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Assessment of Anchor Dragging on Gas Pipelines

T Sriskandarajah and R Wilkins
Halliburton KBR Pipeline Engineering Group
Springfield Drive, Leatherhead, Surrey, KT22 7ND, UK

ABSTRACT

Pipelines laid on the seabed in shallow water locations in areas of shipping movements are susceptible to the effects of anchor dragging. Risks to safety and environment from anchor interaction are usually made via a Quantitative Risk Assessment. As part of the assessment it is necessary to quantify the potential damage from a wide range of vessels. This paper investigates the potential for mechanical damage to a pipeline from the effects of various vessel and anchor configurations. Finite Element analysis is used to assess the integrity of a pipeline to the dynamic effects of ships anchor interaction. The effects of soil conditions and partial burial of the pipeline are considered.

KEY WORDS: Anchor Dragging; subsea pipelines; Finite Element Analysis; Pipe-Soil Interaction

INTRODUCTION

The current trend towards allowing pipelines to rest un-trenched on the seabed has led to some concerns regarding third-party activity. In shallow waters, where pipelines are laid across shipping channels, there is a risk of vessels slipping their moorings and drifting across the locations of pipelines. Commercial shipping is not equipped to anchor in deep waters, where the risk to pipelines comes from offshore construction vessels, exploration and drilling rigs equipped for deep water anchoring. In cases where it is necessary to route gas pipelines through shipping lanes close to ports, the possibility of vessel interaction poses a real threat. Soft, silty-clay sediments do not make for good anchorages and where strong currents are exist it is possible for vessels to slip their moorings and drift, dragging their anchors across pipelines.

The risks to safety, environmental pollution and the need to replace or repair a damaged section of pipeline following an accident are usually made via a Quantitative Risk Assessment (QRA), see for example, de Jonge, M, 1997. As part of the QRA it is necessary to perform a hazard analysis, in which the effects of mechanical damage from various vessel sizes are quantified.

This paper presents an assessment of anchor loads on pipelines and the extent to which potential damage may be inflicted on a pipeline. Pipeline characteristics, in terms of buoyant weight, stiffness, concrete coating all have a significant effect on the behaviour of a pipeline subjected to third-party activity. Previous work (Al-Warthan et al, 1993) considered the effect of ship anchor impact on a freespanning offshore pipelines. Interaction cases considered by Al-Warthan et al were those of a dropped anchor (ramped loading) and hooking onto a freespan. The present work considers the case of anchor dragging onto a pipeline resting on a continuous seabed and a partially buried pipeline.

Anchor types and design parameters such as fluke area, penetration depth etc. are examined in terms of their effect on anchor holding capacity. The effects of vessel characteristics and types of mooring lines on anchor penetration are also considered. In soft soils anchor penetrations are deeper and drag lengths longer than in denser material. This affects the mechanism of contact between an anchor and a pipeline and subsequently the potential for damage to be inflicted on a pipeline.

The extent of pipeline burial / protection also effects the anchor forces exerted on a pipeline. Additional resistance is provided by the soil in front of the anchor fluke and by the pipeline burial. Soft clays with high moisture content tend to develop high pore pressures that lead to a reduction in shear strength on immediate loading.

Dynamic non-linear Finite Element (FE) analyses were performed in order to determine the response of a pipeline to anchor forces. From a design viewpoint, the anchor forces of interest: are the force at which pipeline movement is initiated, the forces at which a pipeline reaches its maximum allowable design stress and force at which pipeline buckling occurs.

Examples of FE analysis of both a surface laid and a partially buried pipeline in a soft clay soil are presented.

VESSEL CHARACTERISTICS

Vessels moored in the vicinity of pipelines will vary in both size and type. The precise method of mooring adopted by the vessels will not be consistent. A number of assumptions need to be made regarding the mooring arrangements of the vessels. The mooring loads for various vessel types and sizes have been estimated based on the assumptions in the following sections.

