t_{nom}	: 16	mm
Corrosion allowance, t_{corr}	: 3	mm
Steel material		
Steel quality	: SML450I U	
Specified minimum yield stress	: 450	N/mm^2
Specified minimum tensile strength	: 535	N/mm^2
Derating at design temperature	: 0	MPa
Coating		
Type	: Concrete	
Thickness	: 40	mm
Specific weight	: 1900	kg/m^3
Content		
Content	: OIL	
Specific weight	: 800	kg/m^3
Design temperature	: 40	ºC
Design pressure	: 100	barg

Environmental data

Water depth, d	: 300	m
Ambient temperature	: 5	ºC

Soil conditions

Sand, friction angle, ϕ	: 35	deg.
Axial friction coefficient	: 0.4	
Lateral friction coefficient	: 0.6	

Safety Philosophy

Fluid category	: B	
Location class	: 1	
Safety class	: Normal	

Trawl equipment and fishing intensity see (Section 2)

The pipeline is operated in an area exposed to consume trawling where the largest (4000kg) polyvalent board is used. No beam trawling is expected in the area. The fishing vessel density (i.e. number of trawlers per area) for the field is found by a separate study to be 0.4 per 10^3 km^2 as a mean for the whole pipeline route. A predominant trawling direction of 70° to the pipeline is found due to the bottom topography. The whole pipeline length is exposed to trawl loads.

Trawl board type	: Polyvalent	
Trawl board steel mass, m_t	: 4 000	kg
Trawl size (length × height)	: 4.5 × 3.5	m
Trawl velocity, V	: 2.8	m/s
Warp line length, L_w	: 3 × d = 900	m

Trawling frequency (see section 2.4)

Vessel density, I	: 0.4	per 10^3 km^2

The trawl gear impact frequency is calculated as (see Equation 2.1):

$$f_{imp} = n_g \cdot I \cdot V \cdot \alpha_e \cdot \cos\varphi = 2 \cdot \frac{0.4}{10^3\, km^2} \cdot 10.1 \frac{km}{hr} \cos(20^o) = 0.0076\, per\ hr{-}km = 64\, per\ year{-}km$$

Impact (see Section 3)

The simplified approach is used to obtain a conservative result. The pipeline is coated with normal density concrete that is stiff enough to conservatively assume a shell stiffness of the coated pipe at least equal to that of a bare steel pipe. The pipe is resting on the seabed with no free spans.

Trawl equipment, additional data for impact calculations (see Table 3-1)		
Trawl board type .... :	Polyvalent	
Trawl board hydrodynamic mass, $m_a = 2.14 \bullet m_t$ .... :	8 560	kg
Trawl board bending stiffness, k_b .... :	10	MN/m
Trawl impact velocity coefficient, C_h .... :	0.85	
Energy reduction factors (see Figure 3-3)		
Steel mass associated, R_{fs} .... :	0.55	
Added mass associated, R_{fa} .... :	0.25	

Pipe wall thickness: $t = t_{nom} - t_{corr} = 16 - 3 = 13$ mm

Absorbed impact energy (see section 3.3)

The absorbed energy due to the impacting steel mass is calculated as (see Equation 3.1):

$$E_s = R_{fs} \cdot \tfrac{1}{2} m_t (C_h V)^2 = 0.55 \cdot \tfrac{1}{2} 4000 \cdot (0.85 \cdot 2.8)^2 = 6.2kJ$$

The impacting force caused by the hydrodynamic mass is calculated as (see Equation 3.2):

$$F_b = C_h V (m_a k_b)^{0.5} = 0.85 \cdot 2.8 \cdot (8600 \cdot 10 \cdot 10^6)^{0.5} = 700kN$$

which then gives the absorbed energy of the hydrodynamic mass (limited by the maximum energy available, see Equation 3.3):

$$E_a = R_{fa} \cdot \frac{2(F_b)^3}{75 \cdot f_y^{\,2} \cdot t^3} \le \tfrac{1}{2} m_a (C_h \cdot V)^2$$

$$E_a = 0.15 \cdot \frac{2 \cdot (700 \cdot 10^3)^3}{75 \cdot (450 \cdot 10^6)^2 \cdot (13 \cdot 10^{-3})^3} \le \tfrac{1}{2} 8600 \cdot (0.85 \cdot 2.8)^2$$

$$E_a = 3.1kJ \le 24.4kJ$$

The absorbed energy is the maximum of E_s and E_a, i.e. 6.2 kJ. This estimate is conservative, especially for smaller pipelines; hence an analysis according to the model given in Appendix A is performed.

