TOW TECHNIQUES FOR MARINE PIPELINE INSTALLATION

ir. M.L. FERNÁNDEZ

DELFT

nr: 13790202

TOW TECHNIQUES FOR MARINE PIPELINE INSTALLATION

Prepared for ETCE, Energy Technology Conference & Exhibition, Contribution by the Petroleum Division of the American Society of Mechanical Engineers, Houston, January 1981.

By: M.L. FERNÁNDEZ
Department of Civil Engineering
DELFT UNIVERSITY OF TECHNOLOGY

TOW TECHNIQUES FOR MARINE PIPELINE INSTALLATION

Mario L. Fernández *

ABSTRACT

Tow techniques for marine pipelines frequently offer competitive and commercially attactive solutions over other installation methods and, on occasion, may represent the only alternative to traditional techniques. An assessment is also made of where each tow method is applicable and technically feasible.

INTRODUCTION

Tow methods for marine pipeline installation are technically feasible and economically competitive with other installation procedures, and in some circumstances may represent the only alternative to conventional techniques. The four tow methods discussed in this paper each require the support of tow vessels such as sea-going tugs, as shown in Figure 1. The methods may be listed as follows:

Bottom tow
Off-bottom tow
Surface tow
Constant tow depth (CTD) or sub-surface tow

Regardless of which of these methods is employed, their main feature or restriction is the limited length of pipe that can be towed. However, the increasing use of subsea completions, the continuing development of deepwater fields, and the growing utilization of early production systems - all of which require the installation of relatively short-length marine pipelines - are effective in promoting the adoption of tow techniques. For towing and maneuvering operations, the tow forces are constrained by the performance capabilities of existing equipment. Typically, tow vessels are limited to less than 2000 kN (220 Tons) bollard pull,

* Delft University of Technology, Delft, The Netherlands.

and tow speeds to between 2 and 6 knots (1 to 3 m/s). Where winch barges or onshore pull winches are employed, then pull speeds are further restricted, but pull forces can be increased up to 8000 kN (880 Tons) at pull speeds of 5 to 15 m/min.

The prime features and advantages of tow techniques are:

- Manipulation of pipelines during towing is relatively easy and safe regardless of water depths or pipe characteristics. Excessive bending or damage during installation can be avoided, and pipeline stresses can be maintained at low, safe levels throughout towing.
- Considerable reductions in pipeline installation time can be achieved in contrast to conventional lay barge methods. Tow vessels by comparison, are fast and their relatively small size assists in giving them outstanding maneuverability.
- Large diameter and heavy pipe can be installed, as can bundled or otherwise difficult pipe configurations. These designs would be slow or impossible to install by lay barge.
- If first or second end (i.e. leading and trailing end) connections are feasible, preferably using mechanical connectors, then significant reductions in construction time and cost can be achieved relative to traditional tie-in methods. These connection methods do not require spool pieces or sophisticated procedures, nor do they involve large tie-in spreads. Apart from the pipelines, tow vessel and standard support and survey systems, little additional surface based equipment is needed. The pipeline length must, however, be properly designed.

Representative cases for the installation of marine pipelines where employment of tow techniques is recommended, or may be mandatory, can be summarized as follows:

- Shore approaches, near shore, in shallow or very shallow water where installation by lay barge is not possible.
- For complex pipe bundles or very large diameter lines, i.e. over 1500 mm (60 inches) which are difficult to handle by lay barge [1, 2].

- Where difficult or dangerous maneuvering by lay barge is required, especially as regards anchor handling, for example in areas of rocky seabed, near platforms and in other locations heavily populated with pipelines [3].
- In very deep waters where existing lay barges may be incapacitated by limitations in tensioner gear, stinger geometry or barge positioning [4, 5].
- In arctic areas with heavy ice cover [4, 6].
- Where, because of high sea states or other excessive environmental conditions, only a short or indeterminate installation season is available.