Vessel Types and Sizes

A typical range of vessels that may be considered for anchor interaction is shown in Table 6. Deadweights of vessels have been used as a measure as opposed to the gross and net tonnage, as different types of vessels have different scales of tonnage.

MOORING EQUIPMENT

All registered vessels are assigned an Equipment Numeral and Letter. This sets the minimum size and weight of the equipment. For the referenced vessels, Lloyds Rules Lloyds Register of Shipping (1972) were used to derive the numeral and letter. Other classification societies have very similar, if not exactly the same formulations. For the referenced vessels, the equipment number and letter, anchor mass and chain diameters were determined, as shown in Table 7.

Numerous different mooring systems have been developed over the years, both temporary and permanent. Semi-submersible drilling rigs tend to use eight point moorings, with two moorings lines connected at each vertical. Floating Production, Storage and Offloading (FPSO) vessels use either turret or spread mooring systems, with turret moorings systems used in harsher weather conditions. The mooring lines are connected to a turntable, which enables the vessel to turn relative to the prevailing weather. For spread moorings, used in less harsh conditions, the mooring lines are connected to the bow and the stern of the vessel.

In shallow waters catenary type wire or chain mooring line configurations are used. In deeper water, however, the weight of these catenary mooring lines limit the depth to which they may be used, and alternative taut leg moorings tend to be used. A typical catenary mooring system comprises a mooring line, connectors and an anchor point.

Mooring Lines

Chain is the most commonly used component for mooring lines. It is available in many different diameters and material grades, and both studlink and studless chain is available. Studlink chain tends to be used for moorings that need to be reset many times, whereas studless chain is more suitable for permanent type moorings.

Wire rope is lighter and is more flexible than comparable chain mooring, but is not is not considered to be as robust and are more susceptible to damage.

Connectors, in the form of shackles, connecting links and swivels are used for both temporary and permanent moorings in order to connect the mooring lines and to prevent the lines twisting in service.

ANCHOR TYPES

Various types of anchors have been developed over the years for temporary, semi-permanent and permanent mooring. These include the traditional drag embedment anchor, the pile anchor and the suction anchor. The pile and the suction anchors tend to be used for permanent type moorings, and therefore do not pose the same threat to pipelines as that of the drag embedment anchors. As such, only drag embedment anchors will be considered here.

Drag Embedment Anchors

The drag embedment anchor is designed to penetrate into the seabed surface and comprises a shank that transmits the load from the mooring line to the flukes via a crown. Anchors may or may not contain stocks which act as stabilisers. Anchor holding power is derived from the fluke surface area, depth of anchor burial and the mechanical properties of soil (Puech, 1978; Vold, 1989 and Walker 1983). This type of anchor is well suited to resisting large horizontal forces, but is less well able to resist vertical loads.

Conventional shipping uses anchors based on traditional design, such as the Admiralty pattern (stocked) based on a design patented in 1821, or based on the Hall stockless type of anchor. Larger and more modern vessels, especially those associated with the oil industry, tend to be equipped with anchors of more modern design, such as the Vryhof Stevpris (Van Den Haark, 2000). These modern anchors typically have an efficiency (defined as the holding capacity / weight) of between 33-55, compared with the older Admiralty stocked anchor that has an efficiency of less than 6. Table 1 indicated the holding power of drag embedment anchors.

Table 1: Efficiency of Drag Embedment Anchors (after Van den Haark, 2000)

Anchor Type	Efficiency
Navy Stockless / Beyers	4 – 6
Stokes	8 – 11
Danforth	8 – 15
Stevin / Flipper Delta	14 – 26
Bruce	17 – 25
Stepris	33 – 55

Soil Conditions

The performance of a drag embedment anchor is dependent on the seabed topology and the nature of the seabed soil. The following types of soil tend to reduce anchor efficiency (le Tirant, 1990):

- Soft, clayey or silty sediment considerably reduce the holding power of drag embedment anchors,
- Firm and stiff clays may require flukes with specially designed teeth in order to obtain penetration,
- Soils containing boulders > 100mm may hinder penetration,
- Cemented Calcareous sand deposits will prevent penetration.