Dynamic analysis:

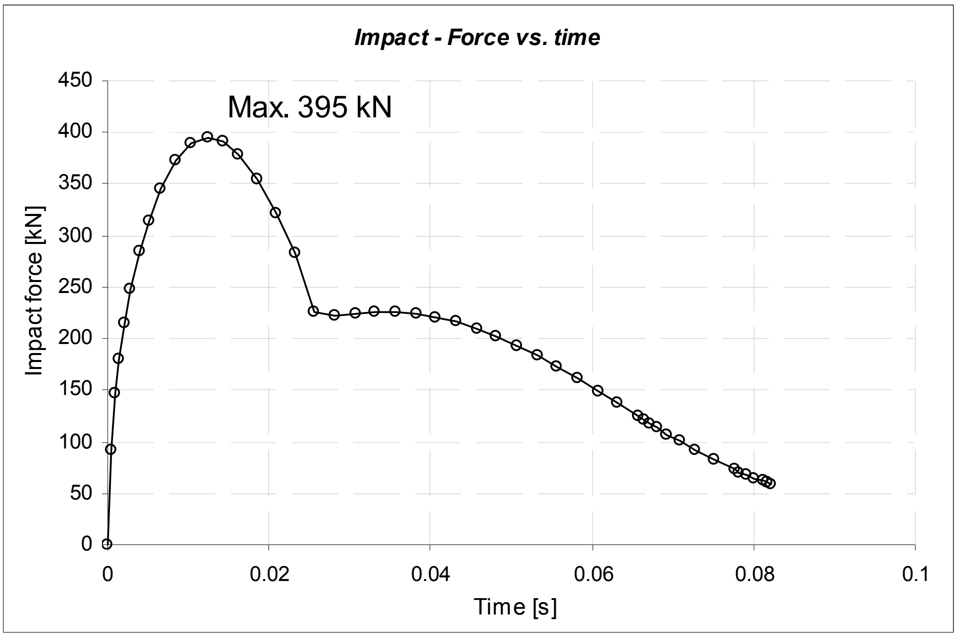


Figure B-1: Impact force versus time, obtained from dynamic finite element analysis

Impact force, obtained from FE analysis, see Figure B-1:	:	395	kN
Energy absorption, Equation A.2	:	3.7	kJ
Permanent dent depth, $H_{p,c}$	:	9.0	mm
Permanent dent depth, as % of outer steel pipe diameter	:	2.5	%

The impact energy to be applied in the testing of coated pipes is reduced from 6.2 kJ to 3.7 kJ using the advanced method given in Appendix A.

Note: The dent depth is calculated with a pipe shell stiffness as for a bare steel pipe, i.e. neglecting the stiffness contribution from the concrete coating. Therefore, this value which slightly exceeds the acceptance criteria must be considered as a conservative estimate. It is believed that the dent depth found during impact testing of the coated pipe will be well within the acceptable limits according to section 6.2.

Pull-over (see Section 4)

The pull-over scenario is analysed using a dynamic finite element analysis. To focus on the pipeline response from the pull-over load only in this example, the pipeline is considered to have released the residual forces by global buckling close to the pull-over location. Hence, the considered pipeline has negligible compressive forces due to thermal and internal pressure effects, and the analyses are based on zero operational pressure and ambient temperature in this example.

