MANUAL

PIPELINE/TRAWLGEAR INTERACTION

DEP 31.40.10.17-Gen.

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the design of submarine pipelines against loads from trawlgear interaction. This also includes predicting the local response of the pipeline due to impact loads and the global (bending) response of the pipeline due to pullover loads and defines acceptance criteria for the integrity of the pipeline following the interaction event.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors nominated by them (i.e. the distribution code is "C", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use on offshore pipelines.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties supplied by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

The following specific definitions and terminology are used in this DEP:

Beam shoe: The two shoes attached at each end of a trawl beam, which provide the connection points for the towing chains and the net.

Beam trawl: The combined trawl beam and beam shoes assembly.

Denting: Local deformations of the wall of the pipeline, primarily due to transient loads at the moment of impact.

Hooking: Trawlgear snagging on a pipeline preventing the passage of the trawlgear.

Pullover: Trawlgear movement over and past the pipeline, typically inducing loads on the pipeline that last several seconds.

Sweep line: The tow wires between each otter trawl board and the net.

Trawl beam: The steel beam between the two beam shoes.

Trawl board: The door beam between the two beam shoes.

Trawlgear: The seabed equipment used for trawling. In the context of trawlgear/pipeline interaction, this primarily constitutes the trawl beam and the two beam shoes for beam trawling, and the two trawl boards for otter trawling.

Warp line: The tow wire connecting the trawler vessel to the seabed trawl board or trawl beam.

1.4 NOTATION

The following notation (with appropriate SI units) is used in this DEP:

α	coefficient of linear thermal expansion ($°C^{-1}$)
β	empirical factor
ρ	density of sea water (kg/m^3)
ϕ	directional weighting factor
κ	bending curvature (1/m)
γ	submerged weight of soil (N/m^3)
μ	lateral friction coefficient
ν	Poisson's ratio
∇	displaced volume of trawlgear
A	cross-sectional area of pipe steel(m^2)
A_e	half area of pipe cross-section embedded below the seabed (m^2)
B	half trawl board height (m)
C_a	added mass coefficient
e	exposed proportion of the pipeline length
d_I	dent depth at impact (m)
E	Young's modulus (N/m^2)
E_I	impact energy (J)
F_p	total pullover force (N)
$\bar{F}_p$	dimensionless parameter group for determining F_p
F_z	vertical component of pullover force (N)
$\bar{F}_z$	dimensionless parameter group for determining F_p
F_r	lateral soil resistance (N/m)

f_c	crossing frequency (year $^{-1}$)
G	span gap below the pipe (m)
$\overline{G}$	dimensionless parameter group for span gap G
h	beam shoe attachment point height (m)
$\overline{H}$	dimensionless parameter group for attachment point height h.
I	fishing intensity (hours/km^2/year)
k	warp line elasticity (N/m)
m	mass (kg)
m_e	effective mass (kg)
N_e	effective axial force in pipeline (N)
OD	pipeline overall diameter including coatings (m)
OD_{st}	pipeline steel outside diameter (m)
P_i	pipeline internal pressure (N/m^2)
S_y	pipe yield stress (N/m^2)
t	pipeline steel wall thickness (m) or pullover duration(s)
$\bar{t}$	dimensionless parameter group for determining t (pullover duration)
ΔT	difference between the predicted maximum operating temperature and the temperature of the pipeline during installation (°C)
V	trawling velocity (m/s)
W	current value of the vertical foundation reaction per unit length (N/m)

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (6) and (7).

2. TRAWLING AND FISHING STATISTICS

2.1 TRAWLING AND TRAWLGEAR

Fishing activities employing bottom trawlgear along the route of a planned offshore pipeline need to be addressed during the design of that pipeline for two reasons:

- possible consequences of fishing activities on the integrity of the pipeline;
- possible hazards to fishermen from the presence of the pipeline.

Fishing activities employing bottom trawlgear can be categorised as otter trawling and beam trawling. The main difference is the type of trawlgear employed.

2.1.1 Otter trawling

Otter trawling is illustrated in (Figure 2.1). The figure shows a single vessel towing the net. Another form of otter trawling, pair trawling, is performed by two vessels each towing one side of the net.

The mouth of the net is held open by two trawl boards, one on each side of the net. The trawl boards are kept apart by hydrodynamic forces induced by the offset between the warp line (between the board and the vessel) and sweep line (between the board and net). The warp line lengths are typically two to three times the water depth.

A number of different types of trawl board are in use. Typical trawl boards are illustrated in (Figure 2.2).

NOTE: The four most common trawl boards used in the North Sea are the oval, polyvalent, 'V' shaped and rectangular shaped boards. The oval, polyvalent and rectangular trawl boards are steel-frame wooden structures. The oval and polyvalent trawl boards are used by most North Sea and Atlantic fishery nations. The rectangular trawl board is the traditional trawl board used by the fisheries of Western Europe, and its abrupt front edge may produce severe impacts with pipelines. The 'V' shaped board is an all-steel structure and is used by several nations fishing in the North Sea and the Atlantic.

2.1.2 Beam trawling

Beam trawling is illustrated in (Figure 2.3). The mouth of the net is held open on a transverse beam which slides across the seabed on shoes at each end of the beam. Currently metal beams are usually used, generally towed in pairs depending on the size of the vessel.

Details of a typical beam shoe are shown in (Figure 2.4). The beam shoes support the beam at a short distance above the seabed. The front edge of the shoe may be straight, sloping or curved. The ability of the shoe to ride over seabed obstructions can be improved by the use of "hoop bars" fitted to the front edge.

The beam is pulled by towing chains which are attached to each shoe. The towing chains are approximately the same length as the width of the trawl beam, and are connected to a single warp line through a towing block ahead of the beam. The warp line lengths are typically two to three times the water depth. The towing chains are attached to one of a number of towing points located on the front of each shoe.

2.2 FISHING STATISTICS

Fishing techniques are subject to constant change. Studies addressing interaction between pipelines and fishing activities should therefore always commence with a prediction of the fishing techniques and fishing intensity, based on:

- a review of available statistics;
- anticipated developments in the fishing industry.

The fishing data to be defined should include:

- trawling techniques;
- trawling velocities;
- gear type, mass and dimensions;
- direction (random, perpendicular or parallel);
- intensity.

NOTES:

1. Trawling intensity is conventionally defined in terms of hours fished per km^2 per year. Fishing statistics are usually held by the International Council for the Exploration of the Seas (I.C.E.S) and relevant Government organisations. For example, potential sources of fishing statistics for the North Sea are:
   Netherlands: Rijksinstituut voor Visserijonderzoek, IJmuiden
   Belgium: Ministère de l' Agriculture, Ostende
   England and Wales: Ministry of Agriculture, Fisheries and Food, Lowestoft
   Scotland: Department of Agriculture and Fisheries for Scotland, Aberdeen
   Norway: Fiskeridirektoratets Havforsknings Institut, Bergen
   Denmark: Danmarks Fiskeri- og Havundersøgelser, Charlottenlund

2. For otter trawls, typical trawling velocities and trawl board masses (1995 figures) are shown below:

Fishing Vessel	Trawlgear Velocity (knots)	Trawlgear Mass (tonnes)
French Stern	4.0	1.4
German Stern	4.5	2.2
Norwegian	5.0	2.3
UK Light	3.2	1.2
UK Motor	2.5	1.2

3. Typical trawling velocities for a Dutch beam trawl are up to 8 knots. Typical trawlgear masses are 2.4 tonnes for both shoes and 2.6 tonnes for the beam (1995 figures).