The extent of penetration of an anchor into the seabed will affect the interaction with a pipeline. The thickness of overlaying deposits also affects anchor performance. In soft soils an anchor may be buried up to twice its largest dimension, or up to 10m for a 120kN weight ((le Tirant, 1990).

DEVELOPMENT OF ANCHOR FORCES

To determine the mooring and anchor forces a number of assumptions as to how a vessels will be moored have to be made. These include:

- Vessel draft
- Size of mooring equipment

- Length of mooring line let out
- Soil Conditions
- Environmental Conditions
- Vessel Configuration with respect to windage

Two cases are envisaged whereby a ships anchor may be dragged across a pipeline:

1. Where a vessel attempts to anchor in the vicinity of a pipeline,
2. Where a vessel slips its anchor and drifts uncontrollably across a pipeline.

Pipelines are not usually routed through anchorage zones, although it is sometimes necessary for construction vessels to moor close to pipelines. When mooring there is some control over the anchor placement and it is considered that 2 above represents the more onerous case and will be considered here.

Environmental Loading

Environmental forces on a vessel need to be determined prior to calculating the anchor forces. Forces on a drifting vessel arise primarily from the prevailing wind and current. The wind load on the non-submerged part of the vessel is calculated based on the wind speed (varies with height), drag coefficient, vessel orientation and projected area. The current is composed of the general flow current, current due to wind and the tidal current. The load exerted onto a vessel due to current is a function of the ships drag coefficient, the projection of the hull surface onto the prevailing current direction, angle between current direction and hull axis and the current velocity.

Anchor Forces

The environmental forces exerted onto the vessel are translated through the mooring system to the anchor. Under a horizontal force, a mooring line takes the form of a catenary and it is a straightforward matter to determine the force transmitted from the vessel through the mooring lines to the anchor. For the worst case scenario it may be assumed that the mooring line does not contact the seabed and that the full force is transmitted through to the anchor point and hence onto the pipeline.

Either a quasi-static of a full dynamic analysis may be performed with forces determined for vessels at both full and half draft. If a quasi-static analysis is performed then the dynamic effects need to be included via a dynamic amplification factor (DAF). Typically, a DAF of 2 is applied to account for these effects.

Typical anchor forces applied to a pipeline by various vessels at 50% load line draft are shown in Table 8.

PIPELINE RESPONSE

Anchor / pipeline interaction may be divided into two phases:

1. The initial impact as the anchor contacts the pipeline,
2. The subsequent dragging of the pipeline across the seabed.

The response may be viewed in terms of local-global events. The initial contact of the anchor may cause local damage due to permanent deformation of the pipe wall or to loss of weight coating. In extreme cases, rupture of a pipeline can occur, leading to loss of inventory. The effect of the local impact event may be determined via an analysis similar to that performed for fishing gear interaction (Sriskandarajah, 1999).

The response of a pipeline to anchor dragging may be determined by means of a FE analysis. Typically, the objectives of such an analysis are to determine the following:

- Impact resistance to initial contact,
- The anchor force at which the pipeline begins to move laterally on the seabed,
- The lateral anchor force at which the pipeline reaches its maximum allowable design stress,
- The lateral anchor force that causes the pipeline section to buckle locally.

Forces developed on the pipeline are dependent on the angle at which the anchor approached the pipeline. Maximum forces are developed when the angle of approach is perpendicular to the axis of the pipeline.

