RECOMMENDED PRACTICE

DNVGL-RP-F107 Edition May 2017

Risk assessment of pipeline protection

DNV GL AS

FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

General

This document supersedes the October 2010 edition of DNV-RP-F107.

The purpose of the revision of this service document is to comply with the new DNV GL document reference code system and profile requirements following the merger between DNV and GL in 2013. Changes mainly consist of updated company name and references to other documents within the DNV GL portfolio.

Some references in this service document may refer to documents in the DNV GL portfolio not yet published (planned published within 2017). In such cases please see the relevant legacy DNV or GL document. References to external documents (non-DNV GL) have not been updated.

Changes

Content related to pipe-soil interaction has been moved to DNVGL-RP-F114 *Pipe-soil interaction for submarine pipelines*, and replaced by references to DNVGL-RP-F114.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.

Changes - current

Acknowledgement

This recommended practice is based upon a project guideline developed by DNV GL for Statoil.

DNV GL would like to take this opportunity to thank Statoil for their financial and technical contributions.

DNV GL is further grateful for valuable co-operation and discussion with the individual personnel in Statoil participating in the project.

This recommended practice has been distributed for both internal and external hearing, DNV GL would like to thank all companies giving valuable feed-back and comments to this document.

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SECTION 1 GENERAL

1.1 Introduction

This recommended practice presents a risk-based approach for assessing pipeline protection against accidental external loads. Recommendations are given for the damage capacity of pipelines and alternative protection measures and for assessment of damage frequency and consequence. Alternative pipeline protection measures are also presented.

1.2 Objectives

The objective of this recommended practice is to provide a basis for risk assessment of accidental events which lead to external interference with risers, pipelines and umbilicals and to give guidance on protection requirements.

The recommended practice gives guidance for pipeline and riser protection design in accordance with the requirements and safety levels stated in DNVGL-ST-F101 *Submarine pipeline systems* and DNVGL-ST-F201 *Dynamic risers*.

1.3 Scope and application

This recommended practice focuses on providing a methodology for assessing the risks and required protection from dropped crane loads and ship impact to risers and pipeline systems within the safety zone of installations. Accidental scenarios with other relevant activities such as anchor handling, subsea operations and trawling are also discussed. Where applicable information exists, specific values or calculation procedures are recommended. If no such information is available, then a qualitative approach is given.

The recommended practice is applicable for the following two scenarios:

a) control that implemented control and protection measures are acceptable
b) optimisation of planned protection.

All the generic frequencies presented in this recommended practice, e.g. the drop frequency, are based on operations of North Sea installations. These frequencies are not generally applicable for other parts of the world. However, the general methodology is applicable throughout the world.

Acceptance of protection measures can be based on operator supplied risk acceptance criteria covering human safety, environment and economics, or the failure frequencies given in DNVGL-ST-F101.

With respect to pipelines, the risk methodology used in this recommended practice is applicable to pipelines within offshore petroleum field developments. It should be noted that this document does not include regular 3rd party risk evaluations as found in onshore developments.

1.4 General considerations

When using this recommended practice, note that the following points are applicable:

1) Risk estimation should normally be conservative.
2) Repeated assessments for alternative protection measures may be required.
3) Economic criteria will often be decisive.
4) In each project, the risk should be kept as low as reasonably practicable.
5) It is important to pay attention to the total risk picture. The pipelines/risers/umbilicals under consideration will give a contribution to the risk of a installation and the total risk-picture of the installation has to be considered.

It is important to realise that a safe and economic pipeline and umbilical design should be considered as part of a complex system, which includes other areas such as:

— template design and field lay-out

— subsea operations (drilling, completion, intervention, maintenance)
— platform activities.

In order to achieve an optimum pipeline/umbilical protection design, the whole life-cycle system efficiency should be evaluated. This implies that relevant interfaces and interactions with other designs, activities and operational procedures shall be identified and described in details as early as possible. The whole system can then be optimised with respect to safe operations and economy, and a sub-optimisation of the pipeline/umbilical design will be avoided.

Among the areas, or aspects, of particular importance are

— *Subsea wells*: Stop of production should be minimised, and measures to achieve this objective are consequently of high priority. A shutdown can also affect the pipeline system as hydrates may form or wax is deposited. The expected scope and frequency of intervention work should also be considered.
— *Field lay-out*: Optimising the field layout with respect to the pipeline length or cable length can, in reality, be sub-optimisation. The layout of pipelines and cables near subsea wells or templates should also be evaluated with respect to rig-operations. At a fixed platform, the optimum pipeline or cable routing can be in areas where the lifting activity is low or nonexistent, thus reducing the protection requirements.
— *Rig heading relative to tie-in corridor*: The pipeline tie-in corridor should take into account the dominant rig heading and anchor pattern.

For subsea wells, possible scenarios involving simultaneous operations shall be defined at the design stage of a project.

1.5 Limitations

This recommended practice covers only risk assessment of accidental loading from external events/interference on offshore risers, pipelines and umbilicals. The limits for the application of this document are (see also Figure 1-1):

— *on a fixed or floating platform,* below cellar deck
— *on a subsea installation,* at the connection point to the subsea manifold/piping.

The above limits indicate that this document covers tie-in towards subsea installations up to the outboard hub. Requirements to any nearby protection structures should comply with this recommended practice.

It is important that all parts of the subsea production system are covered either by this recommended practice or by other standards. For protection requirements of subsea installations reference is made to other standards, e.g. NORSOK.

For purposes other than risk assessment for risers, pipelines or umbilicals as covered by this recommended practice, the information and methodology given should not be used without further documentation/clarification.

Furthermore, this recommended practice covers the risk assessment from accidental external events only and hence is a contribution to the total risk of pipeline operations. Other risks, which contribute to the total risk of pipeline operations as corrosion, erosion, burst etc. are not included.

This recommended practice describes risk assessments related to accidental scenarios of the lifetime of the pipeline during normal operation conditions and planned activities (e.g. drilling and completion operations). Risks related to single, major, critical operations, such as construction work, are not included. The risk of such operations should be addressed separately.

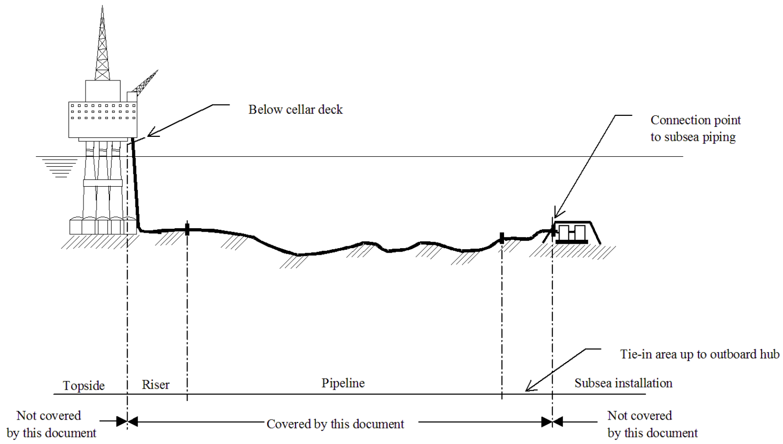

Figure 1-1 Application of the recommended practice

1.6 Definitions

Table 1-1 Definitions of terms

Term	*Definition*
acceptance criteria	criteria used to express an acceptable level of risk for the activities
consequence	describes the result of an accidental event The consequence is normally evaluated for human safety, environmental impact and economic loss.
consequence ranking	used to describe the severity of a consequence The consequence is ranked from 1 (minor, insignificant) to 5 (major, catastrophic).
conditional probability	probability of one event given a preceding event
damage	damage to pipelines is divided into three categories, minor, moderate and major The damage categories form the basis for both the frequency calculations and the consequence evaluations. The damage classification is given in [4.2].
frequency	used to describe the likelihood per unit time of an event occurring
frequency ranking	used to describe the frequency of an event The frequency is ranked from 1 (low) to 5 (high).
platform	refers to a permanent installation, e.g. a concrete gravity base structure (GBS), a steel jacket, a tension leg platform (TLP), a floating production unit (FPU), etc.
rig	refers to a temporary installation, e.g. mobile offshore drilling unit
risk	expression of the product of the frequency (probability) and the consequence of an accidental event

SECTION 2 METHODOLOGY

2.1 Introduction

Prior to any risk assessment, the safety objectives for the activities and the acceptance criteria for the risk shall be defined by the operator.

The basis of any risk evaluation relies on a comprehensive system description. This system description is used to identify hazards with potential to affect the pipeline/umbilical. The identified hazards are evaluated in a risk assessment.

This section describes the above aspects of the risk evaluation procedure and an overview of the total procedure is shown in Figure 2-1.

2.2 Safety objectives

To safely manage the activity, the operator shall define safety objectives for avoidance or survival of accidental events, as required in DNVGL-ST-F101 Sec.2.

2.3 Acceptance criteria

In order to evaluate whether the risk of an accidental event is acceptable or not, acceptance criteria are required. The acceptance criteria shall state the acceptable limits for the risks related to human safety, environment and economy. The operator shall establish the acceptance criteria prior to beginning the risk evaluations. When considering several pipelines, the acceptance criteria should reflect the total risk level for all pipelines.

The acceptance criteria shall be in line with the defined safety objectives of the activity. Alternatively, the structural failure probability requirements given in DNVGL-ST-F101 Sec.2 may be used as acceptance criteria, in which case no consequence assessment is required and only the frequency of failure needs to be established. Note also that this criterion is given per pipeline and if several pipelines are involved, each one should be treated individually.

Guidance note:

The acceptable structural failure probability given in DNVGL-ST-F101 Table 2-5 may be modified, i.e. transformed into a failure probablity per km given that any dependacy of accidental loading between different locations is accounted for.

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Guidance note:

For dynamic metallic risers, see DNVGL-ST-F201.

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The acceptance criteria reflect acceptance of the risk contribution during a certain period. For a platform, the activities are assumed to be continuous throughout the year, hence a year normally forms the basis for the risk assessment. For drilling activities and intervention works with duration less than a year, an equivalent annual risk is to be used.

The criteria for human safety and environmental impact shall be established considering the risk as a contribution to the total risk for the platform or rig or the whole field.

2.4 System description

Prior to risk assessment, a complete system description should be prepared. The description shall cover the entire pipeline/umbilical lifecycle and should as a minimum consider the following:

1) Activities potentially affecting pipeline/umbilical integrity (see Sec.3):
   - crane handling on platform or rig
   - fishing (bottom trawling)

— supply vessels and general ship traffic in the area or close to the area considered
— subsea operations (e.g. simultaneous operations as drilling, completion and intervention)
— others (planned construction work, etc).

2) Physical characteristics of the pipeline/umbilical (see Sec.4):

— type (steel pipeline, flexible or umbilical)
— diameter, wall thickness, coating thickness
— material (steel and coating)
— construction details (connectors, swan necks, etc.)
— content (gas, oil, condensate, water, etc).

3) Mitigation measures (see Sec.4 and [2.7]):

— protection
— routing
— procedures.

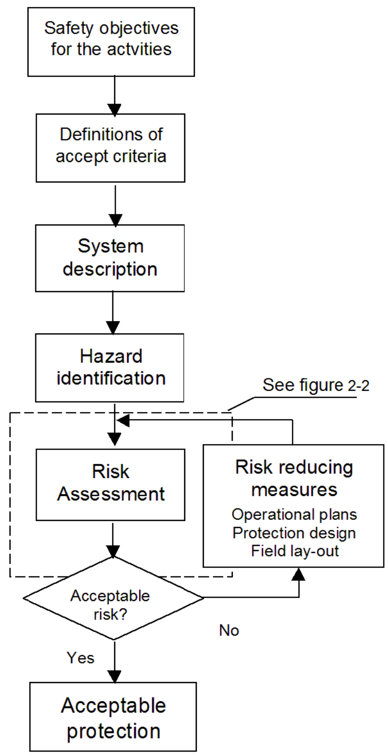

Figure 2-1 Process description of the pipeline protection assessment

2.5 Hazard identification

Possible hazards that can cause damage to pipelines and umbilicals should be identified based on the available information regarding activities in the area, see [2.4]. Hazard identification should systematically identify all external accident scenarios and possible consequences. Table 2-1 states some typical hazards that can cause damage to risers, pipelines and umbilicals. The initial cause of the hazard and the consequences for human safety, environmental impact and economic loss are not included in the table. Additional events should be included as applicable.

It is not normally practicable to protect against accidental events that could occur during installation of pipelines and umbilicals. Risk reduction should therefore be specially considered when drawing up operational plans and procedures for such activities.

Pipelines routed across known fishing areas should be designed against trawl interaction. Pipeline design against trawl interaction should be according to DNVGL-RP-F111 *Interference between trawl gear and pipelines*. If the pipeline is designed against trawling in all phases, i.e. temporary and permanent, the hazard from trawling may be ignored.

Table 2-1 Possible external hazards

Operation/activity	*Hazard*	*Possible consequence to pipeline*
Installation of pipeline	Dropped and dragged anchor/anchor chain from pipe lay vessel Vessel collision during laying leading to dropped object, etc.	Impact damage
	Loss of tension, drop of pipe end, etc.	Damage to pipe/umbilical being laid or other pipes/umbilicals already installed
	Damage during trenching, gravel dumping, installation of protection cover, etc.	Impact damage
	Damage during crossing construction.	Impact damage
Installation of risers, modules, etc. (i.e. heavy lifts)	Dropped objects	Impact damage
	Dragged anchor chain	Pull-over and abrasion damage
Anchor handling (rig and lay vessel operations)	Dropped anchor, breakage of anchor chain, etc.	Impact damage
	Dragged anchor	Hooking (and impact) damage
	Dragged anchor chain	Pull-over and abrasion damage
Lifting activities (rig or platform operations)	Drop of objects into the sea	Impact damage
Subsea operations (simultaneous operations)	ROV impact	Impact damage
	Manoeuvring failure during equipment installation/ removal	Impact damage
		Pull-over and abrasion damage
Trawling activities	Trawl board impact, pull-over or hooking	Impact and pull-over damage
Tanker, supply vessel and commercial ship traffic	Collision (either powered or drifting)	Impact damage
	Emergency anchoring	Impact and/or hooking damage
	Sunken ship (e.g. after collision with platform or other ships)	Impact damage

2.6 Risk assessment

An initial, accidental event (e.g. dropped container) can develop into an end-event (e.g. hit of pipeline). In general, risk assessments consist of an estimation of the frequency of the end-events and an evaluation of the consequence of the end-events.

The frequency of occurrence can be either:

— calculated when detailed information exists (e.g. dropped crane load scenario), or
— estimated based on engineering judgement, operator experience, etc.

The frequency of occurrence is then given a ranking from 1 (i.e. low frequency) to 5 (i.e. high frequency).

Similarly, the consequence is either calculated or estimated, then ranked from 1 (i.e. low, non-critical consequence) to 5 (i.e. high, severe consequence).