2.3 CROSSING FREQUENCY

The frequency of pipeline crossings is related to the fishing intensity by the expression

$$f_c = \phi e I V \qquad \text{(expression 2.1)}$$

Where f_c is the number of crossings per year per km length of the pipeline, I is the fishing intensity in fishing hours per km^2 per year, V is the trawling velocity, and e is the proportion of the pipeline length which is exposed and therefore potentially subject to trawlgear crossings.

The constant ϕ depends on the predominant trawling direction. Values of ϕ are shown in (Table 2.1).

Table 2.1 Trawling Directional Factor, ϕ

Trawling Direction	Constant ϕ
Randomly distributed	$2/\pi$
Perpendicular to the pipeline route	1
Parallel to the pipeline route	0

2.4 TRAWLGEAR/PIPELINE INTERACTION

The interaction event follows two distinct stages.

At the moment of contact, the pipeline experiences an impact force due to the deceleration of the trawlgear. This impact force may be of large magnitude but is of short duration. The impact force can lead to local damage of the pipe coatings and possibly denting of the wall of the pipeline.

The pipeline obstructs the movement of the trawlgear following impact. The pipeline then experiences a more steady force due to the tow force in the warp line, which is transmitted through the trawlgear onto the pipe. This force on the pipeline is commonly referred to as the pullover force. The force on the pipeline increases as the vessel motion continues up to a maximum when the trawlgear is pulled over the pipe. The force is of smaller magnitude than the impact force but acts over a much longer duration. The pullover force can lead to large displacements of the pipeline, and may lead to yield, large strains and possibly local buckling of the pipe.

Another more severe pullover scenario may occur if the trawlgear hooks under the pipeline and cannot be pulled clear by the vessel. In this case the vessel will ultimately be brought to a standstill by the pipeline. This hooking process will induce a large and continuous force on the pipeline.