A systematic approach, as described below, is recommended when assessing the application of tow techniques to pipeline installation. This is followed by a discussion of each of the tow methods in terms of their prime features, their advantages and disadvantages, and the considerations entailed in pipeline design and construction. Certain of the views expressed in this paper are based on the author's personal involvement and experience with various pipeline tow projects during their design and/or construction phases.

METHODOLOGY

For a marine pipeline system, the main objective is to be able to install and operate the line with the minimum of risk. Pipeline installation by one of the tow methods requires a different sequence of design and construction phases than conventional installation. The basic phases which must be individually checked to ensure successful performance comprise fabrication, tow, connection, and operating conditions.

- Phase 1) Onshore fabrication: This involves pipe make-up facilities and a launchway, and the line may frequently be fabricated as a series of long strings which are welded together when the pipe is launched into the water. If possible however, the line should be fabricated as a single string, enabling the entire system to be hydrotested onshore and launched more quickly. During handling and launching of the pipeline, its weight out of the water is considerably greater than later when it is submerged. The weight must be strictly controlled within small tolerances during fabrication. This is because both the negative buoyancy and the tow forces are sensitive to variations in weight. The use of correct launchway design and construction procedures is beneficial in avoiding the need for excessive forces or the possibility of overstressing the pipe.

- Phase 2) Tow or transportation to offshore location: Adequate seabed information is needed to enable selection of the tow method and/or route which will ensure safe levels of pipe stress during towing, with limited bending of the pipe string and acceptable tension levels. Where the route passes through deep water, the application of increased internal pressure to the pipeline can be used to achieve a reasonable margin of safety against buckling or excessive strains resulting from the external hydrostatic pressure.

- Phase 3) Connection or tie-in: After tow-out, the pipeline is ready for connection to the subsea system, utilizing either conventional tie-in methods, or by first and second end connection methods. The leading end connection should be performed using controlled manipulation of the pipe and without delay [4] . For the second, or trailing end connection, an accurate seabed survey and precise positioning of the connection point are required when determining pipeline length. If the pipeline is too long, the pipe may be overstressed; and if too short, it may be difficult to execute the connection.

A careful analysis and accurate calculation are needed to minimize the risks inherent in incorrect design of pipeline length, especially when contrasted against reliable but more expensive conventional tie-in methods. In general it is feasible to attain the main advantages of second end connection, namely speed of completion, reduced costs, and an acceptable degree of reliability.

Before operating the line, additional design and construction activities can be introduced, such as when trenching or burial of the line, either before or after tie-in, is recommended.[1] These aspects however, are outside the scope of this paper.

- Phase 4) Operating conditions: The safe operation of a pipeline is based on correct forecasting and assessment of the extreme conditions likely to be imposed on the line. A pipeline may be subjected to stresses arising from some or all of the following:

  a) The final position or geometry of the line, including pipe restraints and boundary conditions
  b) Gravitational and hydrodynamic forces on the pipe, which may be important if spans have developed in the line as a result either of construction activities or of the seabed configuration and soil conditions
  c) Internal operating pressure
  d) External hydrostatic pressure
  e) Restraints on the line when thermal expansion occurs as a result of temperature variations between the pipe contents and the sea water.

  Conventional tie-in methods may be designed to function as a stress-relieving system, but if tie-in is by means of trailing-end connection, then the entire system must absorb all stresses resulting from the operating conditions. For comprehensive design, the stresses must be checked for each of the various construction phases.

The following are the prerequisites of successful pipeline installation when employing a tow method:

- Careful planning and scheduling covering engineering, design, construction procedures, and onshore and offshore field preparation.

---

[1] Sometimes, there are not technical or safety reasons or government regulations for trenching or burying a submarine pipeline.

- Adequate and reliable construction equipment, including survey equipment (i.e. vessel instrumentation systems), the tow vessel (as regards winches and cables), diving support equipment and one or more submersibles.