Pipeline Burial

The extent of the pipeline burial will effect the response to lateral anchor-hooking forces in several ways. Firstly, the case of complete lack of burial, with the pipeline resting on the seabed surface, will result in the pipeline experiencing its maximum lateral displacement. This does not necessarily represent the case of maximum stress or maximum bending moment that can occur within the pipeline. The partially buried case can develop tighter curvatures within the pipeline than the surface case. This is offset somewhat by the force required to mobilise the lateral movement of the pipeline. The buried case also provides significantly higher axial restraint, which restricts the feed-in to the hooking location and increases the tension within the pipeline.

The holding capacity of a drag embedment anchor is limited by the fluke area, the penetration of the anchor into the seabed, the type of mooring line and the applied load. Anchors connected to wire rope mooring lines tend to penetrate deeper than anchors connected to chain mooring lines. This effect is especially noticeable in soft clay soils. When shallow penetration anchors reach their ultimate capacity a wedge shaped area of soil in front of the anchor fails. The capacity is a function of the following:

- the weight of the anchor
- the weight of soil in the in the failure wedge
- the friction of the soil in the failure wedge
- the bearing capacity of the shank and the mooring line

It is assumed that as the anchor contacts the pipeline the pipeline provides all resistance. Any resistance provided by the anchor fluke contacting the soil is conservatively ignored.

Example

An analysis was performed in order to demonstrate the method of determining anchor forces developed on a pipeline. The analysis was performed using the ABAQUS general-purpose FE package version 5.8 (HKS, 1998) using the static, non-linear solution technique. The program handles the non-linearity due to both material plasticity and large displacements. The non-linear behaviour of the pipe material is introduced by explicitly defining the steel stress-strain curve. Large displacements and rotations that occur as the pipeline breaks-out are handled by the geometric non-linear facility within the finite element formulation.

Finite Element Analysis

A Finite Element model was constructed using ABAQUS 2-noded 3-D elbow elements, ELBOW31B. These elements, based on shell theory, accurately modelled with initially circular sections, susceptible to distortion by ovalisation. The element is able to predict the collapse buckling (or Brazier buckling) that occurs when a circular section is subjected to excessive bending. For large displacement analysis, the non-linear contribution to the load stiffness due to internal overpressure is included, as is the end cap force that develops at the spool location.
Internal pressure is specified as acting on the inside diameter of the inner pipe, so as to give the correct average hoop stress across the wall thickness, and the correct effective axial force. The elements take into account the Poisson's coupling effect between hoop and axial strains. The constitutive equations are evaluated at several stations around the pipe circumference ('integration points') and at locations through the wall thickness, 'section points', in order to model the spread of plasticity across the pipe section.

A total length of 5km of the pipeline was modelled, which considering symmetry represents a pipeline length of 10km. The effects of partial burial were modelled using the concept of equivalent friction factors.

The pipe-to-seabed interface was modelled via the ABAQUS contact algorithm, IRS31 contact elements. The 'softened' contact facility was used, which gives the seabed some 'flexibility', by allowing the contact between the pipe and the seabed to build up gradually. The classical Coulomb friction law was used for the pipe-seabed contact, with different friction factors in the both the axial and lateral direction.

The stress-strain curve used for pipe material was that of API5L X52 with an SYS of 358 N/mm². Linear elastic and post yield plastic sections were used to represent the pipeline material properties.

The pipeline was considered stress free in the initial, straight position. The first load step was that of settling the pipeline onto the seabed by way of prescribed displacements. The second load step was that of gravity, applied to activate the pipe/seabed friction model. The density of the pipe material was adjusted to include the mass of the contents and the concrete coating material. The gravitational acceleration applied to the pipe elements was adjusted to give the correct buoyancy effects, as this directly affects the frictional contact between the pipeline and the seabed. The third load step was the application of internal operational pressure of 125barg, and external pressure of 1.7barg. The final load step was to apply a prescribed lateral displacement of 50m at the anchor hooking location. The reaction force at the prescribed displacement location represents one half of the anchor-hooking load (due to symmetry boundary conditions). All load steps were applied statically.

