GUIDELINES FOR PIPELINE OPERATORS ON PIPELINE ANCHOR HAZARDS

FOREWORD

This document is intended to help pipeline operators and other relevant stakeholders by setting out good practice guidance on the design, management and protection of pipelines from anchor hazards. Recent incidents have shown that the threat to pipeline integrity from anchor damage can be significant and it is important that pipeline operators adequately address anchor hazards in design & within Major Accident Prevention Documents (MAPD) and where appropriate, provide suitable protection and/or controls to manage the risk.

This guidance is primarily focused towards near-shore major trunk pipelines in the vicinity of Port/Harbour areas, where there is likely to be significant marine/vessel traffic and/or anchoring zones. However, it may also be relevant to both in-shore areas (e.g. pipelines crossing major estuaries and rivers) and anchor handling operations in the vicinity of UKCS Installations and associated pipelines.

This document was written and compiled under the direction of a Working Group established to address the final recommendation from the Marine Accident Investigation Branch (MAIB) Report into the Young Lady Anchor incident near Teesport in June 2007. The incident involved anchor damage to the BP Central Area Transmission System (CATS) Gas Pipeline and resulted in the pipeline being shutdown for a number of months before repairs could be completed. The working group which comprised of representatives from the Department of Transport (DfT), Department of Climate Change (DECC), Maritime Coastguard Agency (MCA) and the Health & Safety Executive (HSE) was tasked to conduct a review of the risk assessment process for the protection of pipelines from surface vessel interaction. One of the key findings of the group was that there appeared to be relatively limited coverage of anchor hazards within UK Codes/Standards and other publicly available guidance, with the information spread across a number of different sources. Development of this guidance naturally followed with the key aim to update and pull together all the relevant information and material into a single reference document.

The main body of the document begins with a brief summary on the limitations of existing guidance before presenting an assessment overview of current anchor related incidents from PARLOC 2001. It then addresses the risk assessment requirements for compliance with the Pipeline Safety Regulations and associated Major Accident Prevention Document (MAPD) and provides guidance in relation to failure frequency calculations and consequence assessment. The guidance then highlights key areas that need to be addressed within pipeline emergency procedures when dealing with anchor damage incidents. In particular it focuses on pipeline damage and repair strategies and any required pipeline isolation and depressurisation arrangements. It concludes with an overview of the main protective measures and controls currently available to protect against anchor hazards. References to relevant published information and studies are provided throughout the document.

The Appendices provide more detailed information in relation to the PARLOC anchor incident data and analyses. They also give information on the range and types of modern anchors, giving detailed description of their key features and dimensions. Appendix 3 provides a table of the main physical protection measures along with a brief review of the reasonable practicability and effectiveness of their use to protect against anchor hazards.

This Guidance can be equally used to assist with both the design of new pipelines and in any review of the arrangements for anchor hazard protection of existing operational lines.

Related guidance for Harbour/Port Authorities has also been established, following the CATS incident. It forms part of the Guide to Good Practice on Port Marine Operations which has been prepared in conjunction with the Port Marine Safety Code. The new Port Marine Safety Code (PMSC) and accompanying Guide to Good Practice were officially launched at the end of October 2009 by the Shipping Minister and representatives from industry on HQS Wellington. The latest versions of both documents can be found on the DfT website. A harbour authority needs to be aware of the presence of any subsea pipelines in its area of responsibility. It should recognise and assess the potential for damage to those pipelines from shipping and fishing operations, and the associated potential consequences of such damage as part of its navigational Safety Management System.

This Pipeline Operator Guideline may be reviewed from time to time and it would be of considerable assistance for any future revision if users would send comments or suggestions for improvements to:

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Guidance for pipeline operators on appropriate measures to protect against anchor damage

Background

Following a series of anchor damage incidents to offshore subsea pipelines including the Young Lady incident[i] with the BP CATS pipeline in 2007, the regulatory authorities (HSE, DfT, MCA and DECC) identified the need to give guidance on appropriate measures to protect new pipelines and where necessary, provide retrospective protection to existing pipelines.

Anchor hazards can pose a significant threat to pipeline integrity. However, by ensuring that pipelines are designed, constructed and managed safely in compliance with the Pipelines Safety Regulations 1996, pipeline operators can help ensure that such a threat is minimised.