As Phases 1 and 4, covering onshore fabrication and pipeline operating conditions, are normally predetermined by the nature and location of a specific project, only Phase 2, concerning tow-out to site is discussed in detail hereunder. For Phase 3, discussion centers on the trailing-end connection method in order to emphasize the importance of correctly forecasting the geometry or final configuration of the pipe. No reference is made to problems that may be experienced as a result either of pipeline vibration that may be caused by vortex shedding, or the effects of corrosion or fatigue on the behavior of materials.

BOTTOM TOW

The bottom pull method has been extensively employed on marine pipeline projects, and has established an excellent reliability record. Typically this method employs winches at fixed locations such as onshore, on anchored barges and, more recently, on platforms where it has been used to perform tie-ins. In the near future, it will also be used on ice platforms for installing offshore pipelines in the Arctic.

With the bottom tow method, as shown in Figure 1, a pipeline is towed along the seabed by a tug to which it is attached by a long cable. The line may be a single pipe or a bundle of pipes, as illustrated in Figure 2. From vertical and horizontal equilibrium, the maximum length of pipeline that can be towed using available tow vessels, may be estimated by assuming: firstly that the pipe bottom is in direct and continuous contact with the seabed, with no spans being present; secondly that the system has a uniform negative buoyancy along its entire length; and thirdly, that the coefficients of friction between the pipe and the tow route are known, based on reliable data concerning the seabed soils configuration and the pipe characteristics.

Seabed and Route Selection

A detailed marine survey is required to enable selection of the tow route corridor from the pipe launchway to the location for final pipe positioning. The width of the corridor is a function of the accuracy and tolerance of the positioning system and survey equipment. The planned and actual tow routes must be checked for the presence of any maritime hazards.

The seabed along the tow route should preferably be relatively flat and straight, and be free of obstructions such as sharp depressions or elevations, rock outcrops, ship wrecks, and subsea structures. Allowable span lengths, and minimum horizontal bending of the pipeline must be calculated as criteria for route selection. The two limiting conditions are considered as being when the pipe is at rest without tension, and moving under tow.

To ease the task of a design analysis and route selection, it is feasible to reduce possible variety in types of soils along the route by grouping them into convenient categories. This tactic should still enable acceptable forecasting of the lateral and longitudinal friction coefficients needed for calculation of stability on the seabed and the magnitude of the tow forces. For estimating the conditions when the pipe is static; at the start of towing; and the dynamic case where the pipe is being towed; it is necessary to have a knowledge of the extremes of longitudinal coefficient. Because of continuous variations in the seabed configuration and soils along the tow route, there are corresponding variations in the friction coefficients and dynamic tow forces. For a given type of soil, the starting friction forces are larger than the dynamic friction forces. In particular with cohesive soils, the ratio of these forces may be as high as 3 : 1.

The formulae for evaluation of skin friction coefficients for cohesive and non-cohesive soils have been developed and documented by Potyondy [7] . In the case of submarine pipelines, other factors contributing to determination of the friction coefficients are:

- Smoothness of pipe surface, which is important when estimating the adhesion with cohesive soils.
- Settlement of and/or grooving by the pipe in the seabed, this being a function of the soil's load-bearing capacity, the pipe characteristics, and the negative buoyancy.

Pipe Stability

To maximize the pipeline length and/or optimize the tow speeds and forces for long distance bottom tow by tugs, the negative buoyancy of the system must be minimized. The negative buoyancy and stability of the line are determined by risk analysis rather than by standard stability criteria. To quantify the risks, the following factors may be taken into consideration:

- The contents of the pipeline, e.g. water, gas or crude oil, during and after installation, and in the operating condition.
- The expected maximum bottom current velocities during tow-out and operation of the line.
- The possible use of a holdback tension vessel during tow-out, or a holdback anchor when stationary, to enhance stability.
- The possible use of pipe burial, trenching or anchoring following tow-out.
- For weight-coated pipes, the spallage, abrasion and water absorption of the concrete
- The probable need for a more reliable survey when weight-coated pipe is being used.