The point of anchor hooking was taken as a point of symmetry in the model. Displacement across the plane of symmetry was prevented, as was the rotation about the two axes normal to the pipe longitudinal axis. In order to prevent rigid body movement of the pipe, the lateral displacement and the rotation about the pipe longitudinal axis was restrained at the end remote from the hooking location.

Pipe-Soil Interaction

The effects of the pipe-soil interaction were considered via the concept of equivalent friction factors. The resistance provided by the soil in both the axial and lateral directions was computed in terms as per the recommendations of RP E305 (DnV, 1988). The friction factors are determined as a function of the pipeline outer diameter, undrained shear strength and submerged weight. Table 2 gives the equivalent axial and lateral friction factors for the pipeline on the seabed surface.

Table 2: Equivalent Friction Factors for Pipeline on Surface

Axial Friction Factor	Lateral Friction Factor
0.5	0.55

For the partially buried case the equivalent lateral friction factor was computed based on the AGA Level 2 assessment. It was assumed that the pipeline was buried to a depth of one half of the pipeline outer diameter. The analysis was carried out using the in-house computer program AGA Level 2 (PRCI, 1998). The Level 2 design process involves a quasi-static analysis program and has been designed to take advantage of the results from the AGA's hydrodynamic and pipe/soil interaction tests. The program computes the lateral soil force due to both friction and passive resistance. The equivalent lateral friction factor is then given by:

$$\mu_{EQ} = \frac{F}{W_s}$$

Where

- F is the lateral soil resistance per m
- W_s is the submerged weight of the pipeline

The equivalent axial friction factor was computed based on the area of pipe in contact with the soil and the shear strength of the soil, as:

$$\mu_{EQ} = \frac{A_P S_U}{W_S}$$

where

- A_p is the area of pipe in contact with the seabed
- S_u is undrained shear strength of the soil
- W_s is the submerged weight of the pipeline

Table 3 gives the equivalent axial and lateral friction factors for the pipeline partially buried.

Table 3: Equivalent Friction Factors for Partially Buried Pipeline

Axial Friction Factor	Lateral Friction Factor
2.1	6.4

Analysis

A mesh was constructed using 710 elements graded from 0.5m long elements at the hooking location to 40m long elements at the end 5km from the point of hooking. The pipe-soil interaction was modelled using the equivalent friction factors shown in Table 2.

Two analyses were performed to determine the effects of lateral anchor hooking forces on the pipeline. The displacements and buckling loads were computed using non-linear pipe material properties, whilst the lateral force at which the pipeline reaches its design maximum stress was determined based on linear pipe material properties, as required by BS8010 stress-based design (BSI, 1993).

Pipeline Exposed on Seabed Surface

The results of the analysis, presented in Figs 1 - 3 shows the lateral force / displacement relationship for the pipeline under operating conditions. The anchor hooking force required to displace the pipeline laterally by 1m is 73kN. The design stress limit is based on the equivalent (von Mises) stress due to combined axial and bending stress. The maximum design stress is reached at a lateral anchor force of 150 kN. The moment-force relationship is shown in Fig 3. The bending moment at which the local buckling occurs is taken to be that corresponding to the characteristic bending strain according to BS8010 (BSI, 1993), given by:

$$\varepsilon_{bc} = 1.5\left(\frac{t_{nom}}{D_0}\right)^2$$

which corresponds to a strain of 2.1%. At this limiting strain, the lateral force on the pipeline is 525kN. Table 4, below, summarises the results.

Table 4: Lateral Force Limits for Pipeline on Surface

Pipeline Design Limit	Lateral Force (kN)
1m Lateral Displacement	73
Design Stress Limit	150
Onset of Lateral Buckling	525

Pipeline Partially Buried

A mesh was constructed similar to the above. Pipe-soil interaction was modelled using the equivalent friction factors of Table 3.