FIGURE 2.1 OTTER TRAWLING

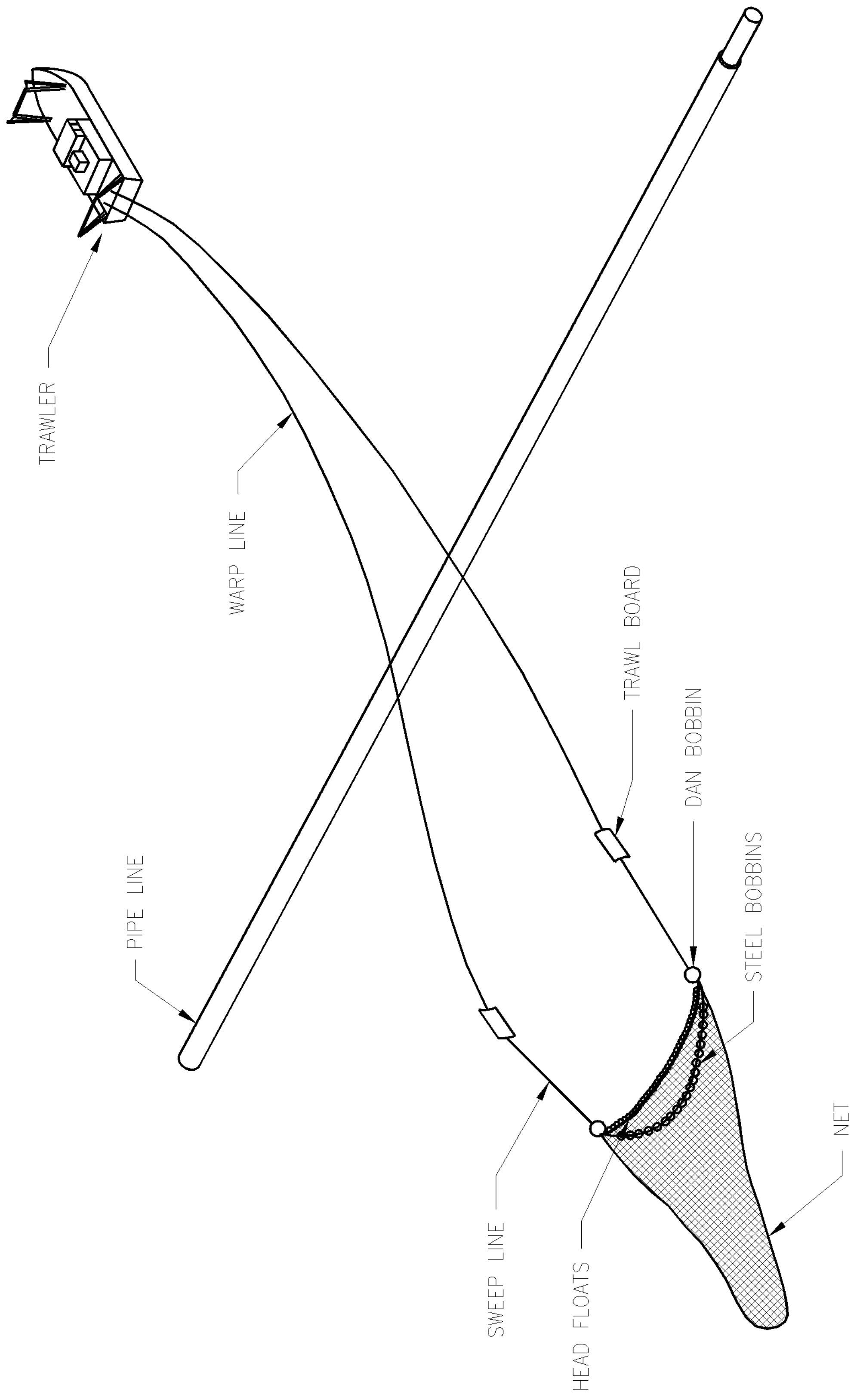


FIGURE 2.2 TYPICAL TRAWL BOARDS

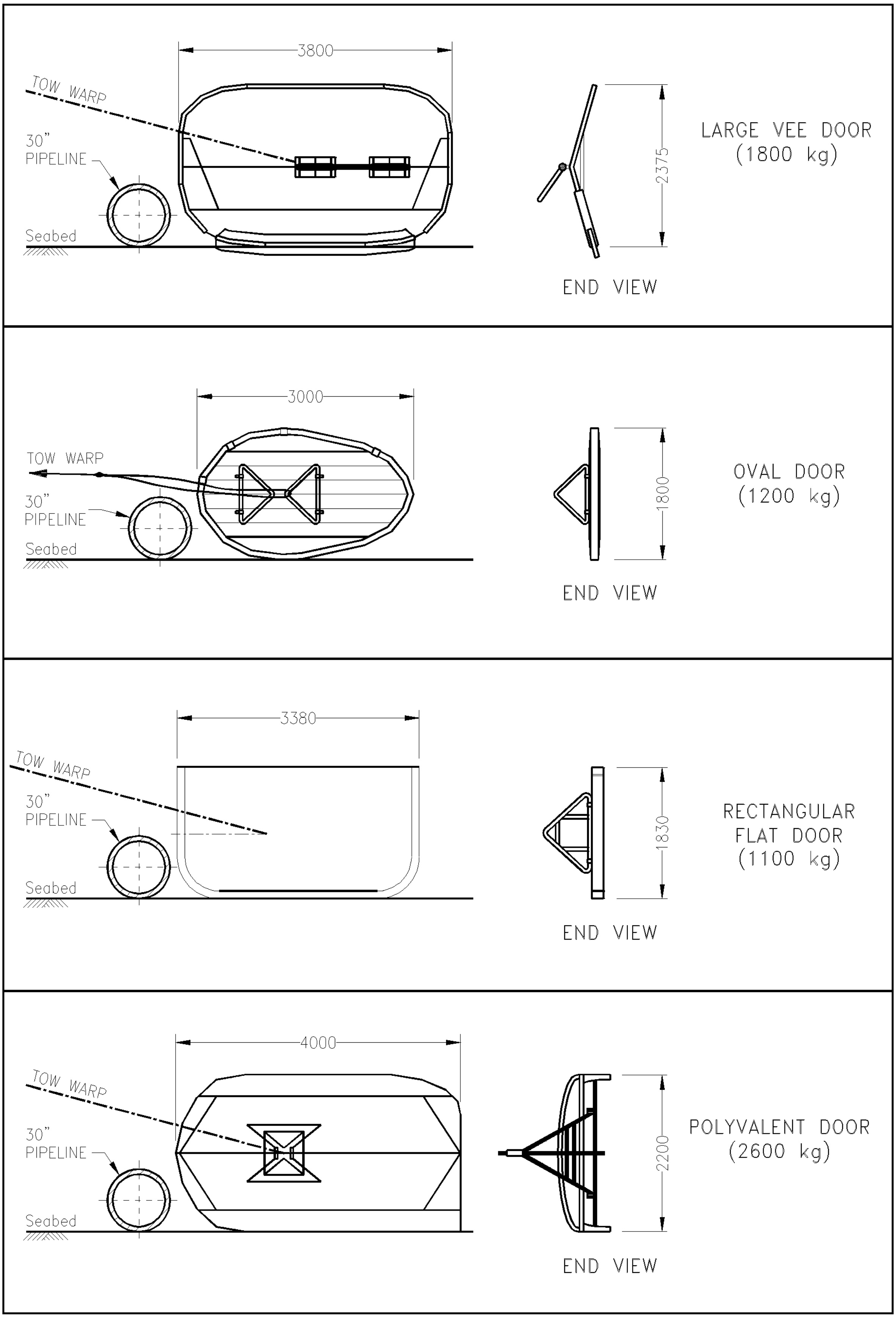


FIGURE 2.3 BEAM TRAWLING

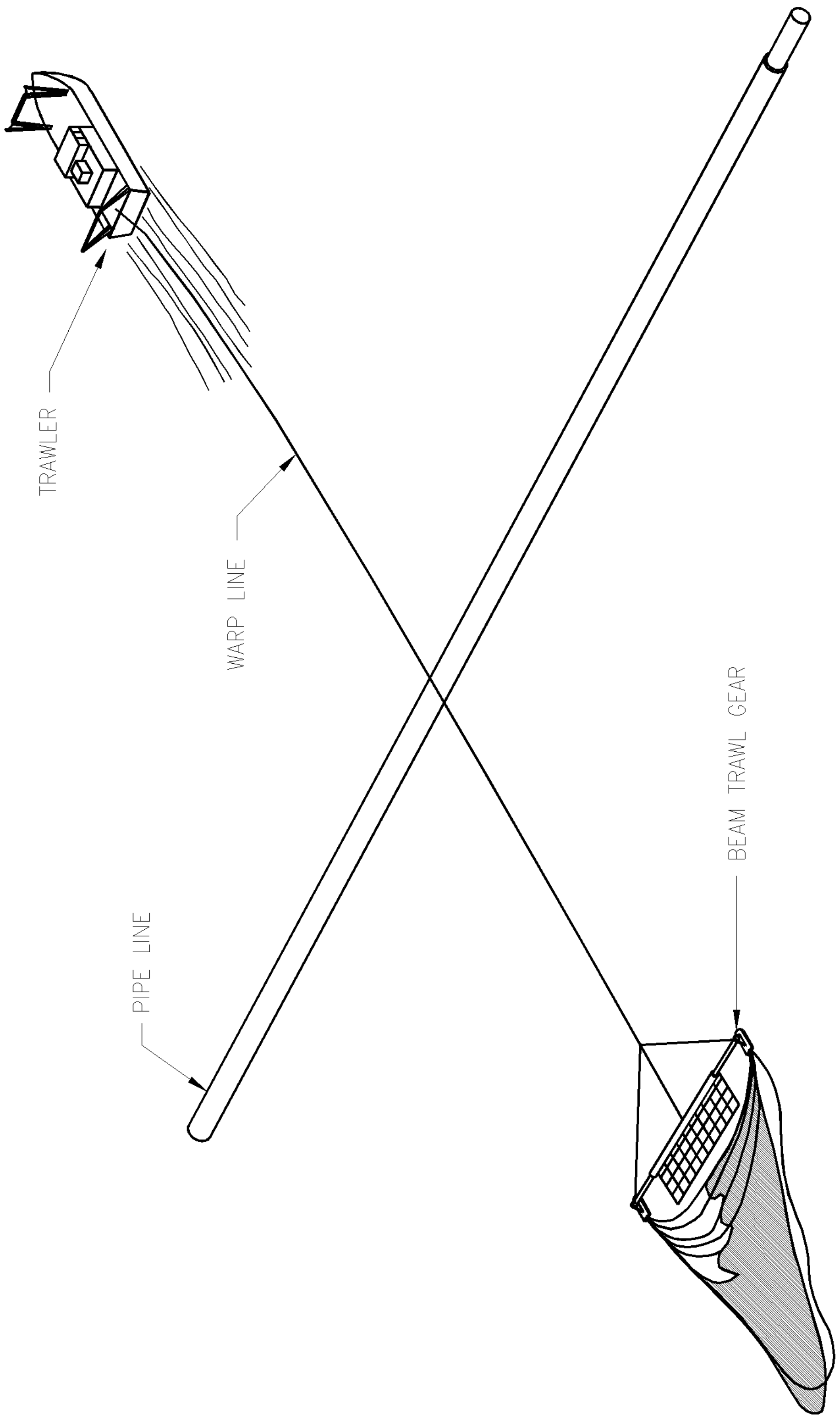
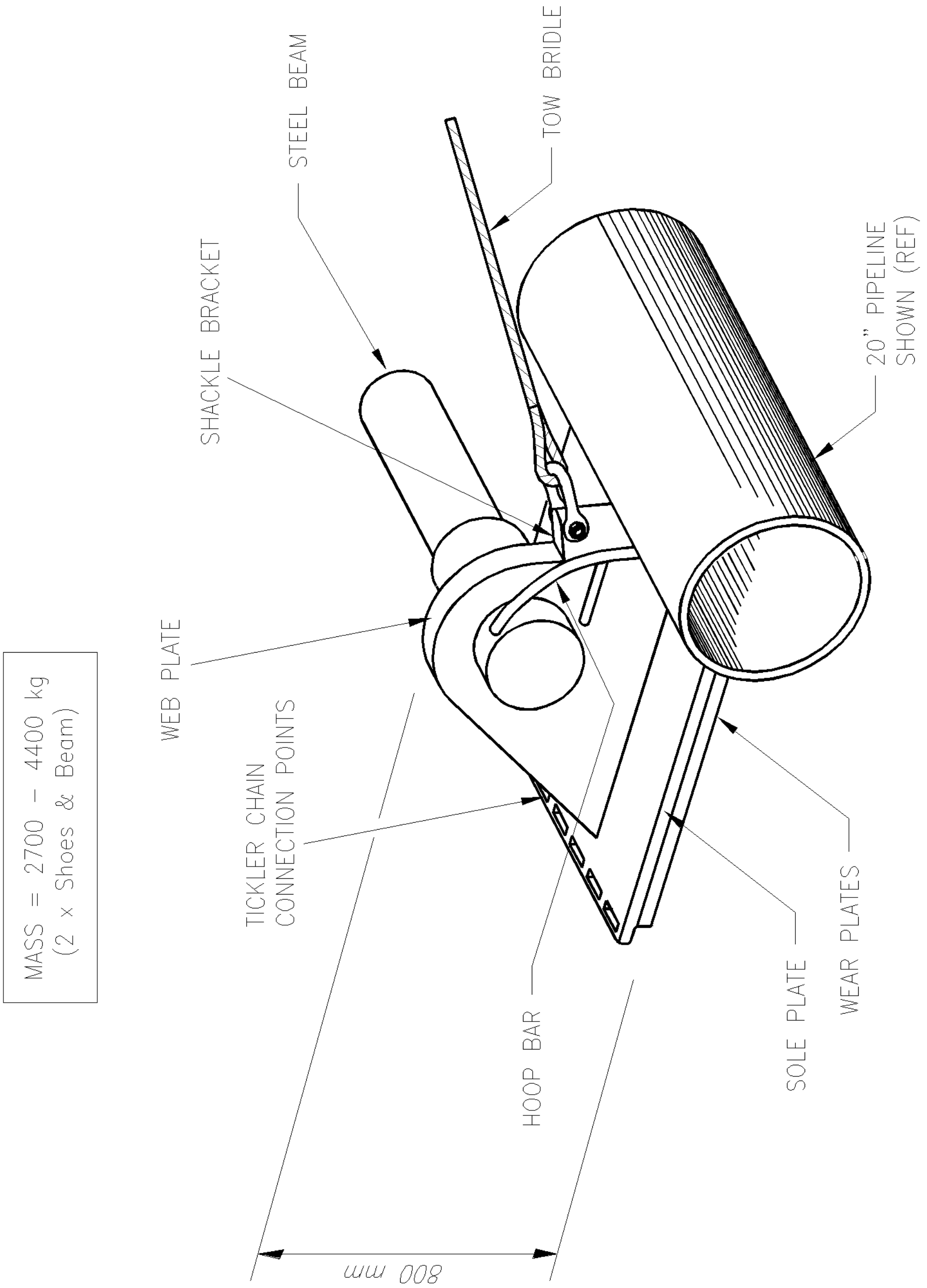