The consequences of damage to a pipeline could include loss of life, injury, fire, explosion, loss of buoyancy around a vessel and major pollution. Even minor pipeline damage that does not result in loss of containment could lead to the requirement to reduce operational pressure or lock in the pipeline, and methods and equipment for isolation /depressurisation may not be readily available. The pipeline could be out of service for several weeks causing disruption to supplies downstream and large financial implications.

Given the reliance on gas as major energy source in the UK, the consequences of loss of supply from a major gas feeder pipeline could be severe economic and social disruption for several weeks to many hundreds of thousands of domestic, commercial and industrial consumers.

Aim

Available standards (e.g. BS EN 14161, PD 8010 Part 2, DNV OS-F101) give limited guidance on protection against anchor damage. The aim of this work is to give guidance for pipeline operators to enable them to undertake risk assessment and specify appropriate measures against anchor damage.

Existing guidance

The issue of anchor loads is identified in current standards but guidance tends to be very basic and does not cover in any detail the assessment of risks posed by large modern anchors. BS PD8010-2:2004 s6.10.4 details light anchor protection for crossings and s7.6.1 mentions that protection from heavy anchors should be taken into account. Annex C (informative) on hazards in pipeline design, identifies anchoring but no detail is given. Annex D (normative) on safety evaluation does not provide specific guidance on anchor damage but does require identification of all credible failure modes. DNV OS-F101 identifies dragging anchors as a typical accidental load but again, guidance is limited. Oil and Gas UK has published guidelines on the anchoring of vessels in the vicinity of UKCS installations and pipelines and their subsea equipment.[ii]

Quantification of the risk of anchor damage

A review of HSE and Pipeline and Riser Loss of Containment (PARLOC) data shows that several previous incidents have been recorded and these are detailed in appendix 1. The anchor damage incidents on the BP CATS 36" pipeline and the Statoil Kvitebørn 30" gas pipeline (Norwegian sector) are not included in this data.

From PARLOC there were 11 recorded incidents of anchor damage over 25,000km of subsea pipelines between 1996 and 2001. PARLOC identifies 1 anchor damage incident in the shore zone for the same period. There are around 50 hydrocarbon pipelines making landfall in the UK.

The MAIB investigation report[i] identified two incidents (1996 and 1997) in the Humber Estuary on the Amethyst gas pipeline both of which affected production.

The MAIB investigation report[i] also identified that since 1992 there have been 20 accidents in UK territorial waters where merchant vessels over 500 gross tons dragged their anchor and subsequently grounded. The number of incidents where vessels dragged anchor but avoided grounding is unknown but is likely to be an order of magnitude higher.

The sequence of events leading to a dragging anchor interacting with a pipeline is complex, but calculation of the overall risk is possible with some basic assumptions and this is detailed in the Risk Assessment section.

Major Accident Prevention Document (MAPD)

Regulation 23 of The Pipeline Safety Regulations[iii] (PSR) (1996) requires the operator to prepare a MAPD before completion of the design of the pipeline and revise this as appropriate. HSE publication L82[iv] gives detailed guidance on what these documents should contain. For existing pipelines, operators should review regularly their MAPD and Emergency Procedures to ensure that the issues identified within the following sections are covered.

The MAPD should include:

- A description of the pipeline
- Hazard identification- this should include third party activities such as anchoring
- Risk assessment- described below
- Prevention and mitigation measures, including those taken into account during design, construction and operation of the pipeline
- Pipeline management system
- Emergency response

There is no requirement for the MAPD or Emergency Procedures to be submitted to HSE but they must be kept up to date and should be made available for inspection.

Hazard, Consequence and Risk Assessment

The potential for anchor interaction causing damage to the pipeline should be identified during the design stage through the vessel interaction hazard identification and risk assessment. This would normally include hazards from dredging, fishing gear and construction activities in close proximity to the pipeline. The routing of a pipeline away from known harbour approaches and shipping lanes should be explored to avoid these areas wherever possible. Close liaison with harbour authorities during design and construction phases is essential. Anchoring in deep sea shipping lanes is rare but can occur in emergency situations and should be included in the HAZID/ risk assessment. Various risk assessment techniques have been published looking at both likelihood of interaction with anchors and the effects on pipelines[v vi vii viii ix].