The results of the analysis, presented graphically in Figs 4 - 6 shows the lateral force / displacement relationship for the pipeline under operating conditions. The anchor hooking force required to displace the pipeline laterally by 0.2m is 400kN. The pronounced stiffening effect is due to the geometrical non-linear pipe (or large deflection) behaviour. The moment-force relationship is shown in Fig 6. The bending moment at which the local buckling occurs is taken as 575 kN.

Table 5: Lateral Force Limits for Pipeline Partially Buried

Pipeline Design Limit	Lateral Force (kN)
0.2m Lateral Displacement	400
Design Stress Limit	420
Onset of Lateral Buckling	575

It may be observed that the anchor force required for the pipeline to reach its design stress limit varies markedly from the 150kN for the surface laid pipeline to 420kN for the partially buried pipeline. The anchor force required for the onset of local buckling, however, differs by only 50kN. This is due to the buried pipeline being held at a tighter curvature than the surface laid pipeline, which is free to move laterally.

CONCLUSIONS

The following conclusions are drawn from the analyses performed:

1. Both the cases of the pipeline exposed on the seabed surface and partially buried have been considered within the assessment. For the surface case, the pipeline reaches its maximum design equivalent stress at a substantially lower hooking force than does the partially buried case.
2. The pipelines reach their maximum design stress at an anchor hooking forces of 150kN and 420kN respectively. This is substantially below the forces at which local buckling occurs.
3. It is likely that the pipeline considered in the analysis will suffer local buckling failure for anchor forces exceeding 52tonnes for pipeline resting on the seabed surface, which correspond to vessel deadweights greater than 70,000t.
4. The onset of local buckling was taken as the limiting strain criteria set-out in BS8010. The anchor loads at which complete collapse of cross section due to local buckling and/or loss of integrity of the pipeline occur were not determined. Determination of these anchor loads requires more detailed FE analyses, taking into account the post-yield and bifurcation behaviour of the pipe cross section.
5. The values for the lateral anchor forces at which the maximum design stresses and local buckling occurs contain no factors. It is assumed that this is addressed within a QRA.
6. The case of anchor hooking at a pipeline span was not considered in the assessment. These effects should be considered if seabed erosion is likely to be problem.
7. The local effects of impact on the pipeline wall were not considered within the assessment. Whilst the concrete coating will provide some protection in the form of energy absorption, the effects of local damage, particularly on girth welds due to impact at a field joint location.
8. The above results of this type of analysis are intended for use as input into a QRA in order to determine the risk to the pipeline due to anchor dragging forces and to determine mitigation measures.

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Table 6: Details of Typical Vessels

Type	LOA (m)	LBP (m)	Beam (m)	Depth (m)	Draft (m)	D/Weight (tonne)
Tug	32.72	31.74	11.84	5.00	4.50	-
Tanker	91.40	88.66	14.78	7.39	6.02	4,500
Cargo	115.30	108.00	18.60	10.25	7.10	8,300
Offshore Support	113.57	110.16	22.00	9.50	6.75	5,728
Cargo	168.00	162.96	27.20	13.80	8.75	19,570
Container	185.00	175.00	32.20	16.10	11.27	45,000
Car Ferry	197.50	191.58	25.20	12.00	7.50	11,089
Tanker Amax	220.00	213.40	42	19.34	14.2	100,000
Tanker	-	221.6	35.5	21.5	14.0	80,000
Tanker	-	237.5	38.5	22.5	14.7	100,000
Tanker	-	254.0	40.0	23.5	15.5	120,000
Tanker	265.00	256.50	42.50	22.00	15.65	126,650
VLCC	334.45	320.00	58.00	31.00	21.00	311,189

Key:

LOA	Length Overall
LBP	Length Between Perpendiculars
Beam	Moulded Beam
Depth	Moulded Depth at side
Draft	Summer load line, maximum draft
D/Weight	Vessel deadweight, carrying capacity of the vessel.