FIGURE 2.4 BEAM SHOE



3. IMPACT FORCES AND RESPONSE

3.1 IMPACT ENERGY

The impact energy to be absorbed by the pipeline, including coatings, may be conservatively assumed to be equal to the total kinetic energy of the trawl boards or beam. The total kinetic energy shall be calculated from:

$$E_I = \frac{1}{2} m_e V^2 \quad \text{(expression 3.1)}$$

Where m_e is the effective mass of the trawlgear, and V is the trawling velocity.

For trawl boards, the effective mass is equal to the sum of the mass of the trawl board and its hydrodynamic added mass.

For beam trawls, the effective mass may be assumed to be equal to the mass and hydrodynamic added mass of one beam shoe only. The effective mass of the beam and the other shoe may be ignored.

NOTE: The hydrodynamic added mass may be calculated from

$m_a = C_a \rho \nabla$

where ρ is the sea water density, ∇ is the displaced volume of the trawlgear, and C_a is the added mass coefficient. Unless more detailed data are available, the hydrodynamic added mass coefficient may be taken as equal to 1.

Lower values for the impact energy transferred to the pipeline may be used provided they can be justified. Possible causes of lower impact energy transfers which may be evaluated include:

- The trawlgear does not come to a full stop during the impact. This could, for example, occur when the contact point between trawlgear and pipeline is below the centre of gravity of the trawlgear, or following slip in an non-perpendicular impact;
- Deformation of trawlgear;
- Energy absorbed by the seabed.

3.2 COATING AND INSULATION

3.2.1 Damage

Damage to all pipeline coatings, including corrosion and weight coatings, and to field joints and insulation shall be considered.

The potential for damage shall take into account the frequency of pipeline crossings.

Where possible, damage should be determined from full-scale impact tests rather than theoretical analyses. All relevant coating and insulation properties, including water adsorption and ageing in seawater, should be simulated during impact testing.

NOTE: The response of a concrete weight coating to impact, including crushing, cracking and spalling, is complex and highly non-linear. The impact resistance is generally measured with a simple impact test using a heavy striker designed to simulate the impact energy of the trawlgear and its shape at the location of the impact, see DEP 31.40.30.30-Gen.

3.2.2 Damage acceptance criteria

Exposed metal due to damage of the corrosion coating shall be protected by the cathodic protection system. The cathodic protection design shall make an allowance for increases in current demand from the additional metal exposure.

A pipeline with insulation coatings should be buried unless protected by impact-resistant sleeving.

Damage of the concrete weight coating may be allowed if it can be demonstrated that the loss of weight coating is local and cannot result in horizontal and/or vertical pipeline instability.

3.3 PIPELINE RESPONSE

3.3.1 Damage

Impact damage to the pipe steel should take into account the energy absorbed by the concrete weight coating, if present. Reduction of impact energy by insulation and corrosion coatings should not be considered.

NOTE: The behaviour and influence of a concrete coating in terms of pipeline protection against local denting is complex. The capacity of the concrete coating to absorb the impact energy depends on the concrete thickness, elastic modulus, density, crushing strength, method of application and type of concrete reinforcement. Some experimental work has been performed to investigate how much of the impact energy is absorbed by a concrete weight coating. Methods for quantifying the protective effect of concrete coating against local denting are not readily available.

The impact force may lead to local deformation in the wall of the pipeline in the form of gouges, sharp indentations and/or dents.

Full-scale impact tests can be employed to indicate the likely extent of damage.

The dent depth may be determined by a conservative estimate from the following formulae:

Ellinas and Walker (7.1)

$$E_I = 25 S_y t^2 \sqrt{\frac{d_I^3}{OD_{st}}} \qquad \text{(expression 3.2)}$$

Wierzbicki and Suh (7.2)

$$E_I \sqrt{\frac{128\,\pi}{27}} S_y (t d_I)^{1.5} \qquad \text{(expression 3.3)}$$

where d_I is the dent depth, OD_{st} and t are the pipe steel diameter and wall thickness respectively, and S_y is the pipe yield stress.

NOTE: The Ellinas-Walker denting model is based on a semi-empirical analysis, supported where necessary by experimental observations. The model assumes that the impact energy is dissipated locally, and that the denting process takes place at a sufficiently slow rate. The Wierzbicki and Suh denting model is based on a simplified theoretical analysis of a cylindrical shell under a line indentor. The work done by the indentor is equated to the work dissipated plastically as the pipeline deforms. The model includes some bold simplifications but agrees with experimental results.

The dent depth will decrease following impact due to relaxation of the dent under the internal pressure of the pipeline. Empirical correlations may be used to determine the ratio of the residual dent depth to the initial dent depth as a function of the pipeline diameter to wall thickness ratio and the internal pressure.

NOTE: The ratio of the final to initial dent depth has been investigated by Maxey (7.3).