Risk assessment for anchor interaction should incorporate a traffic survey to quantify the frequency of vessel movements near the pipeline and the type of vessels involved (e.g. fishing vessels, ferries, small coastal vessels, ocean going vessels, tankers, patrol vessels and supply boats). Real data for vessel movements over a time period (minimum 6 months) may be obtained from Automatic Identification System (AIS) maritime tracking surveys. Consideration must be given to the risks to pipelines from anchors deployed during mooring of mobile drilling units and other offshore operations vessels (e.g. dive support vessels, laybarges etc.) around platforms. Further guidance is given on this in UK Oil and Gas publication VES10[x]. Appropriate safeguards should be built into the vessel/rig procedures.

Each vessel type will have different anchor types and anchoring frequencies and will be operated in distinctly different ways. Different anchor methods /frequencies will present different probabilities of interaction with pipelines, and also different consequences should interaction occur.

The risks identified should cover a range of potential scenarios including those arising from different weather conditions (e.g. potential for dragging anchors in various storm wind directions). Where anchorages are identified on charts close to pipelines (within 5 nautical miles), the frequency of weather conditions that might lead to anchor dragging (assuming that storms below a certain Beaufort force are unlikely to lead to dragging anchors) in the direction of the pipeline should also be estimated by obtaining wind direction distribution data. Where a vessel drags anchor, the watch may identify this at an early stage and may pay out more cable or prepare to get the vessel underway before reaching the pipeline. However, the watch may not identify the vessel is dragging anchor immediately and a human factors calculation can be performed to determine the likelihood of this occurrence. The risk of the vessel not being able to steam away before the anchor can interact with the pipeline can be calculated based on reliability statistics for the various types of vessels identified in the traffic survey.

Where a risk of anchor interaction with a pipeline is identified, the consequence must be established. This will depend on the size of anchor, its weight, the pipeline burial depth and coating, the pipeline diameter, material strength, the anchor seabed penetration depth, the velocity of the dragging anchor and the potential load should the pipeline be hooked. For instance, if ocean going vessels of 100,000 tonnes and above are identified as likely to pass over the pipeline that traverses a shipping lane, it is likely that these could carry anchors of up to 20 tonnes. Various anchor types are in use and these are detailed in appendix 2. Software packages that calculate anchor seabed penetration and behaviour for various anchor types are available[xi]. The typical anchor dimensions/weights that could be encountered should be obtained for the various segments (inshore, offshore, shipping lane, platform zone etc.) of the pipeline.

Analysis should determine the consequence of the interaction be it no damage, damage to coating, local denting, hooking displacement or rupture. Release of gas at from a high pressure subsea pipeline would result in a gas plume from near the sea bed at high pressure expanding as it approaches the surface. The release is likely to last many hours or even days given quantities of gas between shut in valves. Should the gas ignite, there are likely to be high thermal loads on surface vessels and structures. The plume size, potential loss of buoyancy, potential fireball size and thermal radiation levels should be modelled to understand the consequence of failure. The proximity of these hazards to population should also be established to enable a full consequence analysis to be completed.

Characterisation of the damage

Anchor interaction with subsea pipelines can arise from vessels dragging anchor (due to severe weather conditions or the anchor not being deployed properly) or from emergency anchoring due to engine failure or from anchoring activities associated with offshore operations (laybarges, jack-ups etc.) The consequences of anchor damage may not lead to immediate loss containment- it may be delayed.