Table 7: Details of Mooring Equipment

Vessel Type	Equipment Number	Equipment Letter	High Holding Anchor Mass (Kg)	Length Chain (m)	Chain Dia. (mm) (1)
Tug	117	D	270	110	19
Tanker	409	M	970	192.5	36
Cargo	716	R	1,580	220	46
Offshore Support	788	T	1,850	220	50
Cargo	1,529	C+	3,440	275	68
Container	1,858	F+	4,210	275	76
Car Ferry	1,317	A+	3,040	247.5	64
Tanker Amax	3,102	N+	6,980	330	97
Tanker	3,248	O+	7,430	330	100
Tanker	3,692	Q+	8,830	330	105
Tanker	4,076	S+	9,250	330	111
Tanker	4,024	S+	9,250	330	111
VLCC	7,373	D*	16,000	385	127 (2)

Notes:

(1) Grade U1, unless noted otherwise.

(2) Grade U2

Table 8: Anchor Forces Applied to Pipeline for Vessels at 50% Load Line draft

Vessel Type	Draft (m)	Total Force Static [(1)] (tonne)	Total Force Dynamic [(2)] (tonne)	Anchor UHC [(3)] (tonne)	Force Applied to Pipeline [(4)] (tonne)
Tug	2.25	2.07	4.14	1.6	3.7
Tanker	3.01	3.56	7.12	5.8	5.4
Cargo	3.55	5.55	11.1	9.5	8.3
Offshore Support	3.38	6.19	12.38	11.1	9.1
Cargo	4.38	10.30	20.6	20.6	14.4
Container	5.64	15.20	30.4	25.3	22.8
Car Ferry	3.75	8.22	16.44	18.2	11.0
Tanker Amax	7.10	27.92	55.84	41.9	43.3
Tanker	7.00	24.07	48.14	44.6	34.8
Tanker	7.35	27.38	54.76	53.0	38.9
Tanker	7.75	29.91	59.82	55.5	43.2
Tanker	7.83	31.40	62.8	55.5	46.2
VLCC	10.50	58.30	116.6	96.0	87.8

Notes:

(1) The static force is the total quasi-static force.

(2) The total dynamic force includes the effect of the DAF.

(3) UHC based on anchor efficiency of 6.

(4) Based on 30% of UHC.