3.3.2 Acceptance criteria

An impact acting on the pipe should not result in any of the following damage:

- gouges and sharp indentations;
- plastic deformation of longitudinal seams;
- plastic deformation of girth welds unless these welds have sufficient ductility to accommodate the predicted deformation;
- diameter variations, measured across the pipeline and through the centre, in excess of 5% of the nominal diameter.

NOTE: The above criteria apply during the design of a pipeline. Different criteria may be used when evaluating a defect discovered during the inspection of a pipeline in operation.

4. PULLOVER FORCES AND RESPONSE

4.1 PULLOVER FORCE-TIME HISTORY

The pipeline temporarily restrains the motion of the trawlgear following impact. The vessel continues its path away from the trawlgear and the tow force increases due to the stretching of the warp line.

The increase in the force on the warp line is due to the increase in the relative distance between the vessel and trawlgear, and is determined by the trawling velocity of the vessel and the dynamic response of the pipeline. The interaction between the pullover force and the response of the pipeline may be ignored and the force and response considered separately.

NOTE: The warp line can be considered as a catenary under tension. The elasticity of the warp line is primarily due to the tightening of the warp catenary rather than axial extension of the warp line.

4.2 TRAWL BOARD PULLOVER

The motion of a trawl board during pullover is complex and three-dimensional, and is influenced by hydrodynamic forces which are difficult to predict. Predictions of pullover force-time histories for trawl boards should be based on experimental data.

The measured time-history of the pullover force is illustrated in (Figure 4.1 A/B). The force-time history depends on the type of board; in general the force rises up to a maximum as the board starts to lift over the pipeline and then decreases as the board clears the pipeline. The maximum trawl board pullover force and duration may be determined from the following dimensionless groups:

$$\overline{F}_p = \frac{F_p}{V\sqrt{mk}} \qquad \text{(expression 4.1)}$$

$$\overline{F}_z = \frac{F_z}{V\sqrt{mk}} \qquad \text{(expression 4.2)}$$

$$\bar{t} = \frac{t}{V\sqrt{m/k}} \qquad \text{(expression 4.3)}$$

$$\overline{G} = \frac{G + OD/2}{B} \qquad \text{(expression 4.4)}$$

where F_p and F_z are the total force on the pipeline and the vertical force component respectively (both in units of N), t is the pullover duration (in sec), V is the trawling velocity (in m/sec), m is the trawl board mass (in kg), OD is the overall pipe diameter (in m), k is the effective elasticity of the warp line catenary (in N), B is half the board height (in m), and G is the span height below the pipe (in m).

For polyvalent boards:

$$\overline{F}_p = 8.7\left[1 - e^{-0.8\overline{G}}\right] \qquad \text{(expression 4.5)}$$

$$\overline{F}_z = \left[0.2 + 0.8e^{-2.5\overline{G}}\right]\overline{F}_p \qquad \text{(expression 4.6)}$$

$$\bar{t} = 2.0\overline{F} \qquad \text{(expression 4.7)}$$

For rectangular and vee boards:

$$\overline{F}_p = 5.4\left[1 - e^{-1.3\overline{G}}\right] \qquad \text{(expression 4.8)}$$

$$\overline{F}_Z = 0.5\overline{F}_P \qquad \text{(expression 4.9)}$$

$$\bar{t} = 2.0\overline{F}_P \qquad \text{(expression 4.10)}$$

These expressions are applicable to pipe diameters from 300 (12") up to 700 (28") and beam masses up to 2600 kg. The expressions should not be used outside these limits of applicability without further validation.

NOTE: These expressions have been developed during a review of all available experimental data for trawl board/pipeline interaction.

4.3 BEAM TRAWL PULLOVER

Beam shoes are generally smaller than trawl boards. The movement of the shoe during pullover is largely restricted to displacement and rotation around the axis of the trawl beam only. Predictions of pullover force time-histories may be based on either experimental data or theoretical modelling.

The typical measured time-history of the pullover force acting is illustrated in (Figure 4.2). The pullover force rises following the initial impact up to a peak force as the shoe is lifted over the pipeline. The force then drops to an intermediate level as the shoe slides over the pipeline, and then drops rapidly as the shoe moves clear of the pipeline.

$$\bar{F}_p = \frac{F_p}{V\sqrt{mk}} \qquad \text{(expression 4.11)}$$

$$\bar{t} = \frac{t}{\sqrt{m/k}} \qquad \text{(expression 4.12)}$$

$$\bar{H} = OD / h \qquad \text{(expression 4.13)}$$

where F_p and t are the peak pullover force on the pipeline and pullover duration (in units of N and s respectively), V is the trawling velocity (in units of m/s), m is the mass of the beam and two shoes (in kg), OD is the overall pipe diameter (in m), k is the effective elasticity of the warp line catenary (in N), and h is the attachment point height of the tow bridle.

For $\bar{H} < 2.0$ the following may be assumed:

$$\bar{F}_p = 4.4 \qquad \text{(expression 4.14)}$$

$$\bar{t} = 1.4\bar{F}_p \qquad \text{(expression 4.15)}$$

For $2.0 \le \bar{H} < 3.5$ it may be assumed that:

$$\bar{F}_p = 6.4 - 1.0\bar{H} \qquad \text{(expression 4.16)}$$

$$\bar{t} = (1.0 + 0.2\bar{H}).\bar{F}_p \qquad \text{(expression 4.17)}$$

These expressions are applicable to pipe diameters from 400 (16") up to 900 (36") and beam masses up to 4375 kg. The expressions shall not be used outside these limits of applicability without further validation.

NOTE: These expressions have been developed during a review of all available experimental data for beam shoe/pipeline interaction. Data which describe the vertical component of pipe force during beam trawl crossings are not available.

Pullover force-time histories for beam trawl interaction may be predicted using theoretical models provided that the model has been validated using test or field data. (7.4) describes an example of such a model for the dynamic analysis of the motion of the shoe of a beamtrawl over the pipeline.

4.4 SOIL RESISTANCE

The deflections of the pipeline during the pullover event are restrained by soil friction.

Axial soil resistance shall be represented by linear Coulomb friction. Unless accurate information is available, a low value of the axial friction coefficient should be adopted to provide conservative predictions of pipeline displacement.

Lateral soil resistance acting on a pipeline is composed of both linear Coulomb friction resistance and passive resistance due to the embedment of the pipe. Lateral soil resistance should be represented by either a combined linear and passive model, or by a linear model where the effective friction coefficient is chosen to reflect the additional passive resistance.

The passive resistance for a pipeline which is moving in a single direction will not be the same as the passive resistance for a pipeline which moves cyclically under hydrodynamic storm loading. The soil resistance force chosen shall be appropriate for unidirectional movement.

The sensitivity of the predicted displacements to the lateral friction coefficient depends on the relative contributions of the pullover force and the effective axial force in the pipeline. A low lateral friction coefficient leads to conservative predictions of the bending moments due to the pullover force alone, but may lead to non-conservative predictions of the bending moments if the displacement is dominated by the compressive axial force in the pipeline. The sensitivity of the displacement to the lateral friction coefficient should be investigated.

The presence of any vertical pullover force will increase the reaction force between the pipeline and soil and will increase the frictional and passive soil resistance. Any down force should be included in the lateral soil resistance, but shall not be included in the axial soil resistance.