Strict control of weight and dimensional tolerances during pipe manufacture and the application of protective or weight coatings, is recommended. The negative buoyancy, and hence also pipe stability and tow-out, are very sensitive to small changes in weight. For an accurate estimate of the negative buoyancy obtained during installation, every item which contributes to the weight must be considered and checked. This operation, which is in addition to the strict control of weight during fabrication, should include:

- Seawater density and temperature, to facilitate evaluation of positive buoyancy
- Line pipe, steel physical properties, including welds
- Anti-corrosion protection, including coatings, anodes and ancillary equipment
- Pipe contents, such as pressurizing gas
- Pulling head, sled and ancillary equipment
- Equipment, such as pontoons or tanks, cables or chains and attachment lugs, for increasing or decreasing the buoyancy
- Spacers and ancillary equipment required for bundled lines
- Concrete density, thickness, abrasion, spallage, water absorption and steel reinforcement for weight-coated pipe
- Field joints, i.e. mastic, steel wrap-around etc.

In areas of high current velocity, such as shore approaches and river crossings, heavyweight pipe and weight coating are usually recommended. The negative buoyancy of the system is normally determined by means of a standard stability analysis; and installation is performed using pull winches positioned at a fixed location. Considering the typical speed of a bottom pull and the probably detailed knowledge of the pull route, abrasion and spallage in this case are likely to be sufficiently small as to be neglected.

Link Cable and Alternative Bottom Tow Method

Selection of the link cable and forecasting the cable geometry and related parameters, can be done using normal catenary equations. The known factors are: the available tow forces; tow speeds; drag forces on the cables as per Kullen [8] or similar references; and the cable properties. The cable must transmit only axial forces to the pipeline. Torsional forces originating from possible cable spin or stretch should be avoided by installing a swivel at the connection point between the cable and pipe pullhead.

Compared with the length of cable necessary to maintain the pullhead on the sea bottom, shown in Figure 1 Bottom Tow, considerable reductions in link cable length can be achieved by carefully lifting the pullhead off the bottom after towing has commenced. This modified bottom tow method, which is shown in Figure 3, offers the following additional advantages:

- Reduced abrasion and friction forces on the cable as it is no longer in contact with the seabed
- Enhanced control, positioning and maneuverability of the pipeline because of the reduced cable length
- Some reduction in the longitudinal friction forces because the pipeline is lifted off the bottom under tension

As identified in Figure 3, tow parameters such as the lift-off distance 'Y'; the tensions at points '1' and '2'; and the maximum stresses at section '2' - '3', may, with some assumptions, be obtained from the equilibrium equations of the system and by use of the following procedures:

- Normal catenary equations for the link cable over section '1' - '2'.
- Equations derived from elastic beam theory and small deflections for section '2' - '3' of the suspended pipe: these are solved for boundary conditions where the pipeline is horizontal on the seabed from touchdown point '3'; and where there are no bending moments at '3' or at the pipe end '2'. (For further details, see analysis of the constant tow depth method).
- The horizontal and vertical equilibrium of section '3' - '4'.

The operational differences between the 'conventional' and 'modified' bottom tow methods, may be summarized as follows:

- Continuous application of tension is required for safety reasons, while the pipe is lifted off the sea bottom.
- Pay-out of the cable and changes in tension are necessary when concluding the tow, and to ensure safe lay-down of the lead-end of the pipe on the seabed. Monitoring charts listing tow parameters such as a schedule of tensions and cable lengths, are required with the modified bottom tow method for use during initiation and termination of towing.

With careful planning and supervision, it should be possible to achieve the same levels of reliability with the two methods.

Installation Stresses

The stresses used for design purposes are those induced by the forces acting on the pipeline. They are mainly functions of:

- Maximum water depth since it determines external hydrostatic pressure
- Pipe diameter and out-of-roundness. A pipe section is never perfectly circular, and the deviation from this condition, which is termed out-of-roundness, is expressed as a percentage of the pipe diameter.
- Wall thickness and the pipe material properties such as the stress-strain relationship.
- Internal pressurization, where this is recommended.
- Pipeline geometry and seabed configuration.