Trawl equipment, additional data for pull-over calculations:

Water depth, d	:	300	m
Trawl board height, ($h = 2B$)	:	3.5	m
Span height, H_{sp}	:	0.0	m
Warp line diameter	:	38	mm
Drag coefficient	:	2.0	
Added mass coefficient	:	2.0	
Axial friction coefficient	:	0.4	
Lateral friction coefficient	:	0.6	
Load effect factor	:	1.1	
Condition load effect factor, γ_C	:	1.07	

Note: the load effect condition factor, γ_C, is to be applied on the vertical component of the pipeline response from the trawl pull-over load, i.e. to the moment acting about the horizontal axis perpendicular to the pipeline axis.

The functional load factor, γ_F, is to be applied to the total pipeline response from the pull-over load, i.e. both the axial force and moment response from the pull-over load.

Pull-over load (see section 4.3)

Dimensionless height (see Equation 4.5):

$$\overline{H} = \frac{H_{sp} + OD/2 + 0.2}{B} = \frac{0 + 0.436/2 + 0.2}{1.75} = 0.239$$

The empirical force coefficient (see Equation 4.3):

$$C_F = 8.0 \cdot (1 - e^{-0.8\overline{H}}) = 8.0 \cdot (1 - e^{-0.8 \cdot 0.239}) = 1.39$$

The warp line stiffness is estimated as (see Equation 4.8):

$$k_w = \frac{3.5 \cdot 10^7}{L_w} = \frac{3.5 \cdot 10^7}{3 \cdot 300} = 39 \ kN/m$$

The maximum pull-over force becomes (see Equation 4.2):

$$F_p = C_F \cdot V(m_t k_w)^{1/2} = 1.39 \cdot 2.8 \cdot (4000 \cdot 39 \cdot 10^3)^{1/2} = 48.6 \ kN$$

The corresponding maximum downward acting force becomes (see Equation 4.9):

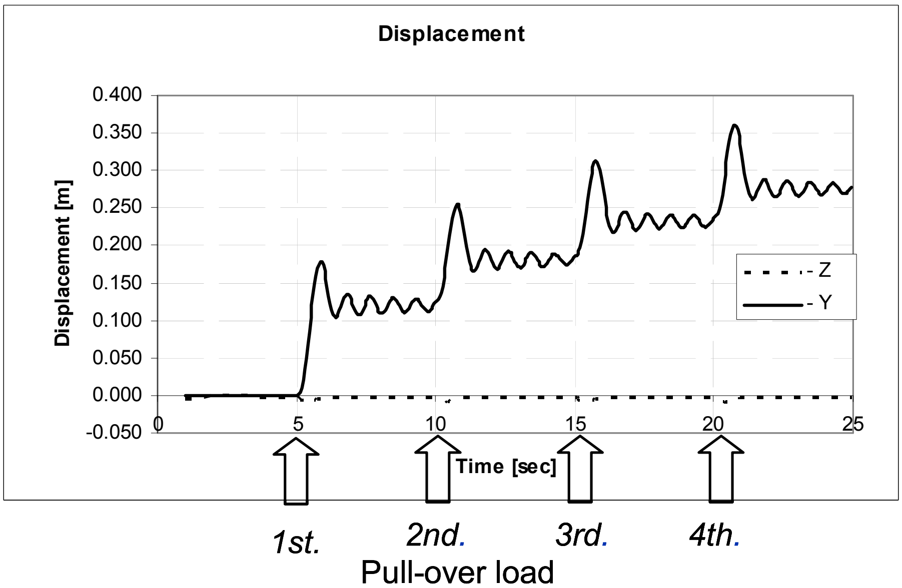
$$F_z = F_p(0.2 + 0.8 \cdot e^{(-2.5 \cdot \overline{H})}) = 48.6 \cdot (0.2 + 0.8 \cdot e^{-2.5 \cdot 0.239}) = 31.1 \ kN$$

Pull-over load duration (see section 4.5)

Pull-over duration (see Equation 4.19):

$$T_p = C_T C_F (m_t / k_w)^{1/2} + \delta_p / V = (1 + 0.1) \cdot 2.0 \cdot 1.39 \cdot (4000 / 39000)^{1/2} = 0.98 \ s$$

Acceptance criteria (see Section 6.4):
The resulting pipeline effective axial force before the pull-over load is applied, is -81 kN. The loads specified in the following reflect the total response from the finite element analysis:



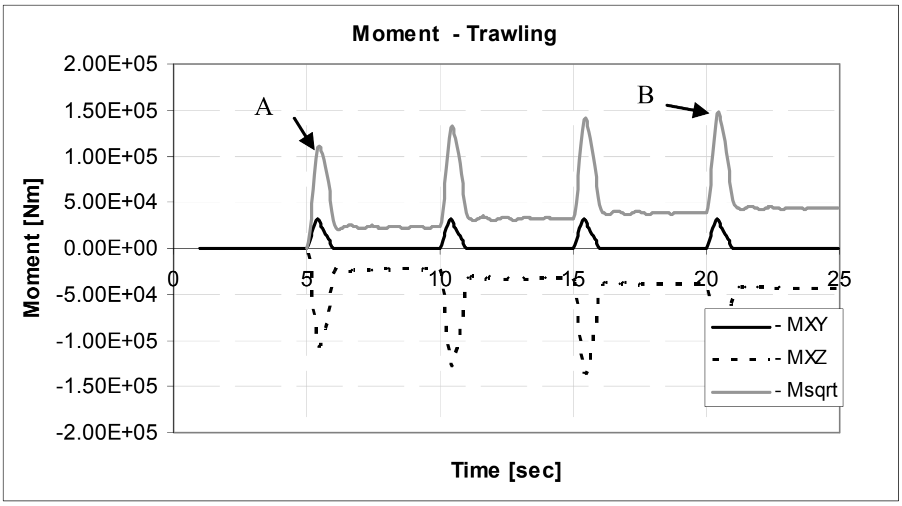


Figure B-2: Pipeline response, obtained from dynamic finite element analysis

First pull-over (dynamic analysis):		
Effective axial force (functional) .... :	-69	kN
Maximum bending moment (functional) .... :	113	kNm
Maximum stress .... :	94	MPa
Utilisation, local buckling (at time “A” in fig. B-2, ref. OS-F101) .... :	0.38	(OK)
Fourth pull-over (dynamic analysis):		
Effective axial force (functional) .... :	-40	kN
Maximum bending moment (functional) .... :	148	kNm
Maximum stress .... :	124	MPa
Utilisation, local buckling (at time “B” in fig. B-2, ref. OS-F101) :	0.46	(OK)

Note: Four subsequent pull-overs at the same location and in the same direction are considered to give a conservative estimate for the effect of subsequent pull-overs for this pipeline that rests at seabed. The lateral displacement increases for each pull-over. However, the pipeline material still behaves linear elastically.

Hooking (see Section 5)
The pipeline has no free span, therefore only part penetration of a board has to be considered.

Trawl equipment, additional data for hooking calculations:

Load factor	:	1.0	

Lifting height (see section 5.5):

Maximum lifting height (see Equation 5.4):

$$H_l = 0.7B - 0.3 \cdot OD = 0.7 \cdot 1.75 - 0.3 \cdot 0.436 = 1.09m$$

Result from static finite element analyses, lifting height H_l = 1.09 m:

Lifting force	:	73	kN
Effective axial force (functional)	:	784	kN
Maximum bending moment	:	340	kNm
Maximum stress	:	290	MPa

Acceptance criteria (see section 6.5):

Load effect factor	:	1.0	
Condition load effect factor, γC	:	1.0	
Load condition	:	Load controlled	
Corrosion allowance subtracted from nominal wall thickness	:	No	
Utilisation, local buckling (ref. OS-F101)	:	0.53	(OK)

Impact testing of coated pipe (see Section 7)

Test equipment, additional data for impact testing:

Test rig efficiency (assumed)	:	0.7	

Test input (see section 7.3)

Impact energy, (i.e. Impact energy / Test rig efficiency)	:	5.3	kJ
Hammer weight	:	4 000	kg
Hammer velocity	:	1.69	m/s
Hammer height	:	0.135	m

Acceptance criteria (see section 6.2 or 6.3)

Minimum number of impacts	:	4	
Dent depth (steel), as % of outer steel pipe diameter:	:	1.5	%

No exposure of the inner reinforcement layer.
No large concrete area spalling off (maximum 200 × 200 mm).