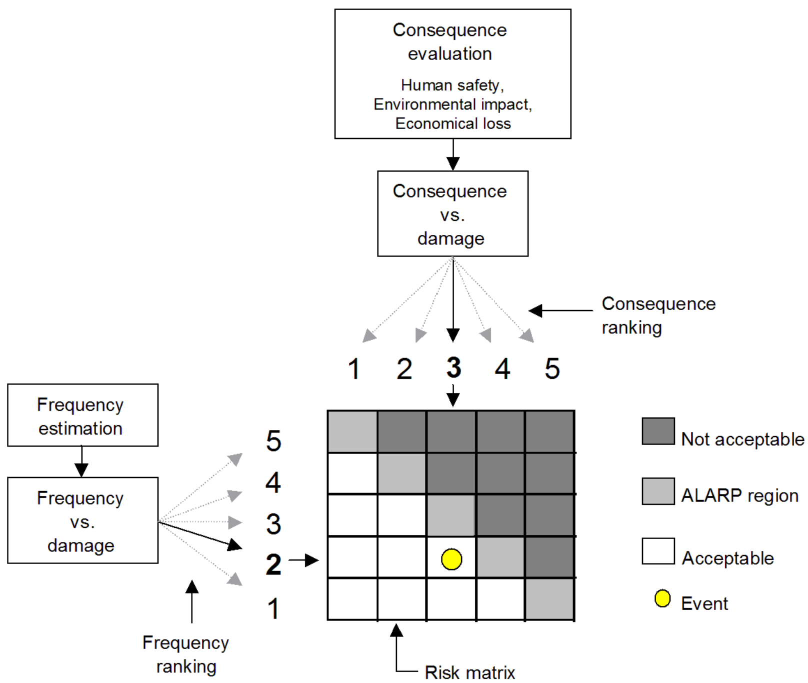

Figure 2-2 Process description of a risk assessment (figure is only schematic, actual acceptable limits need to be given by operator)

In this recommended practice, the end-event is classified into different damage categories (i.e. minor (D1), moderate (D2) and major (D3) damage, see definition of damage in [4.2]) which forms the basis for the consequence ranking into 5 different categories. The frequency ranking and consequence ranking shall be established for each of the relevant damage categories, thus giving the risk for each damage category.

The risk is then evaluated by plotting the established frequency and consequence in a risk matrix. The risk assessment is briefly described in Figure 2-2. The process for a dropped object scenario is described in detail in App.A. The frequency ranking and the consequence ranking are further described in Sec.5 and Sec.6 respectively.

The risk matrix method makes it possible to effectively compare the risk from different events, even when the level of detailed knowledge varies.

For some isolated operations, the risk assessment methodology outlined in this document is not applicable. These are isolated critical operations such as larger lifting operations, e.g. lifting of new modules. There is limited experience with such scenarios, and frequency estimates are therefore difficult to obtain. The methodology should not be applied in cases like these. For such operations hazardous and operability (HAZOP) studies, failure mode effect analysis (FMEA) or other relevant methods can be used to identify critical conditions during the operations and possible equipment failures that can cause or aggravate critical conditions, and ensure that effective remedial measures are taken. Note however, that normally only the consequence, and not the corresponding frequency, of the incidents is found by such worst-case evaluations.

If any of the risk-related basic parameters in the risk assessment changes, e.g. the activity level, design, parameters, operating procedures, are changed, the risk assessment should be updated to reflect these changes.

In Figure 2-2, the ALARP (as-low-as-reasonably-practicable) region identifies an area where the risk is acceptable, however further reduction of the risk should be pursued with cost-benefit evaluation.

2.7 Risk reducing measures

If the estimated risk is above the relevant acceptance criterion, then risk reduction can be achieved by:

— reducing the frequency of the event,
— reducing the consequence of the event, or
— a combination of the above.

Table 2-2 presents some risk reducing measures. For ship collision scenarios, additional risk reducing measures are given in [5.4.5].

In each project, the risk should be kept as low as reasonably practicable. This means that some low cost risk reduction measures should be introduced even if the risk is considered to be acceptable. Frequency reduction measures shall be prioritised before consequence reduction measures.

To evaluate the economic effects of any risk reduction measures, a cost-benefit calculation shall be performed. The cost-benefit value (CBV) is an evaluation of the ratio between the increased cost of any additional measures, $\Delta Cost$, and the reduced risk, $\Delta Risk$. A cost-effective solution will give a ratio less than unity.

$$CBV = \frac{\Delta Cost}{\Delta Risk} \tag{1}$$

This can be calculated according to

$$CBV = \frac{C_M}{\sum_y \frac{\Delta C_R + \Delta C_P}{(1+r)^y} \cdot PoF} \tag{2}$$

Where

C_M = cost of risk reducing measure
ΔC_R = reduction in repair cost
ΔC_P = reduction in production loss

PoF = probability of failure/failure frequency

R = interest rate

Y = number of years.

Table 2-2 Risk reducing measures

Measure	*Reduces*	*Comments*
Limit lifting operations to certain zones, sectors and areas	Frequency	This reduces/eliminates the frequency effectively. Often used when lifting heavy objects as BOP on rigs. The rig is withdrawn from the area when lowering the BOP. For pipe loading onboard a lay-barge only the crane on the side furthest away should be used when laying parallel to or crossing existing line.
Limit the type of objects lifted in certain zones	Frequency	For example, only the cranes furthest away from the vulnerable area may lift heavy objects. Or to not allow pipe loading onboard lay barge within platform safety zone. Reduces the frequency of the most critical objects, however does not eliminate the risk totally.
Introduce safety distance	Frequency	The activity is either planned performed in a safe distance away from the pipeline or vice versa (e.g. anchor handling). Reduces/eliminates the risk efficiently.
Introduce safe areas	Frequency	Activity of a certain kind is not allowed within a specified area (e.g. trawling nearby platforms). Reduces/eliminates the risk efficiently.
Change the field lay-out	Frequency	By careful routing the same effect as for safety distance may be obtained for parts of the pipeline.
Introduce extra chaser tug or anchor chain buoys	Frequency	To ensure that no interference occurs between the anchor chain and the installation take place.
Tie-in corridor in-line with rig heading above installation	Frequency	The tie-in corridor should be in-line with the rig heading, thus the rig cranes are oriented in favourable positions.
Weather restrictions for operations.	Frequency	If a prevailing current direction have been included in a safe distance evaluation, the activity should not be performed if the current direction is other than that considered, or if the frequency have shown to increase with increasingly worse weather, the activity should be postponed until the weather normalises.
Increase the protection	Consequence	Increased protection will reduce the damage to the pipeline. Increased protection may be obtained by a variety of solutions. It should be noted that some solutions (e.g. massive tunnel structures) might introduce a very high risk to the pipeline during installation, in addition also introduce scouring problems during the lifetime.
Stop production in pipeline during activity	Consequence	This effectively reduces the consequence of release, however this solution may be very expensive. Further, it does not reduce the economic consequence of damage.

SECTION 3 ACTIVITY DESCRIPTION

3.1 Platform/rig

3.1.1 Lifting activity

The following information on the lifting activity is required for input to the dropped object calculations, see [5.2].

3.1.1.1 Object classification

The lifting activity description should include objects lifted (where applicable):

— between supply vessel and platform/rig,
— between platform/rig and subsea installation, and
— internally on the platform, but with potential for objects to drop into the sea.

Lifting activity information shall be collected for all relevant operations, e.g. normal operating conditions for platforms and drilling, completion, etc. for subsea installations.

All lifting operations with a possibility for a dropped load into the sea over or near to exposed pipelines or umbilicals should be included. For estimating object excursion and hit energy, the object inventory should be as detailed as possible including size and weight, see [5.2]. All lifting activities during a representative time-period should be covered. In lieu of more detailed information, the object categories in Table 3-1 may be used to establish the load data.

Table 3-1 Object categories, typical load data

Cat.	*Description*	*Weight in air (tonnes)*	*Typical objects* [1,2]
1	Flat/long shaped	< 2	Drill collar/casing, scaffolding
2		2 – 8	Drill collar/casing
3		> 8	Drill riser, crane boom
4	Box/round shaped	< 2	Container (food, spare parts), basket, crane block
5		2 – 8	Container (spare parts), basket, crane test block
6		> 8	Container (equipment), basket
7	Box/round shaped	>> 8	Massive objects as BOP, pipe reel, etc.

1) Objects lifted during normal operation and maintenance will normally be of all categories ranging from 1 to 6. Platform cranes have a lifting capacity around 50 tonnes, thus only derricks are normally used for lifting massive objects as in category 7.

2) The categories in the table is based on platform activities to/from supply vessels. For other activities e.g. to/from subsea installations, an alternative category may be more relevant.

Guidance note:

The possibility of smaller objects, which are not normally accounted for in a dropped object scenario, falling into the sea should be identified and taken into account. Inspections have revealed that there are a significant number of smaller objects on the sea bottom close to platforms. These objects are not reported as dropped from cranes.

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3.1.1.2 Lifting frequency

The lifting frequency of the identified objects shall be established. The lifting frequency should include all activities over a relevant time-period.

3.1.1.3 Crane information

A typical platform has between one and four cranes, whereas a typical drilling rig has two cranes. Crane information should be established considering:

— crane location, for both derrick and normal cranes (note that drop from some of the cranes may not have the potential to hit a riser/pipeline)
— crane operational radius and capacity, including limitations in operational area
— dedicated supply vessel off-loading locations
— platform specific aspect (e.g. one crane is normally used for food containers only).

3.1.2 Anchor handling

For input to the dragged anchor calculations in [5.7], the following detailed information on the anchor handling activity of a rig should be collected:

— anchor handling procedures
— anchor landing area and final placement, etc.
— type of anchor (size of anchor, chain and wire)
— anchor penetration depth and dragging distance to achieve required holding capacity.

3.2 Subsea operations

For input on the subsea operation evaluations in [5.5], the following information on subsea operations should be collected:

— procedures (drilling, completion and intervention)
— simultaneous operations (e.g. one well producing while intervention work is performed on another)
— manoeuvring routes above pipelines and umbilicals
— tools and equipment size
— frequency of operations.

3.3 Fishing

For input on the trawling evaluations in [5.6], the following information should be established:

— type of activity (e.g. bottom trawling, pelagic trawling, etc.)
— frequency for bottom trawling (based on normal activities covering a relevant time-period)
— type of trawl equipment.

3.4 Ship

Ship traffic data is used as the basis for a ship collision study, see [5.4]. The following ship traffic data are the typical background data required for the ship collision study:

— merchant vessels passing the installation (per year)
— supply boats to nearby platforms (per year)
— supply boats to distant installations (per year)
— shuttle tanker to the platform (per year)
— fishing vessel density (per km^2)
— supply boat arrivals to the platform (per year)
— internal field transportation (per year)

— effective loading/unloading time at the platform(hours per year).

In addition, the ship traffic in the area should be established as input for emergency anchoring evaluations (see [5.7]) for which information regarding the number and size/class of the different vessels should be obtained.

SECTION 4 PIPELINE AND PROTECTION CAPACITY

4.1 General

There are two typical accidental loading scenarios that can lead to damage to riser, pipelines and umbilicals. These are either impact (e.g. due to dropped objects) or pull-over/hooking (e.g. due to dragged trawl board or anchor).

The impact scenario is a complex dynamic, non-linear mechanism that involves numerous parameters. In short, the response (i.e. damage) of the riser, pipeline or umbilical is of a local nature, where the wall thickness and coating thickness are important parameters.

In this recommended practice, the given damage capacities of the pipeline and coating are conservatively assumed to absorb all of the available kinetic energy of the impacting objects. However, energy absorption of the impacting object itself, or into the soil, etc, may be accounted for, if documented.

Guidance note:

This is conservative as it is found that for small diameter pipelines and soft soil conditions the absorption in the wall may be down to 50-60 % of the total kinetic energy. Further, for "non-rigid" objects such as containers, a considerable amount of energy will be absorbed by the object itself and not transferred to the pipeline.

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The pull-over and hooking scenarios are of a global bending behaviour and the bending stiffness of the pipeline or umbilical is of importance.

The impact capacities of pipelines, umbilicals and typical protection measures are given individually in this section. Typical pipeline failure modes are indentation or puncturing of the pipe/umbilical wall (for impacting loads) and excessive bending (for pull-over loads). The failure modes will be further classified according to the damage (i.e. D1 to D3) and release (i.e. R0, R1 and R2) categories, see the following section for damage class descriptions.

The capacity of the pipelines to withstand impact, pull-over and hooking loads is dependent on both local pipeline geometry (e.g. size and stiffness) and load behaviour of load (e.g. impact energy and energy absorption by object). Until the event occurs, this information of the loading is not readily available and hence estimates of the capacity should be conservative. The capacity models given below describe an average capacity and should be used in risk assessments only. The capacity models should not be used for design purposes unless a characteristic lower bound model including safety factors is used and the applicability is further documented.

Guidance note:

For design of protection against trawling, the capacity formulation given in the DNVGL-RP-F111 *Interference between trawl gear and pipelines*, which takes account of the shape of typical trawl boards, should be used.

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For dropped object scenarios, it should be noted that the results of the risk assessment are not normally very sensitive to an absolutely "correct" capacity assessment. When the loading is a complex compound of type of objects giving a variety of impact energies, a capacity estimate within ± 20% will normally give acceptable variations in the resulting risk level. However, the final risk estimate sensitivity to variations in capacity estimates should be checked if there is reason to believe that the final result is sensitive to the capacity. For thin-walled, small diameter pipelines, flexibles and umbilicals without extra protection, the capacity is normally negligible and may conservatively be set equal to zero.

The given capacity models given are focused on impact loading and are given as energy absorption for different levels of indentation, displacement or damage. The capacity for buckling due to pull-over/hooking loading is only discussed and is covered by the criteria for steel pipelines and risers given in DNVGL-ST-F101 and DNVGL-ST-F201 respectively. For umbilicals and flexible pipelines, the capacity should be separately documented.

The capacity of nearby fittings, connectors, flanges, etc. should be individually determined. Such items may become a weak link, especially when considering leakage.

Using this recommended practice, the capacities for the different protection methods shall be added to the capacity of the pipeline/umbilical. Further, the protection is assumed to be completely damaged before the pipeline/umbilical is damaged. For concrete or polymer coatings on pipelines some interaction with the pipeline may be expected before the ultimate capacity of the coating is reached. Protection failures are normally classified as minor damage (i.e. D1).

The impact capacity can be determined by testing if the given formulations are not applicable. A testing procedure is given in App.B.

4.2 Damage classification

Material damage to the pipelines is classified by the following categories:

— *Minor damage (D1)*: *Damage neither requiring repair, nor resulting in any release of hydrocarbons.*

  Smaller dents in the steel pipe wall, e.g. up to 5% of the diameter, will not normally have any immediate influence of the operation of the lines. This limit will vary and must be evaluated for each pipe. Note however, if damage occurs then inspections and technical evaluations should be performed in order to confirm the structural integrity.

  Minor damage to flexibles and umbilicals that do not require repair action.

  Any local damage to protective coatings or anodes will not normally require repair action.

— *Moderate damage (D2)*: *Damage requiring repair, but not leading to release of hydrocarbons.* Dent sizes restricting internal inspection (e.g. over 5% of the diameter for steel pipelines) will usually require repair. Ingress of seawater into flexibles and umbilicals can lead to corrosion failures. However, the repair may be deferred for some time and the pipeline or umbilical may be operated provided that the structural integrity is confirmed.

  Special consideration should be given to pipelines where frequent pigging is an operational requirement. For such pipelines, large dents will restrict pigging and lead to stop in production, and this damage should then be considered as being major (D3) rather than moderate (D2) even though no release is expected.

— *Major damage (D3)*: *Damage leading to release of hydrocarbons or water, etc*. If the pipe wall is punctured or the pipeline ruptures, pipeline operation must be stopped immediately and the line repaired. The damaged section must be removed and replaced.

In case of a damage leading to release (D3), the following classification of releases are used:

— *No release (R0)*: *No release.*

— *Small release (R1)*: *Release from small to medium holes in the pipe wall (≤80 mm diameter)*. The pipeline may release small amounts of content until detected either by a pressure drop or visually.

— *Major release (R2)*: *Release from ruptured pipelines.* Full rupture will lead to a total release of the volume of the pipeline and will continue until the pipeline is isolated.

The damage categories are used for economic evaluations, whereas the release categories in addition are used for estimating the risk for human safety and leakage to the environment. The release categories are of concern for the human safety and for the environmental risk evaluations. The classification of different failures into these categories will depend on the type of line, e.g. steel or flexible, and the protection.