The stress-strain limits and associated safety factors are derived from the appropriate design codes and related criteria. For maximum combined stresses, the total stress may be calculated as a function of longitudinal and circumferential stresses as formulated, for example, by the Huber-Hencky-von Mises expression.

The longitudinal stress is a function of tow conditions, water depths, pipe geometry and seabed configuration. For practical purposes, only the extreme conditions are assessed. From an analysis of the Von Mises formula, it may be seen that the limiting condition is that associated with maximum longitudinal compressive stress, and maximum circumferential compressive stress. As the axial stresses from hydrostatic head and tow tension forces are in opposition, the worst or extreme design condition is when the tow force is ignored: in other words, when the line is at rest.

The circumferential compressive stress is induced by the positive difference between the external hydrostatic pressure and the pipe internal pressure. Under these circumstances, the main factor affecting the longitudinal stress is bending and, as in principle the pipeline follows the local contours of the seabed over which it is towed, this becomes an important factor when selecting and evaluating the tow route. The sources of bending imposed during towing are:

- Curvature of the tow route in the horizontal plane
- Deflections in the vertical plane caused by the configuration of the seabed, spanning, obstructions in the tow route and other restraints of the soil on the pipe.

The circumferential stress induced by a positive difference between the hydrostatic and internal pressures, which may cause collapse, is greater for out-of-round pipe than for perfectly round pipe. For either type of pipe, the stress may be calculated using standard elasticity theory. To prevent the line from collapsing and buckling, an approach based on theoretical and experimental results, is recommended.

The majority of published work on the state-of-art [9, 10, 11] , even taking into account the most recent research on collapse and buckling, does not adequately reproduce the conditions of a pipeline in deep water in terms of its bending stresses, axial compressive forces, stress-strain relationship, pipe diameter/wall thickness ratios, out-of-roundness, and positive pressure differential.

For design purposes, one possibly conservative approach which may be adopted is as follows:

- Introduce air or gas to the pipeline at a pressure sufficient to reduce the effects of the hydrostatic head without significantly increasing the negative buoyancy. The degree of internal pressurization may be based on the criteria for buckle initiation pressure as presented by Mesloh et al [10] . As per this reference, the theoretical collapse pressure for a long, straight and perfectly round pipe subjected to external pressure may be calculated using standard elasticity theory.

- Calculate the minimum bending radius for the pipeline which avoids buckling, using Ikedo's empirical expression [10, 11] . As per these references, which relate only to bending and external pressure, the theoretial collapse bending moment at atmospheric pressure may be determined using standard elasticity theory.

OFF-BOTTOM TOW

The off-bottom tow technique as shown in Figure 1, may be considered as a variation of the bottom tow method. The main distinguished feature is that the pipeline is floating at a uniform height off the seabed. Negative buoyancy and stability are introduced by means of chains, and positive buoyancy or lift force may be provided by the buoyancy of the pipeline itself, or by pontoons or floats attached to the line, as illustrated in Figure 2. Following installation of the line, the floats may be released to the water surface, of flooded on the seabed. Provision for this operation is made beforehand, during fabrication.

The length and weight of the chains are a function firstly of the lateral stability analysis with the line at rest, and secondly of the tow speed. In the static case, the negative buoyancy and lateral stability of the system are determined by the weight and length of the chains. During tow, the longitudinal drag forces on the chains reduce the length of chain which is in contact with the seabed. To confirm that the chains will maintain the pipeline at a set height above the seabed, it is recommended that a stability analysis of the system is made, during tow.

Analysis of the design, fabrication, and tow-out for off-bottom tow is similar to that employed for the bottom tow method. The advantages of off-bottom tow compared to bottom tow are:

- Smaller tow forces at the start and during towing may be expected because of: -
  a) Lighter pipe and probable lower negative buoyancy of the system, after risk and stability analysis
  b) Soil friction forces relate only to the lengths of chain in contact with the seabed, and even this contact is reduced during tow as a result of the drag forces on the chains.
  c) The lack of contact of the pipeline with the seabed, resulting in an absence of adhesion or skin friction forces.
- Smaller stresses induced by changes in seabed topography. This is because, when traversing an uneven seafloor, the pipeline will tend to remain more horizontal, without following all sea bottom variations, under the influence of its own stiffness and the applied tension: only the chains will tend to follow these vertical contour changes [12] .
- With the system floating off the bottom, there are less risks of damage or abrasion to the pipeline from contact with the seabed, or from impacts.