NOTE: Most pipelines are partially embedded in the seabed, and the resulting passive resistance provides a significant increase in the lateral resistance to pipeline movement. Pipeline stability research (7.5) has shown that, for small degrees of embedment, the overall lateral resistance to pipeline movement in sand and clay may be written in the form

$$F_R = \mu W + \beta \gamma A_e$$

in sand, and

$$F_R = \mu W + \beta c A_e / OD$$

in clay. Here W is the current value of the vertical foundation reaction per unit length, μ is the effective friction oefficient, A_e is half the area of the segment of the pipe cross-section embedded below the seabed, and β is an empirical factor. For sand, γ is equal to the submerged unit weight. For clay, c is equal to the undrained shear strength.

The passive resistance component increases with lateral movement. Continued pipeline movement pushes a growing heap of seabed soil in front of the pipeline, which adds to the passive resistance force. This effect may be allowed for by an increase in the empirical factor β .

4.5 PIPELINE RESPONSE

4.5.1 Pipeline behaviour

The pullover force on the pipeline causes the pipeline to deflect sideways. The pipeline response is induced by the combined action of the pullover force and the effective axial force in the pipeline, and is opposed by axial and lateral soil resistance, and the bending stiffness of the pipeline.

The behaviour of the pipeline is influenced by the dynamic response of the pipeline, large displacement (second order) structural effects, and possible plastic deformations located at the point of contact between the trawlgear and the pipeline.

4.5.2 Pullover analyses

Models for predicting the pullover behaviour of pipelines should be capable of accounting for:

- The effect of the effective axial force in the pipeline. The effective axial force may be conservatively assumed to be equal to the fully constrained axial force,

$$N_e = EA\alpha\Delta T + (1-2\nu)p_i \frac{\pi D^2}{4} \qquad \text{(expression 4.18)}$$

  where EA is the axial stiffness of the pipeline, α is the thermal expansion coefficient, ν is Poisson's ratio, P_i is the internal pressure, and ΔT is the temperature difference above ambient. Lower compressive forces should be considered where the pipeline is not fully constrained.

  Residual lay tension should not be considered when determining the axial force for a pullover calculation.

  NOTE: For the majority of subsea pipelines, the fully constrained axial force is large enough to contribute to significant lateral displacement via an Euler buckling instability. Euler buckling may contribute to rapid deflections of the pipeline which may have an effect on the transient behaviour of the pipeline and on the pullover loads.

- Change in the effective axial force from pipe elongations due to the horizontal deflections.

  NOTE: The lateral displacement during pullover induces a tensile elongation in the pipeline, which generates a tensile force component (i.e. reduces the compressive force in the pipeline) and pulls in straight lengths of pipeline on either side of the deflected section. The axial feed-in movement is opposed by axial friction. An equilibrium is obtained between the tensile elongation force in the displaced section and the axial friction generated in the feed-in zones on either side. This axial friction, and any other axial restraint forces, oppose pullover displacements.

- Elastic-plastic material response if elastic stresses are exceeded.

- Transient pipeline dynamics and inertia.

  NOTE: The pipeline inertia will resist the acceleration during the initial stage of the pullover and the deceleration at the end of the pullover.

- Hydrodynamic drag and inertial loads on the pipeline.

  NOTE: The hydrodynamic drag and inertial forces will generally act to limit deflections, but the hydrodynamic added mass will also maintain pipe deflections following the peak of the pullover force. Hydrodynamic forces on the pipeline may be predicted using the Morison equation, with suitable choice of drag and inertia coefficients.

A concrete weight coating increases the global bending resistance and axial stiffnesses of the pipeline, and increases the ultimate bending moment of the cross-section. However, the coating is discontinuous and can lead to the localisation of bending strains at uncoated field joints. The bending and axial stiffness of the concrete coating should only be considered in conjunction with the effect of localisation of bending strains at field joints.

It is not necessary to account for the effect of hydrodynamic loads from current and wave action during pullover.

For trawl board pullover, the downward vertical component $\bar{F}_z$ may be used to calculate contact form between pipe and seabed for determining the lateral friction.

4.6 PULLOVER ACCEPTANCE CRITERIA

The maximum equivalent stress in the pipeline during the pullover event should be less than permitted in DEP 31.40.00.10-Gen.

The equivalent stress criterion may be replaced by a strain criterion if the effective axial compressive force N_e causes the stresses to exceed the allowable limits.

NOTE: Deflections due to the axial compressive force are self-limiting due to the elongation of the pipeline during the horizontal movement.

The pipeline shall also be checked against the possibility of local buckling and excessive ovalisation.

4.7 WORKED EXAMPLE

(Appendix A) contains two examples for determining the pullover force-time history using the expressions in (4.2) and (4.3).