4.3 Steel pipeline

4.3.1 Impact scenario

Most impacts are expected to result in a relatively “smooth” dent shape. The *dent – absorbed energy* relationship for steel pipelines are given in equation (3), (Wierzbicki and Suh, 1988).

$$E = 16 \cdot \left(\frac{2\pi}{9}\right)^{\frac{1}{2}} \cdot m_p \cdot \left(\frac{D}{t}\right)^{\frac{1}{2}} \cdot D \cdot \left(\frac{\delta}{D}\right)^{\frac{3}{2}} \tag{3}$$

where:

m_p = plastic moment capacity of the wall (= ¼ $\sigma_y t^2$)
δ = pipe deformation, dent depth
T = wall thickness (nominal)
σ_y = yield stress
D = steel outer diameter.

Equation (3) is based on a knife-edge load perpendicular to the pipeline, and the indenting object covers the whole cross section, see Figure 4-1. For conservatism, the effect of internal pressure is not included.

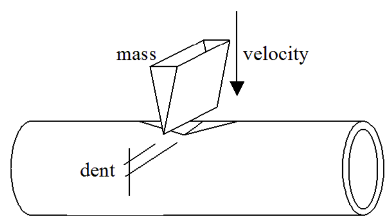


Figure 4-1 Dent prediction model (schematic)

Detailed capacity evaluations, by e.g. FE analysis, may be individually performed. Note however, that this requires detailed knowledge of the geometry of the impacting object.

The additional failure of punching through the wall, leading to leakage, can occur for higher velocity impacts or locally small and sharp impact geometry. The possibility of leakage and total rupture is included as a progressive conditional probability, where probability increases with increasing impact energy.

Table 4-1 gives the proposed damage classification used for bare steel pipes.

Table 4-1 Impact capacity and damage classification of steel pipelines and risers

Dent/ diameter (%)[1]	*Impact energy*	*Damage description*	*Conditional probability*[2]					
			D1	*D2*	*D3*	*R0*	*R1*	*R2*
< 5	Equation (3)	Minor damage	1.0	0	0	1.0	0	0
5 – 10	Equation (3)	Major damage Leakage anticipated	0.1	0.8	0.1	0.9	0.1	0
10 – 15	Equation (3)	Major damage. Leakage and rupture anticipate.	0	0.75	0.25	0.75	0.2	0.05

Dent/ diameter (%)[1]	Impact energy	Damage description	Conditional probability[2]					
			D1	D2	D3	R0	R1	R2
15 – 20	Equation (3)	Major damage. Leakage and rupture anticipated	0	0.25	0.75	0.25	0.5	0.25
> 20	Equation (3)	Rupture.	0	0.1	0.9	0.1	0.2	0.7

1) The energy limits for larger damage (i.e. 15 – 20%) should be carefully assessed as the energy levels might get unrealistic high.
2) For definition on damage categories (i.e. D1, D2, etc), see [1.6] and [4.2].

4.3.2 Pull-over/hooking scenario

Typical damage due to pull-over/hooking loads is local buckling (i.e. buckling of the cross-section as a result of excessive bending). Buckling and other relevant failure modes are covered in the criteria given in the DNVGL-ST-F101. If these criteria are exceeded then the pipeline will experience either increased ovalisation leading to a collapse of the cross-section or rupture due to excessive yielding in the longitudinal direction, the latter being most relevant for small diameter pipelines (i.e. less than 6” – 8”).

4.4 Flexible pipeline

4.4.1 Impact scenario

Unbonded flexible pipelines are typically built up of several layers of reinforcement within layers of polymer. The actual capacity will vary for similar pipes, which have only smaller individual differences in design. No easy way of establishing the capacity exists, and the capacity should be determined for each individual pipe design. However, the impact capacity of a flexible pipeline (or riser) is usually significantly less than for a steel pipeline. If no other information exists the capacities given in Table 4-2 may be used as indicative values for impact capacity of 8”-10” flexible.

Guidance note:

Note that neither calculations nor tests verify these levels, as tests are normally performed up to minor damage only. Flexibles may be conservatively assumed to have no capacity.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 4-2 Impact capacity and damage classification of flexible pipelines and risers

Impact energy[2]	Damage description	Conditional probability[1]					
		D1	D2	D3	R0	R1	R2
< 2.5 kJ	Minor damage not leading to ingress of seawater	1.0	0	0	1.0	0	0
2.5 – 10 kJ	Damage needing repair Possible leakage	0	0.50	0.50	0.50	0.50	0
10 – 20 kJ	Damage needing repair Leakage or rupture	0	0.25	0.75	0.25	0.25	0.5
> 20 kJ	Rupture	0	0	1.0	0.1	0.2	0.7

Impact energy[2]	*Damage description*	*Conditional probability*[1]					
		D1	*D2*	*D3*	*R0*	*R1*	*R2*

1) For definition on damage categories (i.e. D1, D2, etc), see [1.6] and [4.2].
2) The capacities are given for 8-10 inch flexibles and should be adjusted for other dimensions. It is proposed to reduce the capacity by 25% for 4-6 inch and increase the capacity by 25% for 12-14 inch lines.

4.4.2 Pull-over/hooking scenario

In general the pull-over/hooking scenario for a flexible pipeline is similar to that for steel pipelines. However, the flexible pipelines will then have a much larger final lateral displacement and a smaller bending radius. The capacity must be specifically determined or given by the manufacturer.

4.5 Umbilical

Umbilicals are typically a complex compound of tubing, electrical wires, reinforcement and protective layer. The most vulnerable parts of the umbilical are normally electrical wires, and not the steel tubing. The weakest link in the umbilical should represent the capacity for the whole umbilical. The actual capacity should be determined for the specific design. However, if no other information is available, the capacities given in Table 4-3 may be used.

For pull-over/hooking loads acting on umbilicals, capacities as for flexibles may be applied.

Normally, the only significant consequence of an umbilical breakage will be of an economic nature. It is assumed that loss of umbilical functions results in production stop (i.e. fail-safe principle). If this is not the case, then the environmental and human safety consequences of umbilical damage should also be evaluated.

Table 4-3 Impact capacity and damage classification of umbilicals

Impact energy[3]	*Damage description*	*Conditional probability*[1]			
		D1	*D2*	*D3*	*R0, R1 & R2*
< 2.5 kJ	Minor damage not leading to ingress of seawater	1.0	0	0	Note [2]
2.5 – 5 kJ	Damage needing repair Possible loss of function	0	0.50	0.50	
5 – 10 kJ	Damage needing repair Possible loss of function	0	0.25	0.75	
> 10 kJ	Loss of function	0	0	1.0	

1) For definition on damage categories (i.e. D1, D2, etc), see [1.6] and [4.2].
2) Not normally applicable, see [6.1].
3) The given capacities are given for a reinforced umbilical. For umbilicals without reinforcement and for power cables, etc. the capacities should be reduced.

4.6 Different protection methods

4.6.1 Concrete coating

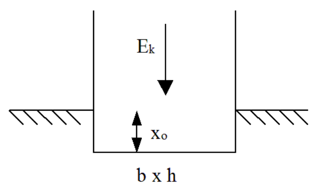
Concrete coating may be used to shield pipelines from potential impact damage. The energy absorption in the concrete coating is a function of the product of the penetrated volume and the crushing strength, *Y*, of the concrete. The crushing strength is from 3 to 5 times the cube strength for normal concrete density, and from 5 to 7 times the cube strength for lightweight concrete (Jensen, 1978, 1983). The cube strength varies typical from 35 to 45 MPa.

The kinetic energy absorbed for two different cases may be expressed as given in Equation (4) and Equation (5) (Jensen, 1978). Here, x_0 denotes the penetration, b is the breadth of the impacting object, h is the depth and D is the pipeline diameter.

For larger pipe diameters, Equation (5) may give non-conservative estimates and a denting shape more like Equation (4) should be considered.

If no other information exists, energy absorption of 40 kJ may be used for 45 mm normal density concrete coating subject to a 30 mm wide indenting object.

$$E_K = Y \cdot b \cdot h \cdot x_0 \tag{4}$$



$$E_K = Y \cdot b \cdot \frac{4}{3}\sqrt{D \cdot x_0^3} \tag{5}$$

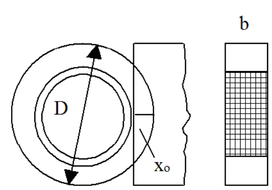


Figure 4-2 Impact in concrete coating

4.6.2 Polymer coating

Polymer coating may be used to protect from potential damage. Polymer coatings normally consist of a combination of several layers of different thickness and material properties. Experimental results are necessary in order to determine the potential absorption of energy for a given coating.

If no other information exists the energy absorption capacities given in Table 4-4 may be used.

Table 4-4 Energy absorption in polymer coating

Type of coating	*Energy absorption*
Corrosion coating with a thickness of maximum 3 – 6 mm.	0 kJ

Type of coating		*Energy absorption*
Thicker multi-layer coating (typical insulation coating with varying thickness)	6-15 mm	~5 kJ
	15-40 mm	~10 kJ
	>40 mm	~15 kJ
Mechanical protection systems (e.g. Uraduct)		5 – 10 kJ

If polymer coating is to be used as protection against specific design loads, (i.e. trawl board impact loads) the protection effect should be documented separately.

4.6.3 Gravel dump and natural backfill

Gravel cover is the most common protection method for pipelines. Specific guidance on energy absorption in gravel and natural backfill can be found in DNVGL-RP-F114.

Effective protection against dragged commercial ship anchors can be obtained by burying the pipeline. The required depth will depend on the size of the anchors of the passing ships and the local soil conditions, i.e. how deep anchors will penetrate.

4.6.4 Other protection methods

Table 4-5 gives a short description of other protection methods and the assumed lower bound impact capacity.

Table 4-5 Other protection methods

Method	*Description*	*Impact resistance*
Concrete blankets	Concrete blankets are well suited for low energy impacts (e.g. trawl board impacts). In general, individual cones of concrete have only limited impact capacity (in the order of 3 kJ), however several cones may be activated during an impact. Note that the stability of such blankets need yo be confirmed.	5 – 20 kJ
Sand bags	Sand bags are normally used to build artificial supports. Can be used for protection.	5 – 10 kJ (assumed)
Bundles	The bundle will act as an effective protection against impact loads. The energy absorption can be calculated as for a bare steel pipe, however the damage classification will be changed. The only critical failure will normally be leakage. Special attention should be made to towheads and to intermittent bulkheads.	Acc. to equation (3)
Pipe-in-pipe	Similar to bundles. Special attention should be made to intermittent bulkheads.	Acc. to equation (3)
Tunnel structures, nearby protection structures	Tunnel structures are normally introduced in order not to restrain pipeline movements. Tunnel structures can be made up with a variety of geometry and material. Thus almost any required capacity level can be obtained.	Varies, normally at least 50 kJ
Trenching	Trenching without backfilling will have a positive but limited effect against dropped objects, ships sinking, etc, as these will reduce the possibility to hit the pipeline/ umbilical depending on the width of the trench and the size of the impacting object. (i.e. only direct hits will be accounted for)	N.A.

SECTION 5 FAILURE FREQUENCY

5.1 Introduction

In order to assess the pipeline/umbilical risk from accidental loading, it is necessary to establish the frequency of such event. The assessment can be approached deterministically (quantitative) by considering frequency of exposure, drop frequency and probability of impact, or heuristically (qualitative) through the approach of generic data based on operator experience.

The quantitative approach requires a significant amount of information regarding the field specific activities and the system. This method is applicable to activities which are regularly performed, e.g. crane activities, and where operational experience exists.

For irregular activities, such as emergency anchoring, a more general evaluation may be the only means to assess the frequency.

The various input parameters are given in the following sections. The procedure to establish the failure frequency for dropped objects from cranes is detailed described in App.A.

5.2 Crane activity

5.2.1 Drop probability

The drop frequency is based on the accident data issued by the UK Department of Energy covering the period 1980-86[1] (DNV 1996b). During this period, 81 incidents with dropped objects and 825 crane years are reported. The number of lifts in the period was estimated to 3.7 million, which corresponds to 4.500 lifts to/from vessel per crane per year. This gives a dropped object probability of $2.2 \cdot 10^{-5}$ per lift. For lifts above 20 tonnes the drop probability has been estimated to $3.0 \cdot 10^{-5}$ per lift. The frequency is further split between fall onto deck (~70%) or into the sea (~30%).

Lifts performed using the drilling derrick are assumed to fall only in the sea, and with a dropped loads frequency as for ordinary lifts with the platform cranes, i.e. $2.2 \cdot 10^{-5}$ per lift.

The data show that the frequency of losing a BOP during lowering to or lifting from a well is higher than for other typical crane lifts. A frequency of $1.5 \cdot 10^{-3}$ per lowering or lifting operation is proposed used (SikTec, 1992). For the last part of the lift, when the BOP is directly above any vulnerable parts, a significantly lower probability of a drop is assumed.

The proposed dropped object frequency is given Table 5-1. It is possible to refine these estimates for given operations considering the experience with individual crane types and specific operating conditions. The frequency of a crane or crane boom falling into the sea is from $4.4 \cdot 10^{-7}$ to $6.7 \cdot 10^{-7}$ per lift.

Table 5-1 Frequencies for dropped objects into the sea

Type of lift	*Frequency of dropped object into the sea (per lift)*
Ordinary lift to/from supply vessel with platform crane < 20 tonnes	$1.2 \cdot 10^{-5}$
Heavy lift to/from supply vessel with the platform crane > 20 tonnes	$1.6 \cdot 10^{-5}$
Handling of load < 100 tonnes with the lifting system in the drilling derrick	$2.2 \cdot 10^{-5}$
Handling of BOP/load > 100 tonnes with the lifting system in the drilling derrick	$1.5 \cdot 10^{-3}$

[1] Detailed dropped object data are available for this period. No more recent data are yet available in sufficient detail to be used in this methodology.

5.2.2 Object excursion and hit probability

The object excursion in water is extremely dependent on the shape and weight of the object. Long slender objects, e.g. pipes, may experience an oscillating behaviour, see Aanesland (1987) and Figure 5-1, whereas massive, box-like objects will tend to fall more or less vertical.

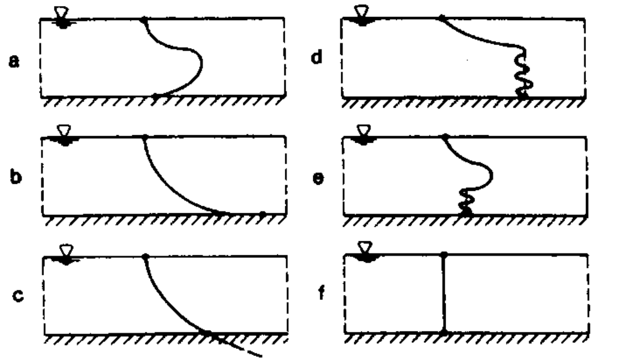


Figure 5-1 Observed fall-patterns for dropped pipe joints in water (Aanesland, 1987)

The actual fall-pattern for a pipe is dependent on the entry angle into the sea, however patterns a), d) and e) in Figure 5-1, are dominant and found for most entry angles.

The following values are recommended for use in calculations of the object excursion on the seabed. The object excursions on the seabed are assumed to be normal distributed with angular deviations given in Table 5-2.

The normal distribution is defined as:

$$p(x) = \frac{1}{\sqrt{2\pi}\,\delta} e^{-\frac{1}{2}\left(\frac{x}{\delta}\right)^2} \qquad (9)$$

where:

$p(x)$ = probability of a sinking object hitting the sea bottom at a distance x from the vertical line through the drop point.

x = horizontal distance at the sea bottom (metres)

δ = lateral deviation (metres), see Table 5-2 and Figure 5-2.

Table 5-2 Angular deviation of object category

No	*Description*	*Weight (tonnes)*	*Angular deviation (α) (deg)*
1	Flat/long shaped	< 2	15
2		2 – 8	9
3		> 8	5
4	Box/round shaped[1]	< 2	10
5		2 – 8	5
6		> 8	3
7	Box/round shaped	>> 8	2
1) A spread on the surface before the objects sinks is included.			