Anchor damage can be characterised as follows:

1. Damage or disturbance to pipeline protection such as rock cover or backfill that leaves the pipeline vulnerable to further damage
2. Damage caused by the direct impact of the anchor on the pipeline. Anchor wires and chains, if laid on top of pipelines, can abrade coatings and damage the pipe. Damaged coatings can lead to increased requirements for cathodic protection. Where direct anchor impact occurs, the pipe may be dented, making internal inspection or maintenance difficult and this may result in loss of flow capacity and even blockage. In extreme circumstances, anchor flukes can damage the pipe wall leading to loss of containment which may occur some time after the impact. If the released product is gas, this would bubble up to the surface and could cause instability of surface vessels. Gas also presents an asphyxiation risk to those on board vessels or platforms. In certain circumstances, ignition sources on vessels or platforms could also lead to a gas fire or explosion.
3. Dents due to sustained pullover forces on the pipe after the initial impact. Dents also affect the pipeline fatigue life under operational cycling.
4. The anchor hooking or snagging the pipeline leading to displacement of the pipeline which may be tugged along the seabed by the movement of the vessel. In extreme circumstances, this leads to severe upheaval of the pipeline with the potential for loss of containment through pin holing, pipe tearing or complete rupture. Unsupported span of pipeline caused by loss of contact with the sea floor can lead to excessive stresses developing in the pipeline due to its weight and hydrodynamic forces (such as tides).

Emergency Procedures

The operator of a major accident hazard pipeline (MAHP) is required by PSR Regulation 24 to prepare emergency procedures and have appropriate organisation and arrangements to deal with the consequences of a major accident involving a pipeline, and this should include anchor damage scenarios. Further guidance is given in HSE publication L82[iv].

The operator is also required to test the procedures, organisation and arrangements as often as may be appropriate. The arrangements for incident notification and emergency response should be tested on a frequent basis with input from relevant bodies such as port/harbour authorities. There is also a requirement to revise these arrangements as often as is necessary.

In preparing Emergency Procedures, the pipeline operator should consider the following:

- How pipeline depressurisation can be achieved (e.g. flaring arrangements, isolation facilities both onshore and offshore). This might lead to the requirement for provision of facilities to enable rapid depressurisation in a controlled manner which may be difficult to achieve with dense phase pipelines unless appropriate equipment is readily available.
- The impact on operations of depressurising or pressure reduction
- The management of any liquid drop out following depressurisation
- Mobilisation of engineering personnel to undertake
    - Risk assessment for inspection to minimise risks to which divers are exposed
    - Pipeline stress analysis- excavating the subsea pipeline could lead to additional stresses on the damaged area that require further reduction in pipeline pressure
    - Fatigue and defect analysis
    - Developing repair methods
- Mobilisation of pipeline inspection contractors
- Mobilisation of pipeline repair contractors
- Arrangements for holding of spares for pipeline repairs

By considering all these issues at an early stage, designers and operators should be able to ensure that systems are in place to manage such an occurrence. The commercial/ financial implications of pressure reduction following an incident should also be considered especially for trunk lines that carry gas from more than one producer. The impact on gas markets and reputational loss forms part of this business risk but is outside the scope of this guidance.

Environmental Oil Pollution Emergency Plans

Operators should note that under the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998 all pipelines engaged in the transportation of oil, condensate, wet gas, or gas must be included within the scope of an approved Oil Pollution Emergency Plan (OPEP). Pipelines (both in-field and trunk export) may be approved within the scope of a combined host installation OPEP or may have a separate individual pipeline OPEP. The OPEP is an operational document that sets out clear procedures for responding to oil pollution incidents from oil and gas installations, including pipelines. The Department of Energy and Climate Change is the approving regulatory authority for OPEP associated with oil and gas activity and further information can be gained within their associated ‘Guidance Notes to Operators of UK Offshore Oil and Gas Installations (including pipelines) on Oil Pollution Emergency Plan Requirements’ https://www.og.decc.gov.uk/environment/msr1998.htm.

Measures for the prevention of anchor damage to subsea pipelines

The measures detailed below fall broadly into pipeline design measures, communication with port/harbour authorities and emergency arrangements.

Prevention of damage must primarily be through good marine control procedures and these are normally out with the control of the pipeline operator but can be influenced by close co-operation with maritime authorities. The level of protection must be based on the risk identified- higher protection standards will be needed in harbour areas or where anchor activity is considered likely such as anchorage areas where vessels wait to enter harbours.

Pipeline Protection Measures

Physical Protection Measures

It is recognised that providing protection to pipelines from anchor damage from large vessels can be difficult. Trenched pipelines are normally laid at depths of around 1-2m, and for the large anchors, this will not provide total protection. Further engineered rock protection measures could be employed where deemed necessary from the risk assessment. Various physical pipeline protection measures are described in appendix 3.