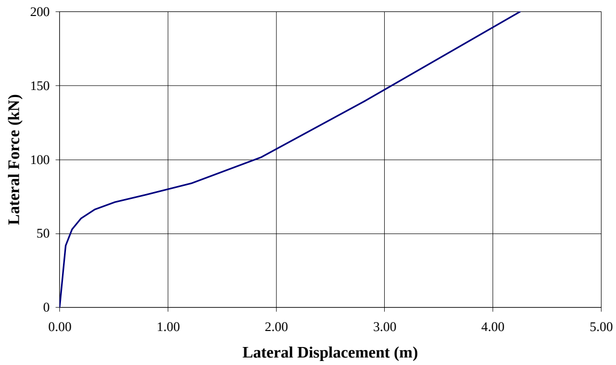

Fig 1: Force / Displacement for Pipeline on Surface

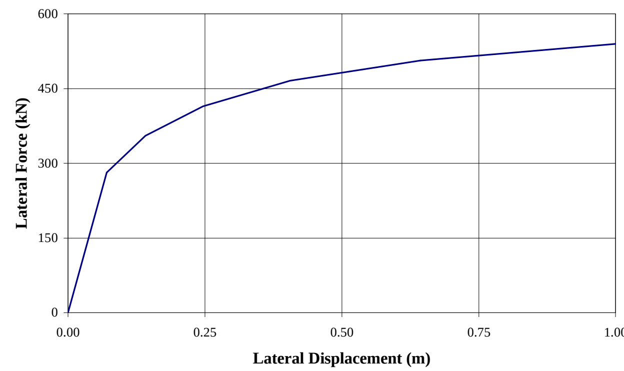

Fig 4: Force / Displacement for Buried Pipeline

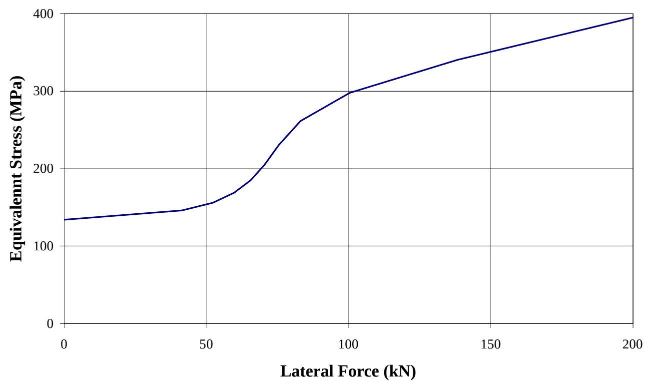

Fig 2: Force / Equivalent Stress for Pipeline on Surface

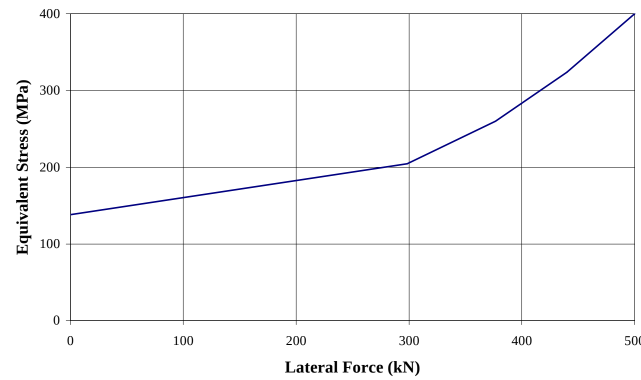

Fig 5: Force / Equivalent Stress for Buried Pipeline

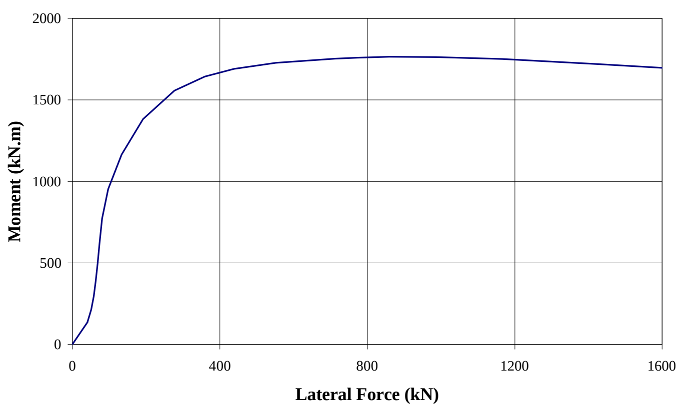

Fig 3: Moment / Force Stress for Pipeline on Surface

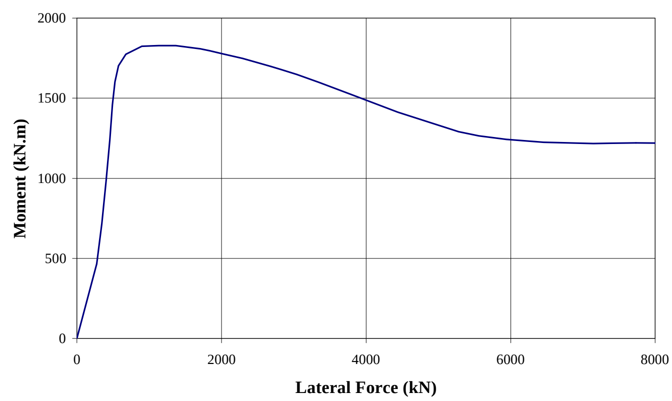

Fig 6: Moment / Force Stress for Buried Pipeline