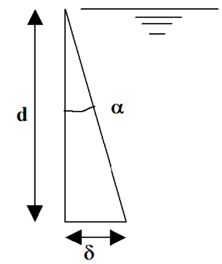


Figure 5-2 Symbols used in equation (9)

The probability of a sinking object hitting the seabed within a distance *r* from the vertical line through the drop point is then

$$P(x \le r) = \int_{-r}^{r} p(x)dx \tag{10}$$

The actual extent of the vulnerable items on the seabed, e.g. pipeline, within each ring can easily be incorporated by dividing the probability in several "rings", see Figure 5-3. The probability of hit within two circles around the drop point, $P_{hit,r}$ with inner radius r_i and outer radius, r_o, can be found by

$$P_{hit,r} = P(r_i < x \le r_o) = P(x \le r_o) - P(x \le r_i) \tag{11}$$

The breadth of each ring can be taken at 10 metre intervals. The hit probabilities within each of these rings may then be calculated for different deviation angles and the actual sea depth.

Guidance note:

Special attention should be given to risers and in particular vertical sections of risers. For risers, any vertical sections will complicate the hit calculations. A way of calculating the probability of hit to a riser is to:

1) Split the riser into different sections (i.e. normally into vertical section(s) and horizontal section(s)), and
2) Calculate the hit probability of these sections. The final probability is then found as the sum of all the probabilities for the different sections.

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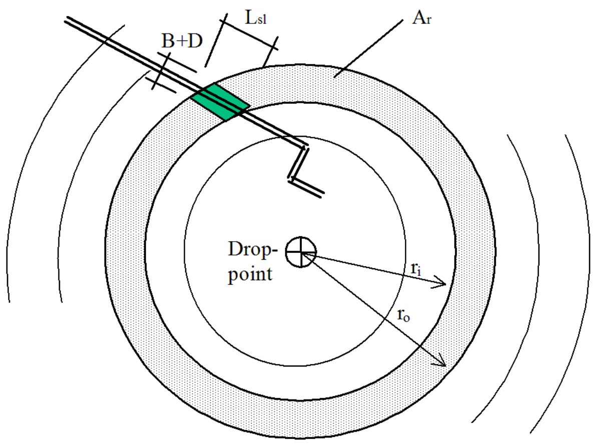

Figure 5-3 Probability of hit within a ring, defined by inner radius, r_i, and outer radius, r_o, from the drop point

Within a certain ring, the probability of hit to a pipeline or umbilical with an object, $P_{hit,sl,r}$, can be described as the exposed area which gives a hit within a ring divided on the total area of the ring, multiplied with the probability of hit within the ring, see Equation (12).

$$P_{hit,sl,r} = P_{hit,r} \cdot \frac{L_{sl} \cdot (D + B/2 + B/2)}{A_r} \tag{12}$$

where:

$P_{hit,sl,r}$	=	probability of hit on subsea line (sl) within a certain ring, *r*
$P_{hit,r}$	=	probability of hit within the ring, equation (11)
L_{sl}	=	length of subsea line within the ring (m)
D	=	diameter of subsea line (m), see Figure 5-4
B	=	breadth of falling object (m), see Figure 5-4
A_r	=	area within the ring (m^2), see Figure 5-3.

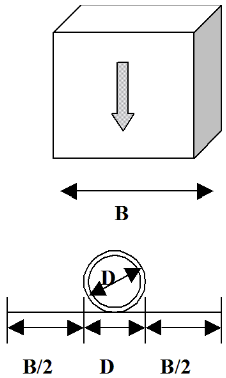

Figure 5-4 Definition of hit area

For containers and massive objects, *B* can be set to the average of the two shortest sides, and for tubular objects, *B* can be set equal to the diameter for front impact and equal to the length for side impacts.

Guidance note:

By including the inclination of the tubulars the hit area will increase. However, including impacts from horizontal oriented tubulars, the capacity evaluations given in Sec.4 may be conservative as they initially only consider knife edge loading.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Initially, one drop point per crane can be chosen. This is normally taken to be located between the loading zone for the supply vessels and the lay-down area(s) on the platform. Alternatively, several drop points may be used to describe the crane activity in details.

Pipes stacked and lifted together should be considered as one lift, however the hit probability should be multiplied by the number of pipes in the stack.

5.2.3 Deep water applications

When considering object excursion in deep water, the spreading of long/flat objects will increase down to approximately 180 metres depth. From 180 metres and further down the spreading does not increase significantly and may conservatively be set constant (Katteland and Øygarden, 1995). Note also that for deep waters, the spreading of objects on the seabed does not necessarily follow the normal distribution, see Katteland and Øygarden, (1995).

5.2.4 Effect of currents

The effect of currents also becomes more pronounced in deep water. The time for an object to reach the seabed will increase as the depth increases. This means that any current can increase the excursion (in one direction). At 1000 metres depth, the excursion has been found to increase 10-25 metres for an average current velocity of 0.25 m/s and up to 200 metres for a current of 1.0 m/s (Katteland and Øygarden, 1995).

The effect of currents may be included if one dominant current direction can be identified. This can be applicable for rig operations over shorter periods, such as during drilling, completion and intervention above subsea wells. However, for a dropped object assessment on a fixed platform, seasonal changes in current directions can be difficult to incorporate. Note also that the current may change direction through the water column for large water depths. If applicable, this should be accounted for.

The effect of currents should be considered when establishing a “safe distance” away from lifting activities. Furthermore, a conservative object excursion should be determined, including also consideration of the drift of the objects before sinking, uncertainties in the navigation of anchor handling vessel, etc.

5.3 Energy calculation

5.3.1 Kinetic energy

The kinetic energy of a dropped object depends on the mass and velocity of the object. Furthermore, the velocityof the immersed object depends on the shape of the object and the weight in water.

The terminal velocity is reached when the object is in balance with respect to gravitation forces, displaced volume and flow resistance. After approximately 50-100 metres, a sinking object will usually have reached its terminal velocity. When the object has reached this balance, it falls with a constant velocity, i.e. its terminal velocity. This can be expressed by the following equation:

$$(m - V \cdot \rho_{water})g = \frac{1}{2} \cdot \rho_{water} \cdot C_D \cdot A \cdot v_T^{\,2} \tag{13}$$

where:

m	=	mass of the object (kg)
g	=	gravitation acceleration (9.81 m/s^2)
V	=	volume of the object (the volume of the displaced water) (m^3)
ρ_{water}	=	density of water (i.e. 1025 kg/m^3)
C_D	=	drag-coefficient of the object
A	=	projected area of the object in the flow-direction (m^2)
v_T	=	terminal velocity through the water (m/s).

Guidance note:

For riser calculations, it should be noted that the terminal velocity of objects hitting the riser close to the surface is hard to predict The velocity could either be higher or lower than the terminal velocity depending on the velocity the objects has as it hits the surface and how the objects penetrate the surface, thus giving higher or lower kinetic energy. In lieu of more detailed information, the objects can be assumed to have a velocity equal to the terminal velocity at all depths below 50 metres and equal to the velocity in a 30-metre drop in air for depths less than 50 metres.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The kinetic energy of the object, E_T, at the terminal velocity is:

$$E_T = \frac{1}{2} \cdot m \cdot v_T^{\,2} \tag{14}$$

Combining these to equations gives the following expression for the terminal energy:

$$E_T = \frac{m \cdot g}{C_D \cdot A} \cdot \left(\frac{m}{\rho_{water}} - V \right) \tag{15}$$

In addition to the terminal energy, the kinetic energy that is effective in an impact, E_E, includes the energy of added hydrodynamic mass, E_A. The added mass may become significant for large volume objects as containers. The effective impact energy becomes:

$$E_E = E_T + E_A = \frac{1}{2}(m + m_a) \cdot v_T^2 \tag{16}$$

where m_a is the added mass (kg) found by $m_a = \rho_w \cdot C_a \cdot V$.

Tubulars shall be assumed completely filled with water unless it is documented that the closure is sufficiently effective during the initial impact with the surface, and that it will continue to stay closed in the sea.

It should be noted that tubular objects experiencing an oscillating behaviour will have constantly changing velocity, and it has been observed that for 50% of the fall-time the object have a velocity close to zero (Katteland and Øygarden, 1995).

5.3.2 Drag and added mass coefficients

The drag and added mass coefficients are dependent on the geometry of the object. The drag coefficients will affect the object's terminal velocity of the object, whereas the added mass has influence only as the object hits something and is brought to a stop. Typical values are given in Table 5-3.

Table 5-3 Drag coefficients

Category no.	*Description*	C_d	C_a
1,2,3	Slender shape	0.7 – 1.5	0.1 – 1.0
4,5,6,7	Box shaped	1.2 – 1.3	0.6 – 1.5
All	Misc. shapes (spherical to complex)	0.6 – 2.0	1.0 – 2.0

It is recommended that a value of 1.0 initially be used for C_d, after which the effect of a revised drag coefficient should be evaluated.

5.3.3 Projected area

For slender objects, the projected area in the flow direction is assumed to equal the projected area of the objects when tilted at a certain angle. This means that the projected area of a pipe is:

$A_{pipe} = L \cdot D \cdot \sin x°$ (where $x^o \in [0, 90]$ deg, measured from the vertical)

As shown in Figure 5-1, a pipe will constantly change direction when falling, and so the projected area will also change. A uniform distribution of the angle should be used, or alternatively the angle may be taken as 45° for object categories 1, 2, and 3, respectively. Other objects are assumed to sink in such a way that the projected area equals the smallest area of the object.

5.3.4 Energy versus conditional probabilities

If accurate information is not available, Table 5-4 may be used for energy estimates. Table 5-4 gives a suggested split of the object's energy into energy bands with a conservative conditional probability of occurrence. The division for the conditional probabilities is proposed for a pipeline with normal protection requirement, and a normal distribution of the impact energies. For pipelines that are required to resist high impact energies and for which the share of objects that give high impact energies is significant, a refinement of the energy groups in the upper range should be considered.

Table 5-4 Conditional probabilities of impact energies (see notes)

Description		*Energy band (kJ)*[8]					
		< 50	*50 – 100*	*100-200*	*200-400*	*400 – 800*	*> 800*
Flat/long shaped[9]	< 2 tonnes [1]	30%	18%	14%	12%	11%	15%
	2 – 8 tonnes [2]	5%	8%	15%	19%	25%	28%
	> 8 tonnes [3]	-	-	10%	15%	30%	45%
Box/round shaped	< 2 tonnes [4]	50%	30%	20%	-	-	-
	2 – 8 tonnes [5]	-	20%	30%	40%	10%	-
	> 8 tonnes [6]	-	-	-	-	70%	30%
Box/round shaped	>> 8 tonnes [7]	-	-	-	-	30%	70%

Description	*Energy band (kJ)*[8]					
	< 50	*50 – 100*	*100-200*	*200-400*	*400 – 800*	*> 800*

1) The distribution is made based on the following assumptions:
   Only (open) pipes included.
   The objects weigh 0.5, 1.0 and 1.5 tonnes, with 1/3 of all objects within each weight.
   The angle at the surface is assumed equally distributed from 0 – 90 degrees.
   The terminal velocity is assumed linear from minimum to maximum for 0 and 90 degrees respectively.
   The length of the pipes is approximately 12 m.
2) The distribution is made based on the following assumptions:
   Only pipes included.
   The object weight is assumed equally distributed from 2 to 8 tonnes.
   The angle at the surface is assumed equally distributed from 0 – 90 degrees.
   The terminal velocity is assumed linear from minimum to maximum for 0 and 90 degrees respectively.
   The length of the pipes is approximately 12 m.
3) The distribution is made based on the following assumptions:
   The object weights are assumed to be between 9 and 10 tonnes.
   Only pipes included.
   The angle at the surface is assumed equally distributed from 0 – 90 degrees.
   The terminal velocity is assumed linear from minimum to maximum for 0 and 90 degrees respectively.
   50% of the pipes have length of approximately 6 m, 50% have length ~12 m.
4) The distribution is made based on the following assumptions:
   Objects considered:
   The object weigh 0.5, 1.0 and 1.5 tonnes, with 1/3 of all objects within each weight.
   Container, baskets (large volume, low density) (30%), velocity ~ 5 m/s
   Equipment, e.g. (small volume, massive, high density) (70%), velocity ~10 m/s
5) The distribution is made based on the following assumptions:
   The object weight is assumed equally distributed from 2 to 8 tonnes.
   Objects considered:
   container, baskets (large volume, low density) (70%), velocity ~5 m/s
   equipment, e.g. (small volume, massive, high density) (30%), velocity ~10 m/s
6) The distribution is made based on the following assumptions:
   The object weighs 10 to 12 tonnes.
   Objects considered:
   container, baskets (large volume, high density) (70%), velocity ~5 m/s
   equipment, e.g. (medium volume, massive, high density) (30%), velocity ~10 m/s
7) The distribution is made based on the following assumptions:
   The object weigh above 8 tonnes
   equipment, e.g. (massive, high density), velocity ~5 to 10 m/s
8) Added mass is included.
9) For objects dropped from the derrick more objects will have a surface entry angle closer to 90 degrees.

5.3.5 Hit frequency versus energy

The frequency of hit can be estimated based on the number of lifts, the drop frequency per lift and the probability of hit to the exposed sections of the subsea lines. For a certain ring around the drop point, the hit frequency is estimated by the following:

$$F_{hit,sl,r} = N_{lift} \cdot f_{lift} \cdot P_{hit,sl,r} \tag{17}$$

where:

$F_{hit,sl,r}$	=	frequency of hit to the subsea line within a certain ring (per year)
N_{lift}	=	number of lifts
f_{lift}	=	frequency of drop per lift
$P_{hit,sl,r}$	=	probability of hit to a subsea line within a certain ring, see Equation (12).

The total frequency of hit to a subsea line is assessed by summarising the hit frequencies to the pipeline within each ring around the drop point.

Finally, within each of the capacity energy regions, see Sec.4, the frequency is added up and given a ranking as proposed in [5.8].

5.4 Ship traffic

5.4.1 Introduction

Risers may be subject to potential interference with ships. Potential ship collisions with riser should be determined to decide;

— whether to locate riser inside or outside a jacket
— whether a J-tube or caisson protection is needed, or
— the location of the riser versus loading operations.

Damage to riser from ship collisions that do not impair the platform integrity but may be of consequence to the riser should be evaluated to ensure that the riser is adequately protected.

Different methods are used to calculate the collision frequency for different vessel types. It is not the type of vessel, but the way the vessels traffic the area around the installation that influences the selection of the calculation method.

An assessment of the frequency and the associated kinetic energy of ship collisions damaging the riser must be based on ship traffic data, type of vessels and geometric evaluations.

The procedure for estimating the frequency of collision, F_{Coll_Riser}, between a riser at the installation and a vessel is described by the equation:

$$F_{Coll\_Riser} = N \cdot P_1 \cdot P_2 \cdot P_3 \cdot P_{riser} \tag{18}$$

where:

N = number of ships involved in a specific activity potentially threatening the installation/riser, i.e. passing ships in the lane per year, arrivals to the platform per year etc.

P_1 = probability of being on collision course, i.e. probability of being on collision per pass for passing ships in the lane, geometric probability of hitting the platform for ships during waiting in the safety zone (normally downwind of the installation) etc.

P_2 = probability of loss of control or faulty navigation onboard the ship

P_3 = probability of failure to warn or divert a ship on collision course, or ship "recovery" from its errant state. The cause for this may be absence from the bridge, absorbed in other activity, accident, asleep, alcohol or radar failure

P_{riser} = probability of hitting the riser given a hit with the platform. This probability may be found by geometrical evaluations of the platform and the riser.