Existing pipelines laid on the surface could be trenched or trenched and backfilled to reduce risk of anchor damage, but as noted previously, this will provide limited protection from large anchors. Periodic surveys should be undertaken to identify damage, displacement or loss of protection or cover. In extreme circumstances, if risk assessment identifies that risk to pipelines is unacceptably high, replacing with a re-routed or re-designed section of pipeline may be necessary.

Communication

Prohibition / exclusion of dropping anchor

Some port/harbour authorities / pipeline operators have established wayleaves or exclusion zones around pipelines (e.g. Ekofisk pipeline) and designated anchor zones which are at a safe distance from pipeline routes. Pipeline operators should consult with harbour authorities and agree suitable exclusion zones where activities are controlled or prohibited. In pipeline corridors that are not part of established anchorage areas, vessels would not normally to drop anchor but this cannot be ruled out in emergency situations.

Informing those likely to drop anchor

Regulation 16 of The Pipeline Safety Regulations (1996) (PSR) requires the pipeline operator to take reasonable steps to inform third parties of the existence and whereabouts of pipelines with a view to preventing damage to them. This should include liaison with port/harbour authorities.

Oil and Gas UK (formerly UKOOA) has issued guidance that details arrangements to be made when pipeline operators are notified that vessels are undertaking operations which will involve placing an anchor within 5km of pipelines[ii]. The guidance describes the arrangements for provision of information.

Construction and supply vessels in particular should be given information on the location of pipelines and guidance on safe anchorage given the risks posed to platforms. Many modern vessels now rely on dynamic positioning but anchors may still be deployed in emergencies or by older vessels. These vessels are usually chartered by the platform operator and contractual arrangements should include risk assessment of anchor damage. However, it should be noted that vessels that are in emergency situations, such as loss of control, power or steerage or collision, may drop anchor immediately without examination of charts for subsea infrastructure.

Testing of emergency arrangements

Pipeline operators should make arrangements to test emergency plans and involve port/harbour authorities in these tests where appropriate. Findings from these exercises should be reviewed and emergency arrangements revised accordingly.

Maritime Control Systems

Guidance[xii] is being provided to UK port and harbour authorities on arrangements to be made where subsea pipelines are close to or within the area of responsibility of the port. This guidance suggests that the harbour authorities ensure their management system includes consideration of pipelines, which should be done in consultation with the pipeline operator. This includes considering the location of recommended anchorages, restrictions around pipelines, measures for monitoring the position of shipping with respect to pipelines and emergency arrangements. It is expected that pipeline operators will work closely with port and harbour authorities to implement suitable pipeline management systems.

Appendix 1

PARLOC "Pipeline and Riser loss of containment" data for offshore pipelines reports are produced for Oil and Gas UK (formerly United Kingdom Offshore Operators Association (UKOOA)) and HSE. PARLOC 2001, which includes nearly 25,000km of offshore pipelines (year 2000) details a total of 44 incidents involving anchoring.

The largest pipeline to suffer loss of containment attributable to anchor damage was 16" diameter.

From the 44 incidents, 2 of these incidents occurred to operating flexible lines, 2 to fittings associated with operating steel lines and 40 of these incidents are among the 209 recorded incidents associated with operating steel pipelines. Of these incidents:

- 18 did not require repair
- 11 resulted in loss of containment

In addition to the loss of containment incidents, in 22 incidents the pipeline needed some degree of repair; in 5 of these cases the pipeline had been moved by the anchor and damage to the pipe body was reported in 8 incidents.

- In 6 incidents the pipelines affected sustained dents, but repair was only required in 1 incident
- In 4 incidents only the concrete coating was damaged
- In 6 cases, no visible damage was reported

2 anchoring incidents affected flexible lines. In one incident the flexible was torn and leaked. In the other there was external damage, but not severe enough to warrant repair. 2 anchoring incidents involved fittings associated with operating lines and resulted in damage to valves, both of which led to leakage.

The report also makes estimates of the leak frequency per km-year due to anchor damage for both the platform safety zone and mid line, and these are all of the order of 1 per 1000.