FIGURE 4.1A TRAWL BOARD PULLOVER FORCE-TIME HISTORY FOR POLYVALENT BOARDS

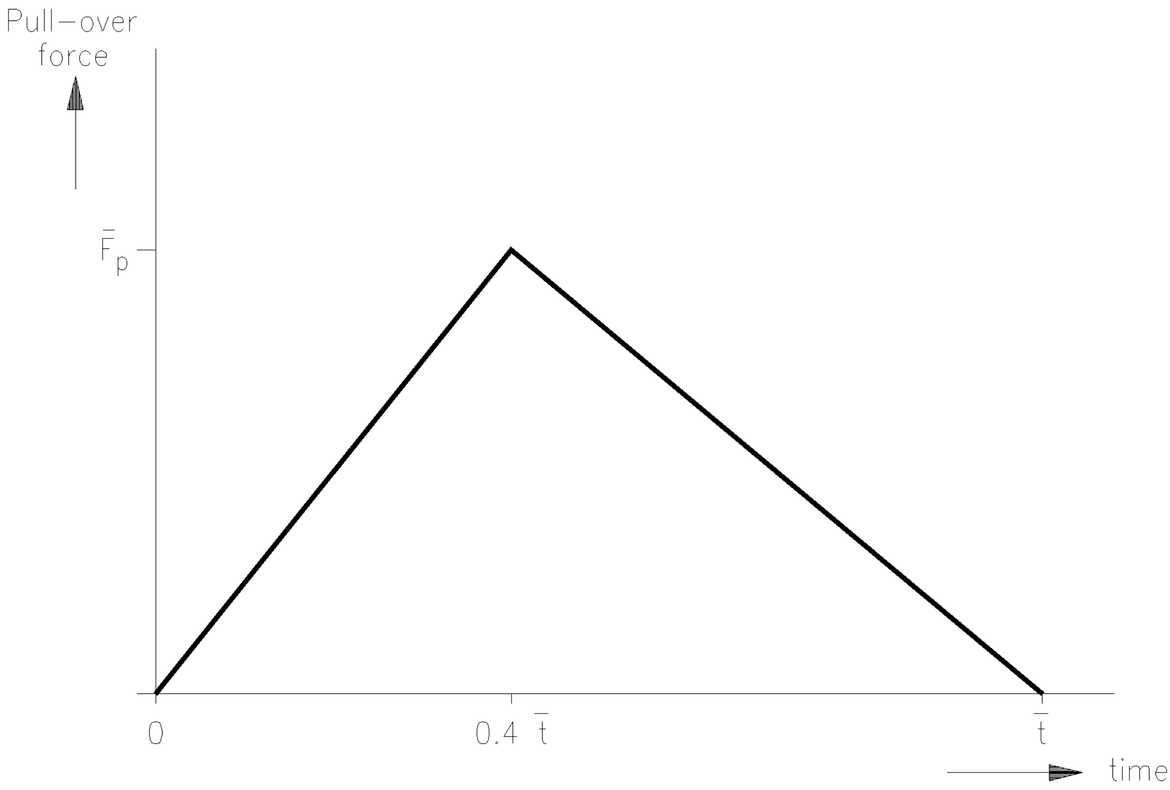


FIGURE 4.1B TRAWL BOARD PULLOVER FORCE - TIME HISTORY FOR RECTANGULAR AND V BOARD

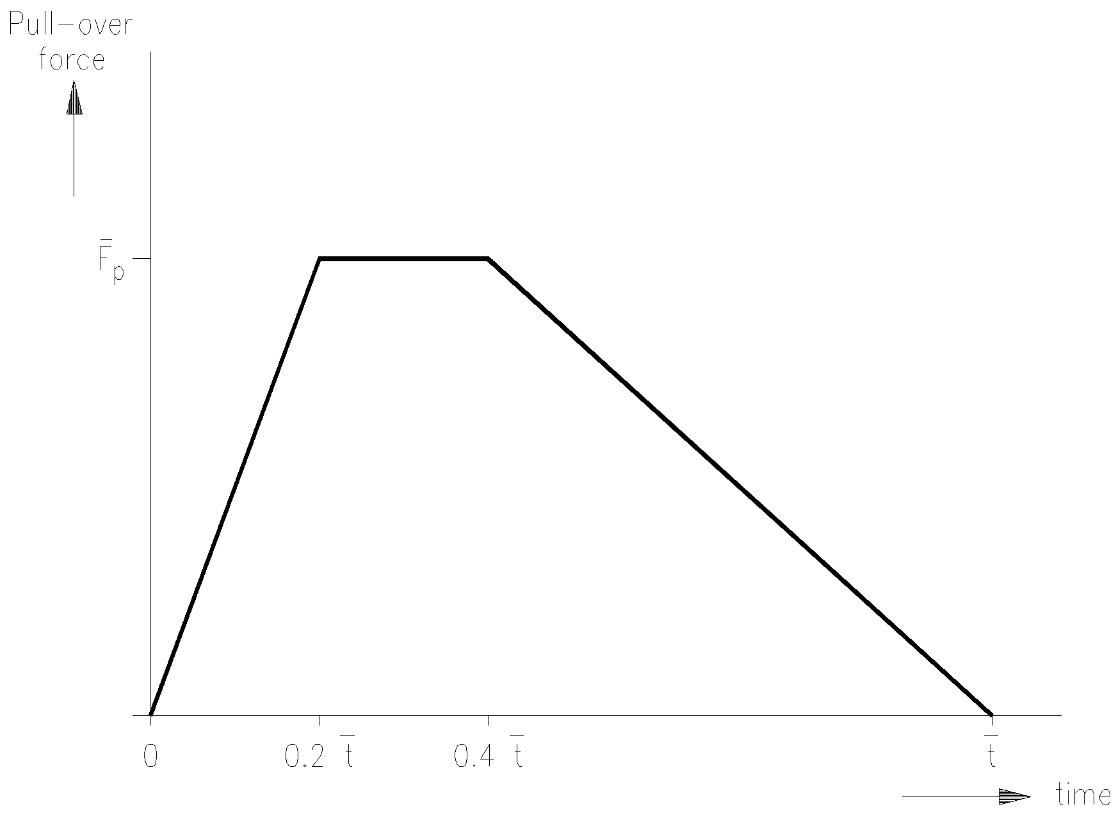
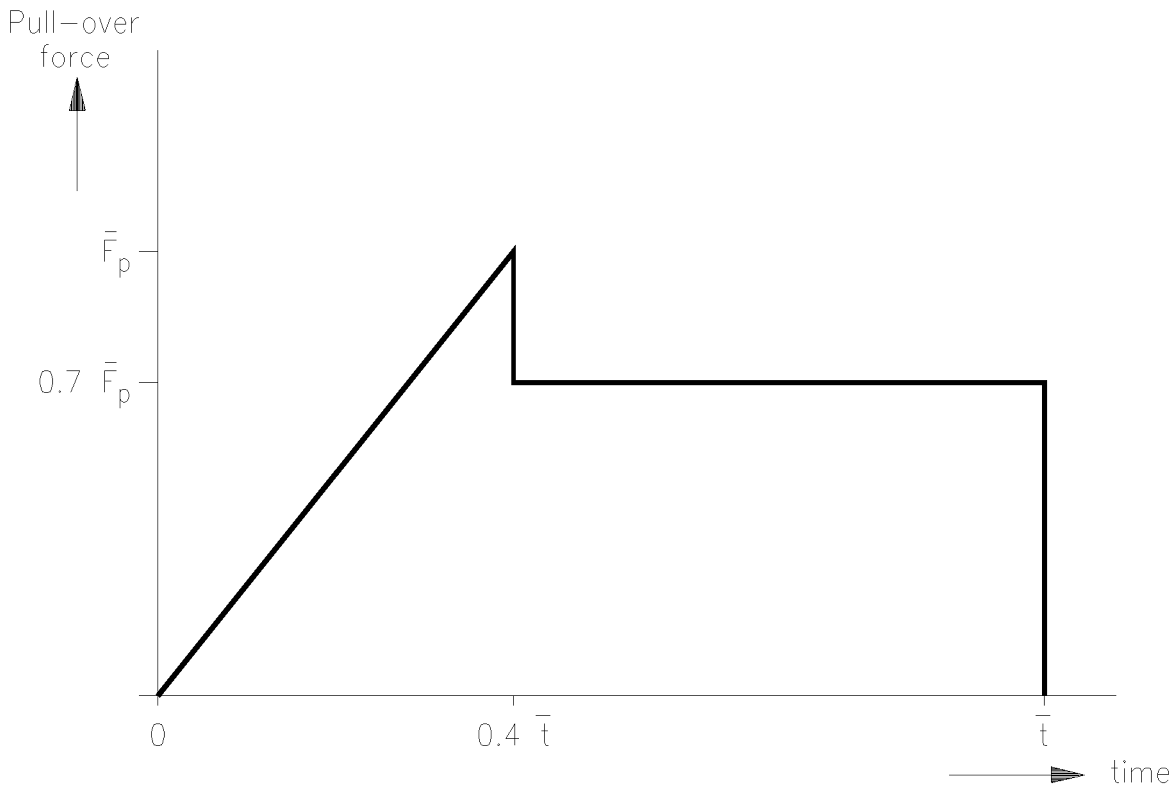


FIGURE 4.2 BEAM SHOE PULLOVER FORCE - TIME HISTORY



5. HOOKING

Hooking occurs when the trawlgear becomes stuck or fastened in some unspecified way to the pipeline. In this case the vessel will ultimately be brought to a standstill. Hooking is often temporary, but may be permanent in which case the vessel may need to free the trawlgear from under the pipeline.

Hooking is a potential problem with trawl boards. The board may be temporarily dragged along the seabed in a flat orientation (usually after the door has been knocked over by an obstruction). The board may then hook under a pipeline.

6. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Pipeline engineering	DEP 31.40.00.10-Gen.
Concrete coating of linepipe	DEP 31.40.30.30-Gen.

7. BIBLIOGRAPHY

NOTE: The following documents are for information only and do not form an integral part of this DEP.