If the last probability (riser collision frequency given a hit with the platform, P_{riser}) in equation (18) is omitted, then the result will be the probability of hitting just the platform. P_{riser} is further explained in [5.4.2.1] to [5.4.2.4]. Different scenarios are also described in these sections.

Ship collision damage to the riser can be due to collision between the riser and:

1) passing vessels; merchant vessel or a supply vessel to other fields
2) shuttle tanker approaching the platform field
3) fishing vessel
4) standby vessel
5) a supply vessel to the current field.

Any of these scenarios can occur while the vessel is:

— powered, or
— drifting.

The last scenario (i.e. supply vessel) can also occur while the supply vessel is:

— waiting to load/unload in the vicinity of the platform
— loading or unloading.

5.4.2 Calculation of the different collision probabilities

The different probabilities presented in equation (18) must be calculated with regard to the specific scenarios 1-5 listed in [5.4.1]. The basic principles for these calculations are described in the subsequent sections. As the riser will represent only a fraction of the platform, the probability of hitting the riser will be smaller than hitting the platform. The probability of hitting the riser given a hit on the platform, P_{riser}, must be based on geometrical evaluations of the installed riser.

Guidance note:

Geometrical evaluations include the riser location, size and configuration. For instance, flexible risers will normally have a steeper path down to the seabed compared with metallic catenary risers. This means that a larger section of the metallic catenary riser is exposed to vessel impact (from a specific direction). Further, the effect of shielding should be accounted for and effects like the vessel may hit another installation or a bridge between two installations and thus the hit energy may be reduced and the course may be changed.

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Given a hit on the riser, the result may be a leak or full bore rupture, but the extent of the damage to the riser is also dependent on the type of protection, if any.

The method described in the following sections is based on a collision example with a riser running eastwards from the underside of a platform, see Figure 5-5. It must be stressed that the calculation for this set-up will be valid only for this particular configuration and adaptations to other studies and configurations should be done only after careful evaluation.

The overall frequency of collision with the riser is found by adding together the frequencies for the different scenarios as described in the following sections.

5.4.2.1 Collision calculations for passing vessels

Merchant vessel routes will pass in dedicated lanes depending on the destination. This will also apply to shuttle tankers to other installations. Vessel routes outside 10 nm will normally give negligible contribution to the collision risk.

Calculations must be performed for each vessel route and then the results are summed to find the total frequency of hits from the passing vessels. Collisions between offshore installations and ships under power, running in a distinct direction, are described by the equation (18) where the different variables will be:

N = number of ships passing in the ship lane per year

P_1 = probability of being on collision course per pass

P_2 = probability of loss of control onboard the ship, when on collision course per pass, typically specified by a minimum time period of 20 min.

P_3 = probability of failure to warn or divert a ship on collision course, or ship "recovery" from its errant state

P_{riser} = probability of hitting the riser given a hit with the platform.

P_1 is often called "geometric collision probability". Merchant vessels will usually sail in dedicated lanes during passage from one destination to another. The location of the ships within these lanes is assumed to be normal distributed. This is illustrated in Figure 5-5. P_1 is given by:

$$P_1 = D \cdot \frac{1}{\sqrt{2\pi\delta}} \cdot e^{-\frac{1}{2}\left(\frac{x}{\delta}\right)^2} \quad (19)$$

where:

D = collision diameter = $W_a + B_{vessel}$, where W_a is apparent platform width and B_{vessel} is ship beam.

δ = standard deviation (normally given together with the ship lanes)

x = distance from centre of lane to the installation.

With respect to P_2, there are normally six different reasons why a vessel will continue on a course towards an installation. These are:

— absence of crew on bridge
— crew absorbed in other tasks
— crew asleep
— accident
— alcohol/drug abuse
— radar failure/poor visibility.

P_2 is normally set to $2 \cdot 10^{-4}$, which is confirmed by Fujii et. al. (1974, 1984) and Solem (1980).

P_3 is dependent on contingency measures on the installation. Aspects that will decide this value are:

— standby vessel always stationed near the installation
— fog horns and navigational aid systems installed at the platform
— RACON (RAdar beaCON), see [5.4.5], installed.

Fog horns and strobelights are mounted on nearly all offshore installations in the North Sea, and do not influence the initial probability P_3.

In case of an errant vessel on collision course, a standby vessel, if present, will go towards the errant vessel and use light and sound to alert the vessel. A standby vessel will also be able to identify the errant ship and therefore the effect of radio calls will be significant.

P_3 is normally set to 1.0 without a standby vessel present and 0.14 with a standby vessel present. If RACON is installed P_3 will be 0.9 without a standby vessel present. If both RACON and a standby vessel are present the probability will be 0.13, (Fujii, et. al., 1984).

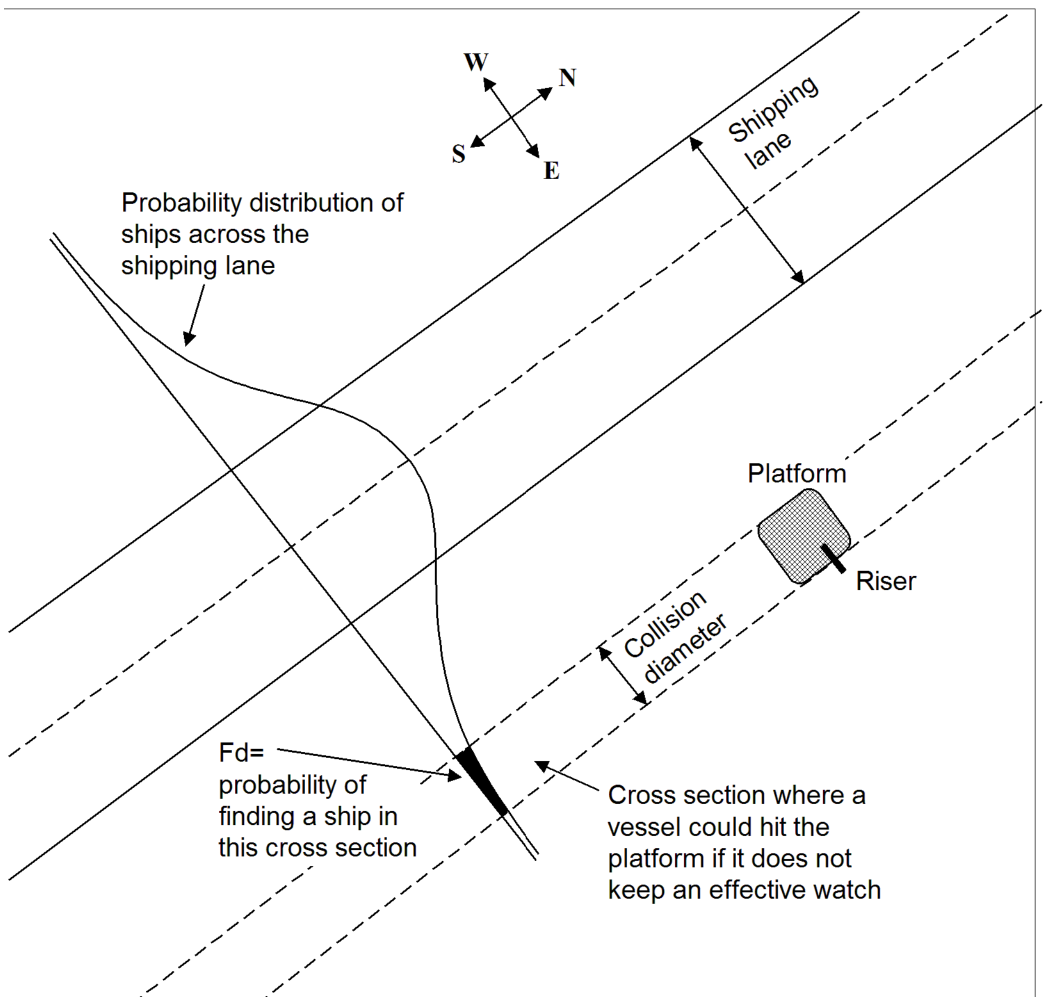

Figure 5-5 Normal distributed geometric collision probability

P_{riser}, the probability of hitting the riser given a hit on the platform, is calculated by assuming that there is a relationship between the probability of hitting the installation and the probability of hitting the riser.

If, for instance, a riser is connected to the east side of the platform and running eastwards, the probability of hitting the riser may be equal from north and south side. The probability of hitting the riser will be lower from the west side of the installation, because the exposed area of the riser will be smaller and the platform structure will hinder the vessels from reaching the riser. From the east side, the supporting structure of the platform will not have any influence on the probability of impact. For all cases (north, south, east and west) the exposed area will be small compared to the platform.

A geometrical evaluation of the probability of impact with the riser, given collision with the platform, is given by:

$$P_{riser\_i} = \frac{(L + B_{vessel}) \cdot \alpha}{W_a + B_{vessel}} \tag{20}$$

where:

i	=	north, south, east, or west
L	=	exposed width of riser
W_a	=	platform width of the current side at sea level
α	=	reduction factor depending on support structure interference
B_{vessel}	=	width of vessel.

The width of the vessel, B_{vessel}, is added to the diameter of the installation as the vessel must pass a minimum of half of the vessel width on either side of the installation to avoid a collision.

The water depth where the riser is vulnerable to a ship depends on the ship type, but a water depth of at least 5 metres should be considered as a vulnerable section.

Equation (20) describes the geometrical relationship between riser and platform for a vessel coming from a particular direction. To account for the four directions, north, east, south and west, it is necessary to summarise the geometrical relationship for all the directions before this is multiplied with the frequency of hitting the platform. The frequency of hitting only the platform is described by the equation:

$$F_{Hit\_Platform} = N \cdot P_1 \cdot P_2 \cdot P_3 \tag{21}$$

If the probability of hitting the platform is assumed to be equal for each side (this may not always be the case), the total frequency of hitting the riser will be:

$$F_{Coll\_Riser} = F_{Hit\_Platform} \times \left(\frac{1}{4} \sum_{j=Riser\_i} P_j \right) \tag{22}$$

Riser_i is the geometrical relationship between the platform and the riser in each direction, e.g. north, east, south and west, see Equation (20).

5.4.2.2 Collision calculations for random distributed vessels

For ships that are distributed randomly near the installation and moving in random directions, as is typical for fishing activities, the frequency per year of collision with the riser may be calculated as (Technica, 1987):

$$F_{Coll\_Riser} = (365 \cdot 24 \cdot V \cdot D \cdot \rho) \cdot P_2 \cdot P_3 \cdot P_{riser} \tag{23}$$

where:

V = ship speed [km/h]

D = collision diameter of installation [km]

ρ = density of ships [per square km]

P_2 = probability of loss of control onboard the ship for a specific minimum of time period (20 minutes) will normally have the same value as in [5.4.2.1], (Fujii et. al., 1974 and 1984 and Solem, 1980)

P_3 = probability of failure of warning or diverting a ship on collision course, either by contingency measures effected on the platform, or on the approaching vessel. Will normally have the same value as in [5.4.2.1]

P_{riser} = probability of hitting the riser given a hit with the platform.

The basis for Equation (23) are:

— The term 365 · 24 · V gives the total distance covered by a vessel travelling at its transit speed normalised to 1 year.
— Multiplication by vessel density gives the total distance covered by all vessels in the vicinity of the platform.
— Multiplication by the platform diameter gives the fraction of those vessels heading towards the platform.
— The terms P_2 and P_3 are equivalent to those given in Equation (18).
— P_{riser} is calculated according to Equation (20) in [5.4.2.1].

5.4.2.3 Collision risk of standby vessels

For standby vessels, only drifting collision is normally included. The vessel does not move as a vessel that passes or visits the installation. If the vessel is loading/offloading from an installation, it will act as a supply vessel, and the risk should be included in supply vessel collisions.

A standby supply vessel has redundant machinery. The frequency of machinery breakdowns should thus be somewhat lower than the frequency for vessels with one engine. On most supply vessels, the two redundant engines normally have several minor machinery systems that are common for both engines. The risk reducing effect is thus assessed to be 30 % by DNV (1998). For single engine tankers operating in the North Sea, the machinery breakdown frequency is $2.0 \cdot 10^{-5}$ per hour (DNV, 1998). A typical machinery breakdown frequency for supply vessels is thus $1.4 \cdot 10^{-5}$ per hour. This frequency corresponds to a machinery breakdown of a certain duration. For most breakdowns, the machinery will be restarted within a few minutes and hence these breakdowns are not included in the frequencies given above.

A standby-vessel will normally be situated close to the installation. It is conservatively assumed that the vessel moves independently of the weather conditions, and thus has equal probability of drifting in all directions. This is a conservative assumption, as a standby-vessel without a special duty normally will be downstream of the installation.

The annual frequency for a standby vessel collision with the riser may be expressed by the following equation:

$$F_{coll,wait} = N \cdot P_1 \cdot (P_2 \cdot t) \cdot P_3 \cdot P_{riser} \qquad (24)$$

where:

N	=	number of standby vessels (per year), normally one
P_1	=	geometric probability of hitting the platform, $D/(2\pi R)$
D	=	typical diameter of installation, plus the average of the width and length of a typical ship [m], $W_a + ½(B_{vessel}+L_{vessel})$
R	=	radius of stand by zone (normally 1 km)
P_2	=	frequency of machinery breakdown per hour (typically $1.4 \cdot 10^{-5}$ per hour)
t	=	hours per year for vessel to be in the vicinity of the platform (8760 hrs for a whole year)
P_3	=	probability of failure to correct the situation. (Normally taken as 1, as machinery breakdowns included in P_2 need longer repair time than available)
P_{riser}	=	probability of hitting the riser given a hit with the platform, given by Equation (20).

A typical standby vessel is a supply vessel with length of 80 metres and displacement of 5000 tons. The kinetic energy of such a vessel is dependent on the drifting speed. The drifting speed is normally about 3-5 % of the wind speed. The maximum speed when a vessel is situated upwind for the installation is assumed to be as for a hurricane, 32.6 m/s. The maximum kinetic energy for a drifting supply vessel is thus 10 MJ.

5.4.2.4 Collision risk of supply vessel

Collision calculations between supply vessel and installation normally include the following scenarios:

a) collision with supply vessel that approaches the installation;
b) collision with passing supply vessel that is sailing to/from other installations;
c) collision with drifting supply vessel during loading/unloading or similar operations.

A) and B) are high energy collisions, and C) is a low energy collision. Shuttle tankers near to the installation will also be included in these categories, but the tonnage will be significantly larger.

The supply vessel activity will depend on the activity at the platform, i.e. start-up, normal operation etc.

The total frequency is calculated according to Equation (18), for which the input is described below.

High energy impacts (scenario A and B)

Modern navigational systems and procedures will ensure that the installation is not used as the final navigational target, and the probability of a collision course is limited (scenario A). Based on experience from similar studies of fixed installations, it is estimated that 10 % of the vessel approaching the installation is on collision course, which gives $P_1 = 0.1$. This value is somewhat high as the process for selection of final navigational target outside the installation is relatively new. For supply vessels using the installation as final navigational target, the probability of being on collision course is 1.0.

The probability of loss of control onboard the supply vessel given collision course is found to be $P_2 = 2.7 \cdot 10^{-6}$ per approach, based on data from Technica (1987). This probability is significantly lower than for merchant vessels, as the crew onboard a supply vessel approaching an installation is aware that the installation exists. The crew on a supply vessel is thus likely to be more observant than the crew on a passing merchant vessel.

For P_3, the contingency arrangements described in [5.4.2.1] are also valid for the supply vessels sailing to/from other installations (scenario B)

Assessments of supply vessels sailing to other installations should also be taken into account.

Low energy impacts (scenario C)

Collision can occur during loading and offloading of the supply vessel. Low energy collision during loading or unloading will follow the same methodology as described in the previous [5.4.2.3]. Supply vessels are designed for several different operations, and have large power compared to size. During poor manoeuvring or in bad weather conditions, the vessel can hit the installation during loading and unloading.