PARLOC Causes of Anchoring Incidents

11 incidents to operating steel pipelines (excluding fittings and flexibles) were caused by construction vessels, 8 occurred within platform safety zones, of which 5 were within 100m of the platform. The remaining 3 incidents occurred to the mid line of the pipeline. None of these incidents resulted in pipe leakage, and only 1 of the affected pipelines needed repair.

1 incident was to a flexible line in the mid line of the pipeline which did not result in a leak.

A further 18 anchoring incidents were caused by supply boats, 11 occurring in the safety zone, 6 to the mid line of the pipeline and 1 in the shore zone. The exact location of 7 of these incidents was reported, only 1 occurred within 100m of the platform; the other 6 occurred further than l00m from the platform. Of the 11 incidents, 6 resulted in loss of containment. Of the lines that did not leak as a result of the anchor impact, one was dented and the other sustained damage to the coating but no repair was necessary in either incident. All of the supply boat incidents were to steel pipelines.

Many pipelines are trenched to protect them from trawling damage or to enhance stability. In the PARLOC pipeline database 57% by length of all lines have some degree of protection, either trenching (lowering) or burial (covering) over part or all of their length.

There is insufficient data to draw any firm conclusions as to whether protected pipelines are damaged less frequently, but it is possible to determine that smaller diameter pipelines are have a higher failure frequency.

Appendix 2- Types of anchors

Anchors deployed from vessels are normally gravity or embedment type. The vessel is secured to the anchor by either chain or wire rope. Large vessel anchors are normally designed to penetrate the seabed. During deployment/recovery and in severe weather conditions, anchors can be dragged along the seabed for considerable distances, resulting in severe seabed scarring. Anchors vary significantly in design and size. Anchors on large vessels can weigh up to 20 tonnes.

Anchors can be described as burying (stockless) or non-burying types (stocked). Guidance on anchor penetration for various anchor types is given in API RP 2SK[xiii] and the Vryhof anchor manual[xiv]. They are normally classified as follows:

- **Hook** designs use a relatively small fluke surface on a heavy, narrow arm to penetrate deeply into problematic bottoms such as rocky, heavy kelp or eel grass, coral, or hard sand. Two of the more common versions of this design are the traditional fisherman and the grapnel. Due to their design, these anchors are likely to snag unburied pipes.
- **Plough** designs are reminiscent of the antique farm plough, and are designed to bury themselves in the bottom as force is applied to them, and are considered good in most bottom conditions from soft mud to rock. North Sea designs are actually a variation of a plough in how they work; they bury into the bottom using their shape.
- **Fluke** designs use large fluke surfaces to develop very large resistance to loads once they dig into the seabed. Although they have less ability to penetrate and are designed to reset rather than turn, their light weight makes them very popular. The Danforth is probably the widest known Fluke anchor. It incorporates a hinged stock which enables the flukes to orient towards the bottom. Flukes can be over 1m in length and therefore can disturb shallow trenched pipelines.

Appendix 3- Physical Protective Measures for Pipelines

Protection measures

If pipeline protection against anchor damage is identified as being required through risk assessment, a number of measures are available. Consideration should be given as to where these measures are required along the segments of the pipeline route. For instance, these might require application along the whole pipeline length, or be limited to areas where the pipeline traverses shipping channels or harbour areas. Measures can be used in combination, for instance thicker wall pipe, concrete protective coating, trenching and engineered rock / gravel protection may be required for inshore areas. The ongoing integrity of protection measures will require periodic assessment through inspection/ survey. Some examples of these measures are detailed in the table below.

Protection measure	Comments	Effectiveness
Extra steel	Where the risk of anchor impact or hooking has been identified through risk assessment and calculations have shown that the capacity of the pipeline to withstand these loads is insufficient, simple overdesign of the pipeline to give thicker wall and greater strength might be the simplest, lowest cost solution.	Effective where small vessel anchor impacts are possible. Relatively low cost.
Protective coating	Concrete coatings offer limited protection to anchor damage. These coatings are readily damaged by anchor chains or anchors and will only be effective against small	Unlikely to offer significant protection to pipelines from