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2. Wierbicki T. and Suh M-S. Denting Analysis of Tube Under Combined Loadings. Massachusetts Institute of Technology, MIT Sea Graant College Program, Report MITSG 86-5 (1986).
3. Maxey W.A. Serviceability of Damaged Line Pipe Rated. Oil and Gas Journal (15 June 1987).
4. Guijt, J. and Horenberg, J.A.G. An Analytical and Experimental Analysis of Trawlgear-Pipeline Interaction. Offshore Technology Conference, Houston, Texas. Paper OTC 5617 (1987).
5. Wagner D.A., Murff J.D., Brennoden H., Sveggen O. Pipe-Soil Interaction Model. Offshore Technology Conference, Houston, Texas. Paper OTC 5504 (1987).
6. Guijt, J. and Horenberg, J.A.G. Recent Investigations Concerning the Effect of Bottom Trawlgear Crossings on Submarine Pipeline Integrity. Offshore Technology Conference, Houston, Texas. Paper OTC 5616 (1987).
7. Langner C.G. Inelastic Analysis of Suspended Pipe Spans. Technical Progress Report WRC 198-76 (1977).

APPENDIX A WORKED EXAMPLES

A.1 SCOPE

The two examples in this appendix illustrate the application of DEP 31.40.10.17-Gen. for the calculation of the force-time history from trawl gear during pullover. The response of the pipeline to impact is not considered.

A.2 EXAMPLE 1 - GERMAN STERN TRAWL

A.2.1 Pipeline and stern trawl data

This worked example is for a 500 (20”) natural gas pipeline in the Central North Sea. The pullover force resulting from an interaction with a German Stern Trawler using a vee type trawl board is considered.

It is assumed that the pipeline is resting on the seabed fully exposed but without spanning.

Table A.1 - Input

PARAMETER	UNITS	VALUE
Pipeline:		
Pipeline overall diameter including coatings (OD)	m	0.720
Trawl board:		
Trawling velocity (V)	m/s	2.3
Trawl board mass (m)	kg	2,200
Half board height (B)	m	1.125
Effective elasticity of warp line (k)	N/m	150,000

A.2.2 Pullover force-time history

The procedure for determining the pullover force-time history for a trawl board interaction event is defined in (4.2). The pipe diameter OD = 0.720 m and board mass m = 2200 kg in this example are within the limits of applicability of the expressions given in (4.2).

The dimensionless span gap parameter is given by (expression 4.4). For G = 0 m (no spanning) and B = 1.125 (half the board height), the dimensionless value can be calculated as:

$$\bar{G} = (0+.720 / 2) / 1.125 = 0.32$$

For a vee board of the type being considered, the dimensionless total pullover pipe force $\bar{F}_p$, the dimensionless vertical force $\bar{F}_z$ and the dimensionless pullover time $\bar{t}$ are given by (expresions 4.8), (expression 4.9) and (expression 4.10) respectively.

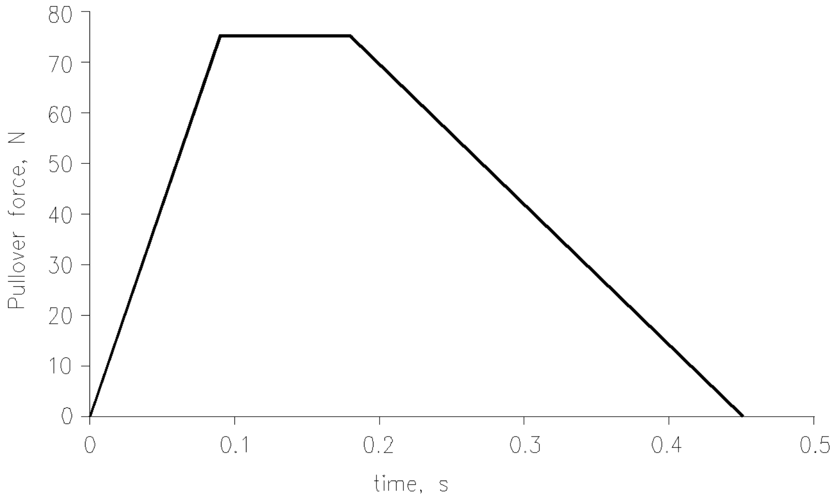
The dimensionless maximum total pullover force is $\bar{F}_p = 5.4 * (1 - e^{1.3*.32}) = 1.84$, the dimensionless vertical force is $\bar{F}_z = 0.5 * \bar{F}_p = 0.92$, and the dimensionless time $\bar{t} = 2.0 * 1.84 = 3.68$.

The maximum total pullover force then follows from (expresion 4.1) as $\bar{F}_p = 1.84 * 2.3 * \sqrt{2{,}200 * 150{,}000} = 76.9$ kN. The maximum horizontal force follows from (expression 4.2) and is $\bar{F}_z = 0.92 * 2.3 * \sqrt{2{,}200 * 150{,}000} = 38.4$ kN.
Finally, the duration of the pullover event is determined from (expression 4.3), which results in $t = 3.68 * \sqrt{2{,}200 / 150{,}000} = 0.45$ s.

The force-time history can now be constructed from Figure 4.1B. The maximum force occurs at 0.2*0.45 = 0.09 s and will last until 0.4*0.45 = 0.18 s following commencement of pullover.

The resulting plot of time-history of the pullover force is given in (Figure A.1) below.

FIGURE A.1 TRAWL BOARD PULLOVER FORCE-TIME HISTORY



A.3 EXAMPLE 2 - DUTCH BEAM TRAWL

A.3.1 Pipeline and beam trawl data

This example addresses the pullover force from a Dutch Beam Trawl on a 750 (30") natural gas pipeline in the Central North Sea. It is assumed that the pipeline is resting on the seabed without spanning and without any burial.

Table A.2 - Input

PARAMETER	UNITS	VALUE
Pipeline:		
Pipeline overall diameter including coatings (OD)	m	0.954
Beam trawl:		
Trawling velocity (V)	m/s	3.4
Trawl beam shoe mass (m)	kg	900
Beam mass	kg	2,200
Attachment point height (h)	m	0.3
Effective elasticity of warp line (k)	N/m	150,000

A.3.2 Pullover force-time history

The procedure for estimating the pullover force time history for the beam trawl interaction event is defined in (4.3). The total outside pipe diameter OD = 0.954 m and the total beam trawl mass m = 2 * 900 + 2,200 = 4,000 kg for this example are within the limits of applicability of the semi-empirical expressions given in (4.3).

The dimensionless attachment point height $\overline{H}$ is given by (expression 4.13). For OD = 0.954 m and h = 0.3 m, the dimensionless attachment point height can be calculated as:

$\overline{H}$ = 0.954 / 0.3 = 3.18.

The value of 3.18 lies between 2.0 and 3.5, therefore the dimensionless total pullover force and time are given by (expression 4.16) and (expression 4.17) respectively and are calculated as:

$\bar{F}_p = 6.4 - 1.0 * 3.18 = 3.22$ and $\bar{t} = (1.0 + .2 * 3.18) * 3.22 = 5.27$, with both parameters dimensionless.

The maximum total pullover force is determined from (expression 4.11) using m = 4000 kg and k = 150,000N, as: $\bar{F}_p = 3.22 * 3.4 * \sqrt{4{,}000 * 150{,}000} = 300$ kN.

The pullover duration is determined from (expression 4.12) as:

$t = 5.27 * \sqrt{4{,}000 / 150{,}000} = 0.86$ s.

The force-time history can then be constructed from (Figure 4.2) with the maximum pullover force of 300 kN occurring after 0.4*0.86 = 0.34 s after commencement of pullover, and a plateau force for the remaining pullover period of 0.7*300 = 210 kN.

The resulting plot of time-history of the pullover force, to be used for the pipeline response calculations, is given in (Figure A.2).

FIGURE A.2 BEAM TRAWL PULLOVER FORCE-TIME HISTORY