A technical failure will lead to only a relatively slow drifting of the vessel into the installation and hence this scenario will not cause impact energies large enough to threaten the integrity of the platform structure, but can cause damage to the riser.

P_{1_i} may be expressed as the probability of hitting a specific side, i, of the platform with regard to the wind directions given a technical failure or faulty manoeuvring. P_1 will therefore be the sum of the probabilities of hitting each side of the platform. Operations in winds exceeding a certain wind force will normally be cancelled.

P_2 will represent technical failure and faulty manoeuvring. The normal failure rate of a single ship engine failure is $2 \cdot 10^{-5}$ per hour (Technica, 1987). Modern supply vessels will have a lower probability of engine failure.

During loading/unloading, the close location and short time from incident to a possible impact means that prevention of a failure situation cannot be expected ($P_3=1$).

If accurate data is not available, the probability of low impact collisions may be found with generic data. A generic collision probability of $6.0 \cdot 10^{-4}$ per visit can be used for impacts with steel jackets (J.P. Kenny, 1998). Note that this probability constitutes the product of P_1, P_2 and P_3. It is assumed that the frequency for collision with other platform types is about the same.

Maximum manoeuvring speed for supply vessels is normally given as 2.8 m/s. Since the collisions are most likely in the longitudinal direction, an added-mass coefficient of 1.1 (10%) (DNV, 1988) is chosen. For supply vessels with 5000 tons displacement, the maximum collision energy during loading and unloading is 22 MJ.

The probability, P_{riser}, of hitting the riser, given a hit on the platform while loading/unloading, is calculated following a different procedure than that used for passing vessels. Supply vessels are located stationary close to the platform while loading/unloading and are normally positioned upwind of the platform with the bow in the wind direction.

Guidance note:

Figure 5-6 shows a typical situation when loading/unloading. The probability of hitting the platform will be in a 180° sector depending on wind direction. The exposed area with a probability of hitting the catenary riser will be smaller, i.e. 20° in this example, see Figure 5-6. (In the figure the centre of the vessel have been used giving an additional width of half the vessel breadth so that the vessel can pass). The probability of hitting the riser will then be a fraction of: 20/180 = 0.11 of the probability of hitting the platform. (It is here assumed that the exposed riesr area is close to the surface and therfore may be hit by a ship)

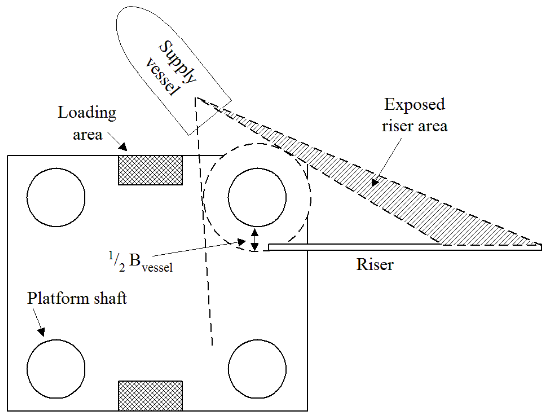

Figure 5-6 Catenary riser area exposed to supply vessel collision during loading/unloading

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5.4.3 Impact calculation methodology

The vessel types that can hit the platform represent different weight categories and velocities, giving different hit energies. A division into different kinetic energies and vessel types is therefore relevant. Risers are normally very fragile, and a collision with a vessel will most likely result in severe damage or rupture.

For a direct hit or impact, the kinetic energy is given by the following equation:

$$E = \frac{1}{2} \cdot (M + a) \cdot V^2 \qquad (25)$$

where:

M = displacement (kg)

a = hydrodynamic added mass (kg), for bow and stern impact it is 10% of the displacement and for sideways impact it is 40% of the displacement with drifting vessels (DNV, 1988)

V = ship speed (m/s).

Guidance note:

The corresponding kinetic energy of a 2500 ton vessel and with a velocity of 4 knots will be:

Bow and stern impacts:

$E = 1/2 \cdot (1.1 \cdot 2.5 \cdot 10^6) \cdot (4 \cdot 0.514)^2 = 5.8$ MJ

Side impacts:

$E = 1/2 \cdot (1.4 \cdot 2.5 \cdot 10^6) \cdot (4 \cdot 0.514)^2 = 7.4$ MJ

For collisions with the platform, the vessel itself may absorb some of the impact energy. For riser collisions this will normally not be the case.

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5.4.4 Total collision frequencies

To find the total frequency of collision between the riser and ship traffic, all the frequencies from different type of vessel activity, as described in the previous sections, can be presented in a tabular form according to impact energy. As an unprotected riser probably will experience a rupture when hit by a vessel, the necessity of dividing the probabilities into different energy classes may be discussed.

5.4.5 Risk reducing measures

The most important overall risk reduction measure is to avoid a collision with the platform. Further, for impacts with relatively low kinetic energies, i.e. 0 – 15MJ, installation of a collision net will reduce the probabilities of hitting a riser. Impacts during loading/unloading can therefore be reduced. However, as this activity will only contribute to some of the total probability of an impact with a riser, the cost benefit effect should be considered. Overall, the design of a riser and it's location relative to the platform will be an important consideration.

Measures that will decrease the risk of hitting the platform, P_3, are:

— RACON (RAdar beaCON): A device emitting a strong pulse when triggered by a nearby ship radar. This makes the installation easy to identify on the ship radars. RACON is assumed to reduce the P_3 for all vessel traffic except supply vessels at low speed in the vicinity of the platform.

— RADAR (ARPA): A radar with a competent operator and 24 hours watch where all ships are plotted and monitored when closer than a predetermined distance, typically 12 nm.

— Assignment of standby vessel: A dedicated standby vessel is assumed to reduce P_3 for all vessels except the supply vessels of low speed in the vicinity of the platform. The standby vessel will take action in situations in which a vessel on collision course is for instance 5 nm from the complex, and will give information on course, speed and size of the errant ship.

5.5 Simultaneous operations

Simultaneous operations are defined as work activities performed on a well or a subsea installation while production continues through the pipeline. The failure frequency should be established based on the whole operation and not isolated sub-operations. Previous operator experience and generic failure data will be the basis for frequency estimation.

The methodology applied in this recommended practice is not suitable for estimating the risk for an accident during critical, isolated operations such as BOP installation. The risk of such operations should be controlled by other methods such as HAZOP, although it should be noted that such worst-case evaluations normally establish only the consequence of an event and not the frequency.

5.6 Trawling

Trawling activity is usually concentrated in certain areas. If pipelines and umbilicals are routed in such areas the annual frequency of a trawl board hit will normally be very high, e.g. from 10^{-2} to 100 per km per year.

The failure frequency of the same order as the hit frequency unless the pipelines and umbilicals are protected against trawling.

If a pipeline is designed to withstand trawling, then the failure frequency is negligible (i.e. only minor damage to the protection). If not already designed, larger diameter pipelines (i.e. larger than 12”-14”) may be protected by coating to reduce the failure frequency. Smaller diameter pipelines, flexibles and umbilicals should be trenched, gravel dumped, etc.

Reference is made to DNVGL-RP-F111 for pipeline design against trawl interaction.

5.7 Anchor handling

5.7.1 Rig operations

A rig entering a new location and performing rig anchor handling poses a risk of external impact to pipelines and umbilicals. There is a risk related to a anchor chain falling onto a pipeline/umbilical or a drifting rig dragging an anchor over a pipeline/umbilical.

A rig is normally moored with eight anchors. Pipelines and umbilicals may cross below the anchor chain. An anchor chain that breaks may hit one pipeline or umbilical depending on the breaking point and on pipeline/umbilical route relative to the anchor chains.

It is proposed to assume a frequency of 0.01 breakage per year per anchor chain (DNV, 1997b). This is based on known anchor breakage events up to 1993 for offshore rigs and production vessels.

Guidance note:

The total duration of a drilling and completion operation is about 70 days, giving a frequency of 0.002 for breakage of one of the anchor chains during drilling and completion. The frequency for permanently moored platforms should be set individually, however it is assumed to be lower than the above.

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Further, a possible manoeuvring failure of the service vessels, which are handling the anchors during the anchoring operations, may cause an anchor to be dropped. If the service vessel is located above one pipeline, the pipeline can be hit. Safe distances to pipelines should be ensured during anchor handling.

The typical weight of a rig anchor is 12 tonnes. If an anchor is dropped during the lowering operation, the anchor may have a kinetic energy exceeding 800 kJ. The kinetic energy of a dropped anchor chain will be in the order of 1-5% of the kinetic energy of the anchor.

5.7.2 Dragged rig anchor

If more than one of the anchor chains breaks, the rig may drift off and there is a risk of impact to the flowlines by dragged anchor chains. According to Worldwide Offshore Accident Databank (DNV, 1996b), the statistical frequency of drifting rig is $6.4 \cdot 10^{-3}$ per rig year.

Guidance note:

This corresponds to a frequency of drifting rig of $1.2 \cdot 10^{-3}$ during a drilling and completion operation (total duration 70 days). The frequency of a failure in the pipeline or umbilical due to a dragged anchor will be less than drifting rig frequency depending on the anchor area relative to the pipeline or umbilical route.

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5.7.3 General shipping

Emergency anchoring due to drifting ship can represent a risk to subsea installations, where potential hazards are related to dropped anchors and dragged anchor/anchor chain. Shuttle tankers, supply vessels and commercial ships may come into a drifting situation. A stand-by vessel can usually change the drifting course of a ship.

The mass of an anchor is typically 10 tonnes for a shuttle tanker and 2 tonnes for a supply ship. Typical reasons for dropped anchor during an emergency situation are human error during the anchoring operation, failure of the chain braking system or loss of power supply to the chain braking system.

Dependent on the mass of the chain and the dragging length, a dragged anchor chain can endanger pipelines and umbilicals (i.e. abrasion of protection and pipe wall) in addition to the more dramatic hooking scenario.

The risk of emergency anchoring from shuttle tankers is generally low. Shuttle tankers are provided with a dynamic positioning system and the redundancy of the machinery is high. The likelihood of machinery failure is consequently lower for shuttle tankers than for other ships. Furthermore, it should be noted that loading of shuttle tankers is weather restricted, i.e. the tankers will usually stay at a safe distance from the installations during bad weather conditions.

Commercial shipping routes should also be evaluated to establish a relevant frequency of emergency anchoring hitting the pipeline. Distribution of the vessel sizes/classes should be established for relevant shipping lane(s) which crosses the pipelines. Given typical anchor size for various vessel classes, distribution of anchor size may be established from the vessel distribution. For the different anchor sizes the seabed penetration may be established for the local soil condition. By combining a generic frequency of emergency anchoring in the area of interest and the conditional frequency of anchor penetration, the required trenching depth of the pipeline can be established to satisfy the acceptance criteria.

Guidance note:

Commercial ships normally uses stockless anchors and the anchor size is determined based on the ships equipment number. The equipment number is a function of the ship displacement, the breadth, the freeboard and the profile area.

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5.8 Frequency ranking

Both a quantitative and qualitative evaluation may be used for a total evaluation of the pipeline protection effectiveness. In order to compare the frequency and risk of any of the relevant hazards, an individual ranking from 1 (low frequency) to 5 (high frequency) is proposed, see Table 5-5. Note, however, that the limits given in Table 5-5 may be adjusted to comply with case specific requirements.

The loading frequency is combined with the damage evaluation to derive at the failure frequency.

Note that the failure frequencies are given for the whole pipeline and as such the length of the pipeline shall not be decisive for the total failure frequency of the pipeline.

Table 5-5 Annual failure frequency ranking for one pipeline/umbilical

Category	*Description*	*Annual frequency*
1 (low)	Likelihood of event considered negligible.	$<10^{-5}$
2	Event rarely expected to occur.	$10^{-4} > 10^{-5}$
3 (medium)	Unlikely for a single pipeline, but may happen once a year given a large number of pipelines.	$10^{-3} > 10^{-4}$
4	Event individually may be expected to occur during the lifetime of the pipeline. (Typically a 100 year storm)	$10^{-2} > 10^{-3}$
5 (high)	Event individually may be expected to occur more than once during lifetime.	$>10^{-2}$

SECTION 6 CONSEQUENCE

6.1 Introduction

Potential consequences of accidental events to pipelines and umbilicals must consider human safety, economic loss and damage to the environment. Table 6-1 presents a matrix for identifying potential consequences for damage to pipelines and umbilicals.

Table 6-1 Identifying potential consequences for pipeline and umbilical damage

Pipeline contents	*Human safety*	*Environmental impact*	*Material damage*
Gas	Relevant	Normally not relevant[4]	Relevant
Condensate	Relevant	Relevant[1]	Relevant
Oil	Relevant	Relevant	Relevant
Water	Normally not relevant	Relevant[5]	Relevant
Umbilical	Normally not relevant[2]	Normally not relevant[2,3]	Relevant

1) Condensate normally disperses/evaporates quicker than oil. During storm conditions the condensate can be gone within hours. This means that leakage from a condensate pipeline is less likely to give significant environmental consequence to the environment.
2) Damage to an umbilical will normally not cause any consequence for humans or the environment. However, safety and environment should be considered if damage to an umbilical leads to failure in the subsea installation which in turn leads to a release.
3) Release of fluids from an umbilical will normally be a small amount and can normally be neglected.
4) Gas release can result in pollution if the gas contains injected chemicals or releases H_2S dissolving into the water.
5) The water may be processed water which contains substances dangerous to the environment.

6.2 Human safety

The human safety consequence of pipeline or umbilical failure should be established with regard to:

— personnel involved in work on the company's facilities (1st party)
— personnel outside the company's facilities who could be affected by the company's activities (3rd party).

There is usually very little human activity in the vicinity of pipelines. Pipeline releases at the platform approach or near subsea structures may have consequences for 1st party personnel on a platform or rig. In the pipeline mid-line zone, releases can endanger 3rd party personnel.

Only major release scenarios (i.e. category R2) from pipelines transporting gas can endanger personnel. A gas cloud nearby the platform or the rig can be ignited resulting in a ball of fire or an explosion. Ignition will only occur if the gas above the sea surface is of flammable concentration and possible ignition sources are present within this cloud.

The size and distribution of a gas cloud from a subsea pipeline release will be influenced by the depth, currents and prevailing winds. In addition, the composition of the gas will influence the cloud formation, as rich gas may form a cloud that does not rise but extend over a large area, whereas dry gas will rise rapidly. It is often difficult to accurately predict the outcome of such events, although it is possible to establish critical zones with major potential for harm to life.

In major release events, it may be assumed in 1-10 % of these events the gas release will ignite and a large number of persons onboard the rig or the platform will be exposed.

The following scenarios have potential for endangering 3rd party personnel:

— emergency anchoring

— pipe laying (when laying parallel pipes, damage to installed and producing pipelines can have potential impact on barge personnel).

The consequences for human safety may be classified as shown in Table 6-2. Note that categories 2 and 4 are not used for human safety consequence ranking.

Table 6-2 Safety consequence ranking

Category	*Description*
1 (low)	No person(s) are injured
2	(not used)
3 (medium)	Serious injury, one fatality (working accident)
4	(not used)
5 (high)	More than one fatality (gas cloud ignition)

6.3 Release to the environment

Environmental consequences should be established both for minor and for major release scenarios (i.e. R1 and R2). The environmental consequence of any leakage from damaged pipelines should consider polluting impacts to:

— eco-systems in the water, including seabed vegetation, plankton, fish and sea mammals such as whales and seals
— coastal environment, including beaches and coastal regions that either have great value as refuge for birds or contain extraordinary vegetation
— seabirds living or mating in the area, including birds of passage
— fish in fish farms and related industries in the area.

The environmental impact on the above are dependent on the:

— the amount and type of spillage
— the weather conditions, including wave heights, wind and current speed
— time to reach and amount to arrive at sensitive areas.