	anchors. The coating will provide a degree of protection by absorbing the initial impact energy which can reduce the risk of gouging or material hardening and micro cracking by dissipating the energy in the immediate vicinity of the impact zone.	large vessel anchors, but may absorb some of the impact and reduce the risk of loss of containment or pipeline damage.
Trenching only/ Trenching and backfill	Sections of vulnerable subsea pipeline can be given some degree of protection from mechanical damage by lowering them beneath the seabed. It is crucial to determine the optimum depth of burial as this is an expensive activity. The likely depth of anchor penetration can be estimated with reference to anchor designs. The largest vessel anchors may penetrate the sea bed to a depth of several metres in soft soils. Dragging anchors however are likely to be at shallower depths. When determining the required depth of trenching, any possible variations in seabed level due to sediment mobility (silting or erosion) should be taken into account as should the type of anchor likely to be encountered. The possibility of the waterway being dredged also needs to be considered. Where backfilling of the trench is required, reliance should not necessarily be placed on the natural action of seabed soil mobility. The design of engineering backfill should take account of the uncertainties inherent in its method of placement. The effects of thermal expansion or contraction should be taken into account particularly where transported fluids are above or below ambient seabed temperature. Consideration should be given to increasing the trenching depth as the pipeline approaches landfall, shipping lanes or anchorage areas. Trenching and gravel backfill can release a dragging Danforth type anchor and allow it to walk over the pipeline[viii].	Trenching only unlikely to offer significant reduction in risk for large vessel anchors which can penetrate the sea bed to several metres but may reduce risk for small vessel anchors. Some researchers claim trenching and backfilling with coarse gravel could protect pipelines[xv] by allowing a dragging anchor to be released from the seabed[viii].
Rock or gravel placement	The pipeline can be protected from external loads by covering it with suitably graded material. This reduces the possibility of impact and abrasion damage, but penetration of the cover is still possible. This type of protection works by causing the anchor flukes to tilt resulting in anchor instability and a reduction in penetration. The following factors should be taken into account when stone placement is planned: a) Stability of the placed material (Further information on rock armour is given in BS 6349-1.) b) Sinking of the placed material into the seabed, particularly where the grain size of the material exceeds that of the underlying seabed- it can be necessary to build up the protective gravel/stone cover in progressively graded layers c) Possible impact damage to pipe from falling stone during placement d) Dispersion of gravel or stone material during the placement operation. Dispersion can be reduced by the use of a fall pipe system. e) Damage to the coating as a result of rock or gravel placement. Protective matting (e.g. polypropylene sheeting) can be placed above the seabed to restrain the rock and limit the potential for rocks coming to	May deflect the anchor away from the pipeline. Dragging anchors that are well embedded are unlikely to be deflected.

	rest in contact with the pipe, which might result in coating damage.	
Grout bags and mattresses	The design of grout bag and mattress systems should take into account a) Stability under environmental loading b) Location of grout filling points for grout bag systems to allow safe and convenient access and operation c) Shape, size and flexibility of mattresses to enable accurate placement d) the effect of vessel motion when placing mattresses e) Likely scour effects f) The possible need to remove mattresses at some future date.	Could offer protection from anchor damage at sensitive areas or within shipping channels or harbour entrances
Protective structures	Protection for valve stations and tees can be accomplished by enclosing them in a protective structure. Protective covers can also be provided for pipelines. Design criteria for protective structures should include the following: a) Stability. The structure should remain stable under hydrodynamic and accidental loads, and avoid transferring such loads to the pipeline system. b) Profile. The structure should present a smooth profile to minimize the risks of snagging loads and of damage to fishing gear. c) Clearances. In determining clearances between the pipeline system and the structure, account should be taken of settlement of the structure foundations and pipeline expansion movements accidental loads d) Access for maintenance and repair e) Allowable stresses. Stresses in the protective structure should be analysed for installation load conditions (including submerged, in air and passing through the splash zone) and in-place load conditions. NB Analyses are given in BS 5400 for steel and BS 8110 for concrete. f) Access. Provision should be made for safe access to the structure for inspection and maintenance. Account should be taken of the risk of detachable access panels being dropped or becoming jammed. g) Cathodic Protection (CP). The design of the CP for the pipeline should be isolated from that of the structure.	Could offer protection from anchor damage at sensitive areas or within shipping channels or harbour entrances

References

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