Environmental consequences are normally expressed as estimated time to achieve full recovery of the affected populations/areas. This will include evaluation of the different species' vulnerability to oil spillage, the effectiveness of the oil spillage preparedness measures in the area, etc.

An environmental consequence assessment of spillage as outlined above is both complex and time consuming. A much more general evaluation may be made by considering only the amount of release and relating this to the annual allowable spillage amounts in the acceptance criteria. This will implicitly account for the impacts on the environment. The amount categorisation given in Table 6-3 may be used as guidance.

Table 6-3 Spillage ranking

Category	*Description*	*Amount of release*
1 (low)	Non, small or insignificant on the environment. Either due to no release of internal medium or only insignificant release.	~ 0
2	Minor release of polluting media. The released media will decompose or be neutralised rapidly by air or seawater.	<1000 tonnes

Category	*Description*	*Amount of release*
3 (medium)	Moderate release of polluting medium. The released media will use some time to decompose or neutralise by air or seawater, or can easily be removed.	<10000 tonnes
4	Large release of polluting medium which can be removed, or will after some time decompose or be neutralised by air or seawater.	<100000 tonnes
5 (high)	Large release of high polluting medium which can not be removed and will use long time to decompose or be neutralised by air or seawater.	> 100000 tonnes

6.4 Economic loss

The economic consequence of any damage to pipelines can be classified with respect to the delay in production from a pipeline. The cost of production delay normally exceeds the actual cost of repairing the damage. However, both the cost of repairing and the cost of any delay in production delivery from affected fields must be included in the evaluation.

The economic consequences may be classified as stated in Table 6-4. It should be noted that variations between different projects can change the limits stated. Alternatively, the actual cost for production delay and repair may be used in the cost-benefit evaluations of the proposed protection design, and would affect the expression in favour of additional risk reduction measures, see also [2.7].

In general, repairing offshore pipelines is a time consuming affair. The work will normally take approximately one to three months to complete, as all work is performed subsea. The actual duration is however strongly dependent on time to mobilise, the efficiency of repair systems and the weather conditions. Typical repair operations that are planned prior to failure occurring are expected to take shorter time than the above estimate, whereas complex repair operations, e.g. bundle repair, are anticipated to take longer time.

Any potentially critical elements with respect to upholding the platform production (e.g. water injection lines, umbilicals) should be identified.

For umbilicals, only economic damage classification is normally relevant, as the tubing typically contains only a small amount of toxic liquids and will not normally endanger human safety.

Table 6-4 Economic consequence ranking

Category	*Description*	*Production delay/ downtime*
1 (low)	Insignificant effect on operation, small or insignificant cost of repair	0 days
2	Repair can be deferred until scheduled shutdown, some repair costs will occur.	<1 month
3 (medium)	Failure causes extended unscheduled loss of facility or system and significant repair costs. Rectification requires unscheduled underwater operation with pre-qualified repair system before further production.	1-3 months
4	Failure causes indefinite shutdown and significant facility or system failure costs. Rectification requires unscheduled underwater operation without pre-qualified repair system before further production. Or Failures resulting in shorter periods of shut down of major parts of (or all of) the hydrocarbon production for the field.	3-12 months

Category	*Description*	*Production delay/ downtime*
5 (high)	Total loss of pipeline and possibly also loss of other structural parts of the platform. Large cost of repair including long shut down of production. Or Failures resulting in shut down of the total hydrocarbon production for a longer period.	1-3 years

SECTION 7 RISK ASSESSMENT

7.1 General

The final risk assessment consists of coupling the relevant frequency rankings with the consequence rankings and then comparing the result against the acceptance criteria. Figure 7-1 gives an example, where the dark shaded areas indicate the defined total acceptance criteria where additional protection is required, see also [2.6].

If the risk level is not acceptable, then mitigation measures should be taken to reduce the risk, see [2.7]. The length of pipeline to be protected should be so that the overall risk of both the protected and the unprotected parts are acceptable.

Risk matrices should be established for

— each identified hazardous situation (i.e. dropped objects, trawling, etc.);
— each relevant location (i.e. mid-line zone, near platform or near subsea installations);
— each consequence (human safety, environmental impact and economic loss).

Note that normally only one of the hazardous situations will dictate the protection requirements. If several hazards give high risk then any cumulative effects, i.e. dependency between events should be accounted for so that the total risk level is acceptable. Alternatively, the acceptance criterion may be adjusted to account for such effects. Note that the same may be observed when splitting hazardous situations into numerous underlying specific events. In such cases the results could indicate acceptable risk levels for all specific events, however the correct cumulative risk could be unacceptable.

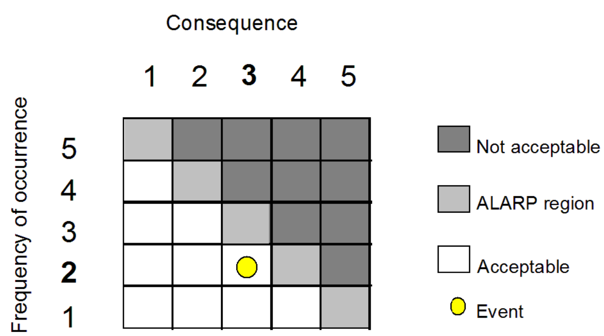

Figure 7-1 Example of risk matrix with acceptable risk level indicated

7.2 Uncertainty assessment

A risk assessment as outlined in this recommended practice is normally based on several assumptions. The main assumptions should be clearly stated and their effect on risk should be discussed or evaluated through sensitivity studies.

Sensitivity studies/evaluations should include:

— variations in load data
— variations in drop point
— variations in pipeline and umbilical capacity
— variations in consequences.

SECTION 8 REFERENCES

8.1 References

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APPENDIX A EXAMPLE OF RISK ASSESSMENT PROCEDURE FOR DROPPED OBJECTS

A.1 Introduction

This appendix gives an example of a detailed risk assessment of dropped objects on a 20-inch pipeline coming into a small platform. References to the recommended practice are stated where applicable.

The field layout with the pipeline approach and crane location is given in Figure A-1. Note that the crane can only work on the platform west side and the vessel approach is from the north. The pipeline exits the platform on the eastern side and continues north after about 40 metres.

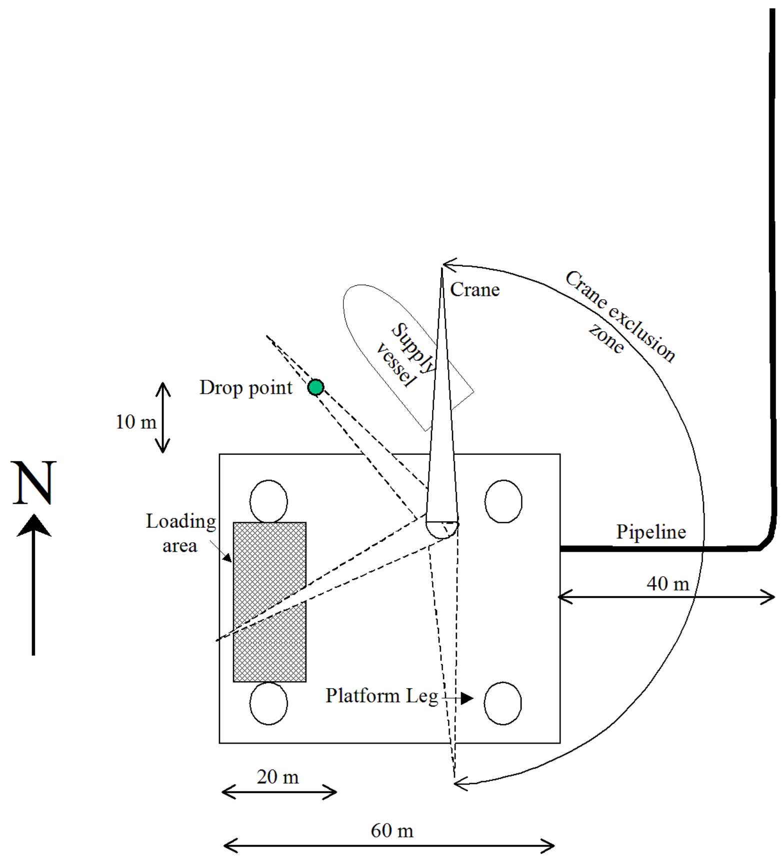

Figure A-1 Field layout.

A.2 Design basis

The following main data are chosen to demonstrate the use of this recommended practice:

Pipeline data:	
Outer diameter (D):	508 mm
Wall thickness (t):	18 mm
Yield stress (σ_y):	450 N/mm^2

Concrete thickness:	60 mm

Environmental data:

Water depth:	100 m

Acceptance criteria:

The acceptance criteria as given in the DNVGL-ST-F101 applies, i.e. the annual failure frequency shall be less than 10^{-5}, i.e. safety class high.

A.3 Categorization of objects ([3.1.1])

The platform has only one crane with a limited operational radius. The items lifted on an annual basis are given in Table A-1. For the simplicity of this example internal lifts are assumed to result in hit onto the platform and not into the sea.

Table A-1 Object classification of annual crane load data lifted to and from supply vessels

No	*Description*	*Weight in air (tonnes)*	*Typical objects*	*Number lifted per year*
1	Flat/long shaped	< 2	Drill collar/casing, scaffolding	700
2		2 – 8	Drill collar/casing	50
3		> 8	Drill riser, crane boom	5
4	Box/round shaped	< 2	Container (food, spare parts), basket, crane block	500
5		2 – 8	Container (spare parts), basket, crane test block	2500
6		> 8	Container (equipment), basket	250
7	Box/round shaped	>> 8	Massive objects as BOP, pipe reel, etc.	0
			Total	4005

A.4 Drop frequency ([5.2.1])

The generic drop frequency for crane activities can be determined according to Table 5-1. For this example all lifts are below 20 tonnes and the frequency of dropped load into the sea is then $1.2 \cdot 10^{-5}$ per lift.

A.5 Excursion of objects ([5.2.2])

Based on the crane location, the vessel approach area and the land area on the platform a most likely drop point is chosen. The drop point is found to be 10 metres off the platform north edge and 20 metres from the platform west side, as indicated on Figure A-1. Some shielding effect from the platform legs is anticipated.

The excursion of different objects is a stochastic event. A normal distribution as given in equation (9) is used to describe the fall pattern for each of the object categories. Due to the limited water depth, any currents will have limited effect on the excursion of the objects and is therefore not accounted for.

From the drop point concentric rings for each 10 m increase in radius are drawn up, see Figure A-2. The conditional probabilities for objects from each of the object categories to fall within these rings are given in Table A-2. As an example, the probability of an object in category one hitting within the first 10-metre ring is calculated in the following.

The lateral deviation, δ, in 100 metre water depth (d) is for objects in category 1 with an angular deviation of α equal to 15 deg, found by

$$\delta = d \cdot \tan\alpha = 100 \cdot \tan 15 = 26.8\,\mathrm{m}$$

The probability of one object in category 1 falling within the first 10 metres then becomes

$$P_{hit,10}(x \leq 10\mathrm{m}) = \int_{-10}^{10} p(x)dx = \int_{-10}^{10} \frac{1}{\sqrt{2\pi}\,\delta} e^{-\frac{1}{2}\left(\frac{x}{\delta}\right)^2} dx = 0.2910$$

The probability of hit per seabed area (m^2) is found by dividing the hit probability within the first 10-metre radius by the area of this radius: (note that $P_{hit,Ar}$ is not given explicitly in the recommended practice, but used to ease the calculations. The only difference to $P_{hit,sl}$ is that the exposed area of the pipeline is not included. This exposed area is accounted for later.)

$$P_{hit,Ar,10} = \frac{P_{hit,10}}{A_r} = \frac{0.2910}{\pi \cdot (10\mathrm{m})^2} = 0.000926\,\mathrm{m}^{-2}$$

This number can be found in Table A-2 as the first item for the category 1 objects.

Table A-2 Conditional probability of hit for each of the objects to fall within 10-metre intervals on the seabed

Object				*Probablity per m^2*												
No	*Desc.*	*Deviation*		*0–10*	*10–20*	*20–30*	*30–40*	*40–50*	*50–60*	*60–70*	*70–80*	*80–90*	*90–100*	*100–110*	*110–120*	*120–130*
		Angular (deg)	*Lateral[1] (m)*													
1	Flat/ long shape	15	26.8	0.000926	0.000269	0.000123	5.79E-05	2.6E-05	1.07E-05	3.95E-06	1.31E-06	3.83E-07	9.93E-08	2.27E-08	4.55E-09	8.02E-10
2		9	15.8	0.001503	0.000341	9.45E-05	2.12E-05	3.52E-06	4.18E-07	3.47E-08	2.01E-09	7.99E-11	2.19E-12	4.09E-14	5.22E-16	4.52E-18
3		5	8.8	0.002378	0.000245	1.38E-05	2.73E-07	1.71E-09	3.18E-12	1.72E-15	2.83E-19	0	0	0	0	0
4	Box/ round shape	10	17.6	0.001367	0.000333	0.000107	2.98E-05	6.62E-06	1.13E-06	1.46E-07	1.41E-08	1.01E-09	5.34E-11	2.09E-12	6.0E-14	1.27E-15
5		5	8.8	0.002378	0.000245	1.38E-05	2.73E-07	1.71E-09	3.18E-12	1.72E-15	2.83E-19	0	0	0	0	0
6		3	5.2	0.003004	5.97E-05	8.63E-08	4.74E-12	8.25E-18	0	0	0	0	0	0	0	0
No items of category 7 are to be lifted, thus this category is excluded. 1 The lateral deviation is for 100 metre water depth.																

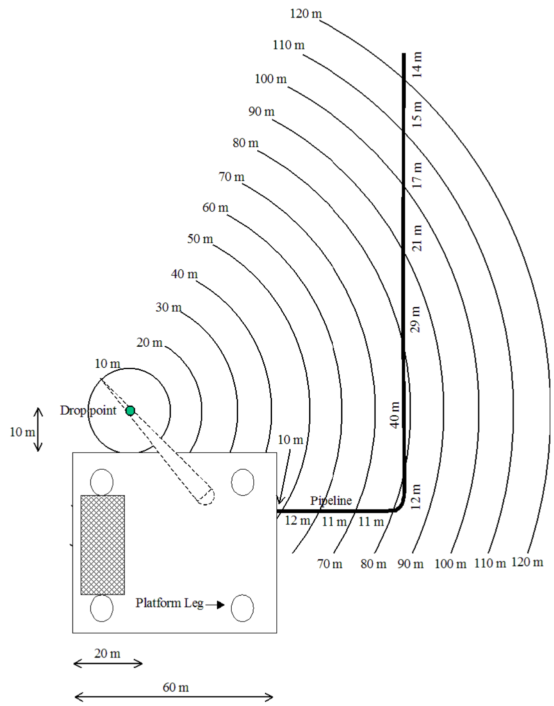

Figure A-2 Field layout with indication of 10-metre interval rings for calculating the object excursion and hit probability

A.6 Hit probability ([5.2.2])

The hit probability depends on the excursion of the objects as calculated in Table A-2 and the length of pipeline within each ring and the pipeline diameter and object size.

The length of pipeline within each section is given in Figure A-2 and Table A-3. The pipeline diameter is 0.63 metres including coating and the object size is assumed to be 12 metres long for the slender objects and 5 metres long for the box shaped.

Table A-3 Length of pipeline within each of 10-metre interval rings on the seabed

	Pipeline length within each ring												
	0–10	*10–20*	*20–30*	*30–40*	*40–50*	*50–60*	*60–70*	*70–80*	*80–90*	*90–100*	*100–110*	*110–120*	*120–130*
Length(m)	0	0	0	0	0*	0*	11	51	41	21	17	15	14
* Assumed shielded by the platform legs and bracing.													

The resulting conditional probability of hitting the pipeline is given in Table A-4. As an example the conditional probability of the 60-70 metre radius ring for object category 1 is calculated. The conditional probability of hitting the seabed within this ring is found in Table A-2, being ($P_{hit,\ 70}$ / A_r) = 3.95E-06 per m^2. The length of the exposed pipeline is 11 metres as given in Table A-3 and the breadth of the object is conservatively taken as the whole length of a pipe string, i.e. 12 metres. The conditional probability of hitting the pipeline then becomes

$$P_{hit,sl,70} = \frac{P_{hit,70}}{A_r} \cdot L_{sl} \cdot (D+B) = 3.95 \cdot 10^{-6}\,\mathrm{m}^{-2} \cdot 11\mathrm{m} \cdot (0.63\mathrm{m} + 12\mathrm{m}) = 0.00055$$

Table A-4 Conditional probability of each of the objects to hit the pipeline within 10-metre intervals on the seabed

Object			*Probablity*													
No	*Descrip.*	*Breadth (m)*	*0–10*	*10–20*	*20–30*	*30–40*	*40–50*	*50–60*	*60–70*	*70–80*	*80–90*	*90–100*	*100–110*	*110–120*	*120–130*	*Sum*
1	Flat/ long shaped	12	0	0	0	0	0	0	0.00 055	0.00 0842	0.00 020	2.63 E-05	4.87 E-06	8.62 E-07	1.42 E-07	0.00 162
2		12	0	0	0	0	0	0	4.83 E-06	1.29 E-06	4.14 E-08	5.8E -10	8.78 E-12	9.88 E-14	8E-16	6.2 E-06
3		12	0	0	0	0	0	0	2.39 E-13	1.82 E-16	0	0	0	0	0	2.4 E-13
4	Box/ round shaped	5	0	0	0	0	0	0	9.02 E-06	4.03 E-06	2.32 E-07	6.31 E-09	2E-10	5.07 E-12	9.99 E-14	1.3 E-05
5		5	0	0	0	0	0	0	1.06 E-13	8.11 E-17	0	0	0	0	0	1.1 E-13
6		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The final hit frequency is found by multiplying the number of lifts given in Table A-1 with the drop frequency of $1.2{\cdot}10^{-5}$ per lift and the conditional hit probabilities given in Table A-4. The results are given in Table A-5.

Table A-5 Resulting hit frequency

Objects			*Number lifted per year*	*Drop frequency per lift*	*Conditional hit probability*	*Hit frequency*
No	*Description*	*Weight in air (tonnes)*				
1	Flat/long shaped	< 2	700	1.2E-5	0.00162	1.36E-5
2		2 – 8	50	1.2E-5	6.2 E-06	3.72E-9
3		> 8	5	1.2E-5	2.4 E-13	~0
4	Box/round shaped	< 2	500	1.2E-5	1.3 E-05	7.80E-8
5		2 – 8	2500	1.2E-5	1.1 E-13	3.3E-15
6		> 8	250	1.2E-5	0	~0
					Sum	1.368E-5

The annual hit frequency is found to be $1.37{\cdot}10^{-5}$. In order to find the failure frequency the energy of the objects and the capacity of the pipeline need to be considered.

A.7 Hit frequency versus energy ([5.3])

The impact energy of each object can be determined as described in [5.2.3]. For the example the conditional impact energy distribution as given in Table 5-4 is used.

Combining Table 5-4 and the results of hit frequency given in Table A-5 above, the hit frequency can be established for different energy distribution of Table A-6 gives the resulting frequency for each object category and Table A-7 gives the resulting accumulated hit frequency, see also Figure A-3.

Table A-6 Hit frequency for different impact energy levels

Objects			*Energy level (kJ)*					
No	*Description*	*Weight in air (tonnes)*	*<50*	*50-100*	*100-200*	*200-400*	*400-800*	*>800*
1	Flat/long shaped	< 2	4.09E-06	2.45E-06	1.91E-06	1.63E-06	1.50E-06	2.04E-06
2		2 – 8	1.85E-10	2.96E-10	5.54E-10	7.02E-10	9.24E-10	1.03E-09
3		> 8	0	0	1.53E-18	2.29E-18	4.59E-18	6.88E-18
4	Box/round shaped	< 2	3.99E-08	2.39E-08	1.60E-08	0	0	0
5		2 – 8	0	6.39E-16	9.59E-16	1.28E-15	3.20E-16	0
6		> 8	0	0	0	0	0	0

Table A-7 Accumulated hit frequency for different impact energy levels

	Energy level (kJ)					
	>0	*>50*	*>100*	*>200*	*>400*	*>800*
Annual hit frequency	1.37E-05	9.58E-06	7.10E-06	5.18E-06	3.54E-06	2.04E-06

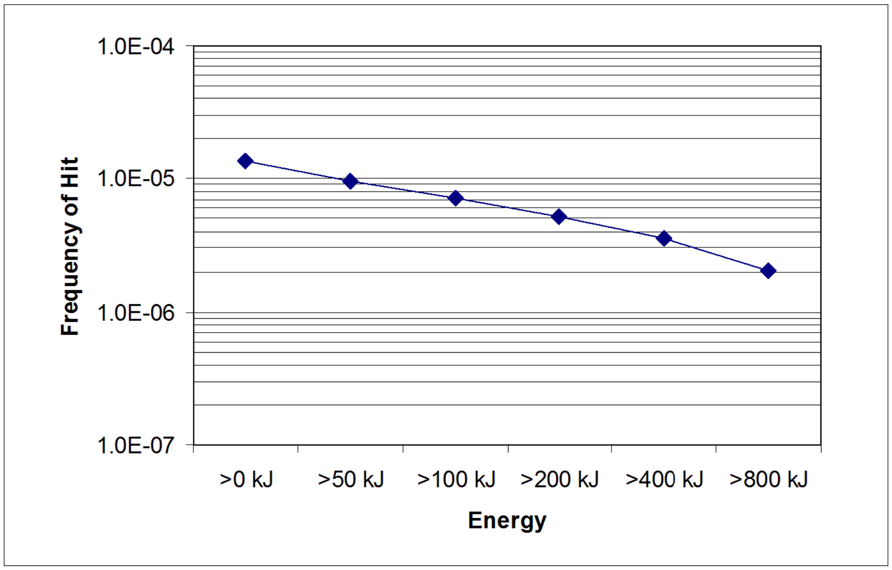

Figure A-3 Accumulated annual hit frequency for different impact energy levels

A.8 Damage capacity versus energy (Sec.4)

For each of the damage classes defined in [4.2] (D1, D2, D3, R0, R1and R2), conditional probabilities for damage to the pipeline can be determined as proposed in Table 4-1. The impact energy required to create a dent of 5% is found by:

$$E = 16 \cdot \left(\frac{2\pi}{9}\right)^{\frac{1}{2}} \cdot m_p \cdot \left(\frac{D}{t}\right)^{\frac{1}{2}} \cdot D \cdot \left(\frac{\delta}{D}\right)^{\frac{3}{2}} = 13.37 \cdot 0.25 \cdot 450 \cdot 10^6 \, \frac{\mathrm{N}}{\mathrm{m}^2} \cdot (0.018\mathrm{m})^2 \left(\frac{0.508\mathrm{m}}{0.018\mathrm{m}}\right)^{\frac{1}{2}} 0.508\mathrm{m} \cdot (0.05)^{\frac{3}{2}} = 14.7\,\mathrm{kJ}$$

The results for larger dents are given in Table A-8. In addition the 60 mm concrete coating has impact resistance. According to [4.6.1] the impact capacity of the coating is taken as (both expressions calculated):

$$E_k = \left(Y \cdot b \cdot h \cdot x_0 ; Y \cdot b \frac{4}{3}\sqrt{D \cdot x_0^3}\right) = \left(3 \cdot 35 \cdot 10^6 \, \frac{\mathrm{N}}{\mathrm{m}^2} \cdot 0.03\mathrm{m} \cdot 0.3\mathrm{m} \cdot 0.06\mathrm{m} ; 3 \cdot 35 \cdot 10^6 \, \frac{\mathrm{N}}{\mathrm{m}^2} \cdot 0.03\mathrm{m} \, \frac{4}{3}\sqrt{0.63\mathrm{m} \cdot 0.06\mathrm{m}^3}\right)$$
$$= (56.7\,\mathrm{kJ} ; 48.9\,\mathrm{kJ}) \approx 50\,\mathrm{kJ}$$

Here the breadth, *b*, and height, *h*, of the impacting object is assumed to be 30 mm and 300 mm respectively. The concrete coating thus has an impact capacity of approximately 50 kJ. The total capacity of the pipeline and coating is given in Table A-8.

Table A-8 Conditional impact capacity of pipeline and coating

Dent/ diameter (%)	*Impact energy*		*Damage description*	*Conditional probability*					
	Steel pipe only	*Total (coating included)*		*D1*	*D2*	*D3*	*R0*	*R1*	*R2*
< 5	< 15 kJ	< 65 kJ	Minor damage	1.0	0	0	1.0	0	0
5 – 10	15 – 40 kJ	65 – 90 kJ	Major damage Leakage anticipated	0.1	0.8	0.1	0.9	0.1	0
10 – 15	40 – 75 kJ	90 – 125 kJ	Major damage Leakage and rupture anticipated	0	0.75	0.25	0.75	0.2	0.05
15 – 20	75 – 115 kJ	125 – 165 kJ	Major damage Leakage and rupture anticipated	0	0.25	0.75	0.25	0.5	0.25
> 20	> 115 kJ	> 165 kJ	Rupture.	0	0.1	0.9	0.1	0.2	0.7

A.9 Damage versus frequency

Damage versus frequency can be determined by combining the "hit frequency versus energy" and "damage capacity versus energy" as found in appendix [A.7] and [A.8] respectively.

Table A-9 Failure frequency versus damage category

Dent/ diameter (%)	*Impact energy*		*Damage description*	*Frequency*		
	Steel pipe only	*Total (coating included)*		*D1*	*D2*	*D3*
< 5	< 15 kJ	< 65 kJ	Minor damage	4.87E-06	0	0
5 – 10	15 – 40 kJ	65 – 90 kJ	Major damage Leakage anticipated	1.24E-07	9.91E-07	1.24E-07
10 – 15	40 – 75 kJ	90 – 125 kJ	Major damage Leakage and rupture anticipated.	0	7.32E-07	2.44E-07
15 – 20	75 – 115 kJ	125 – 165 kJ	Major damage Leakage and rupture anticipated.	0	1.92E-07	5.77E-07
> 20	> 115 kJ	> 165 kJ	Rupture	0	5.85E-07	5.27E-06
			Totals	4.99E-06	2.50E-06	6.21E-06

Damage class D1 is not considered to give damage leading to failure. The failure frequency is obtained by adding the results for damage class D2 and D3. From Table A-8, it can be seen that the annual frequency of failure is $8.7 \cdot 10^{-6}$ which is within the acceptance criteria of $1 \cdot 10^{-5}$.

As the failure frequency is within the allowable and for this example it is assumed that any other hazards do not represent risks for the pipeline of the same order of magnitude as dropped objects, it is concluded that the protection proposed for this pipeline is adequate.

APPENDIX B IMPACT CAPACITY TESTING PROCEDURE

B.1 Introduction

For some components, the stated capacity formulations may not be applicable, or may result in estimates with large uncertainty, etc. If it is necessary to establish the exact capacity, impact testing may be performed. A procedure for destructive testing of components to establish impact capacity to be used in risk assessments is presented below. This procedure is focused on determination of the impact capacity of steel pipes with diameter up to 10”-12”, flexibles and umbilicals.

The testing should reflect the accidental situations under consideration, and should aim to determine the capacity limits for the different damage categories given in the methodology, e.g. D1 to D3.

B.2 Test energy

The test energy shall be based on the kinetic energy that is representative for the objects that are most likely to hit the component, as calculated according to [5.2], or if possible, the energy should be increased until a damage equal to category D3 is obtained.

B.3 Test equipment

B.3.1 General

The test rig should simulate a realistic situation. Such tests are not normally instrumented to record the material behaviour during impact, only the final damage is measured. As the impact calculations for the risk assessment are not detailed, no instrumentation is necessary.

In the simplest form, the test rig could be a crane with a remotely controlled release hook. It shall be ensured that the test hammer will not rotate during the test.

B.3.2 Hammer

The test hammer should normally have a mass of 1 ton, see Table B-1. The front of the hammer should be made up with a rectangular plate of 300 mm height/length and 50 mm width with a conical shape and an edge radius of 7 mm.

If the shape of the falling objects is known, e.g. an anchor chain, the actual shape can be used as the hammer front.

B.3.3 Support conditions

The support conditions should represent the most onerous case for the actual configuration, e.g. soil conditions similar to the actual location, swan neck configuration, etc.

However, if the test is performed on stiff supports, then the test will reflect the true capacity of the component, i.e. all energy will be absorbed by the component and none transferred to supports. In this way, the results will not be project specific and may then be used for other projects.

B.4 Procedure

The testing should be repeated to ensure that the results are consistent. For design applications, the lowest reported value should be used.

For risk assessment, the capacity will normally be the (mean) value found. However, for components whose capacity is sensitive to the shape of the hammer front, the capacity should be taken as 90% of the reported (mean) value. Examples of the latter are multi-layer coatings for pipes, flexible pipes and umbilicals. In Table B-1, the profile of the impacting object is given along with directions to deciding the impact capacity.

Table B-1 Impact testing – applicable profile, mass and capacity

Description	*Test profile*	*Test mass*	*Applicable capacity*
Simulating impact of any object			
Steel pipes, protected or not	R = 7mm	1 tonnes	x
Steel pipes with coating (total capacity)	R = 7mm	1 tonnes	x or $x = 0.9x_{R=7mm}$ [1]
Flexibles and/or umbilicals protected	R = 7mm	1 tonnes	$x = 0.9x_{R=7mm}$
Any additional protection (not coating)	R = 7mm	1 tonnes	x or $x = 0.9x_{R=7mm}$ [1]
Simulating impact of a 7” pipe (equal to tubing/liner) falling horizontally			
Coating for steel pipes	Simulate 7” pipe falling horizontally	0.6 tonnes	$x = 0.9x_{7'' pipe}$
Flexibles and/or umbilicals	Simulate 7” pipe falling horizontally	0.6 tonnes	$x = 0.9x_{7'' pipe}$

1 If protection is sensitive to the test profile, R, the capacity should be reduced to 0.9 the observed capacity

Definitions:

x : observed impact capacity
$x_{R = 7mm}$: observed impact capacity for test profile with R=7mm
$x_{7'' pipe}$: observed impact capacity for test profile that simulates a 7” pipe falling horizontally
R : profile as shown in Figure B-1.

Where nothing else is indicated, pipelines/umbilicals are considered not protected.

Table B-1 applies for activities in the vicinity of subsea templates. The table is to be used as follows:

For the pipeline/umbilical/protection in question, the testing requirements and applicable capacity can be read in the relevant row. For example, for a flexible pipe to be tested for any object hitting the pipe, the following data apply:

— test profile: R = 7 mm
— test mass: 1 tonne
— applicable capacity: $x = 0.9 \cdot x_{R=7mm}$ (i.e. the applicable capacity is 0.9 of the tested value).

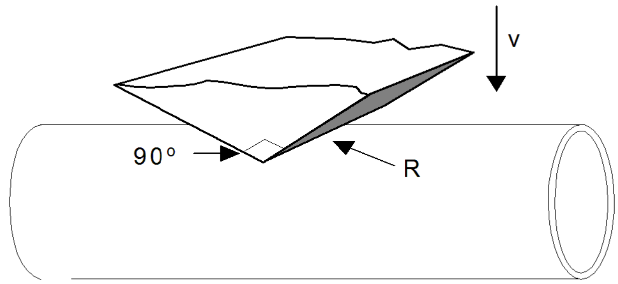

Figure B-1 Profile for deciding impact capacity

CHANGES - HISTORIC

There are currently no historical changes for this document.