SURFACE TOW

With this method a pipeline, buoyed with floats or pontoons as shown in Figure 1, is towed on or near the sea surface to the location where it is to be installed. Taking into consideration the influences of the environment, the pipe characteristics and the installation equipment, the line may be lowered to the seabed in one of the following ways:

a) By coordinated release of the floats or pontoons, a procedure which can only be used in shallow water depths - probably less than 20 m - where little tension is required to ensure safe lowering of the buoyant pipeline. The tension needed for lowering, control and alignment of the pipe may be applied by the tow vessel and/or a holdback winch, possibly onshore. This procedure has been extensively employed, an early example being in the 1960s in the Persian Gulf when a string of several kilometres length was installed by this means; more recently, the method was utilized in the swamp areas south of Mèxico. To analyse the suspended pipe and program the release of the floats, simple beam theory may be used in view of the relatively small deflections involved. Alternatively, the method represented by Konuk [13] and based on rod theories, is particularly appropriate where a heavy pipeline has to be installed under conditions of low tension.

b) By taking the pipe strings consecutively onboard a lay barge; detaching the floats or pontoons; welding the string ends and progressively lowering the pipeline to the seabed. This technique is especially relevant in deep waters where use would be made of a dynamically-positioned lay barge equipped with tensioner gear and a stinger [5] . Under favorable weather conditions, when it is feasible to use long pipe strings, this method can achieve very high laying rates.

c) By taking the pipe strings consecutively onboard a barge, replacing the pontoons with variable-buoyancy floats, welding the string ends and progressively lowering the pipeline to the seabed. Because the variable-buoyancy system remains attached to the line during the lowering process, very little tension needs be applied at the surface and the barge is not required to have a stinger. As with the previous method, relatively long pipe strings may be used. Patented nearly 20 years ago, and called the 'S' curve method, this technique has been employed for laying in very deep waters [5] .

The surface tow method differs from the other tow procedures in that it is also a laying procedure. Its main disadvantage is the sensitivity of the buoyant pipeline to weather conditions. Wind and waves can greatly disturb not only the tow, but also the welding and laying operations. Where other tow methods are feasible, the surface tow technique may be uncompetitive because of its need for a lay barge.

This method may also be rendered too expensive when it is used in conjunction with first and second end connection of the pipe. With the tow-out floats removed, the line will become heavier and difficult to maneuver on the seabed, thus entailing the additional cost of fitting new floats specially for this purpose. A further disadvantage can be the difficulty involved in handling pipeline bundles for welding on the barge.

Conversely, where there is little risk of bad weather, surface tow can offer an attractive solution: for example, in shallow protected waters, method 'a' which requires only a small surface spread to perform the coordinated release of the buoyancy pontoons, is particularly appropriate.

CONSTANT TOW DEPTH METHOD

As the most recently developed tow technique, the constant tow depth (CTD) method, as shown in Figure 1, is effectively a variant of the off-bottom tow method. Fabrication, stability, stress analysis and the limiting design considerations are identical to those developed for off-bottom tow: only the method of transportation is different.

By introducing tension with a holdback vessel, the pipeline system is elevated in a symmetrical curve to any desired height above the seabed. Both the tow vessel at the front and the holdback vessel at the rear apply tension to the pipe continuously throughout tow-out. Although the pipeline system in its suspended condition may be relatively light, the required tension levels are quite high. However, they are probably lower than the tow forces for a system in contact with the seabed, and ensure safe maneuverability and low longitudinal stresses during transportation.

The reliability of the CTD method was recently and successfully confirmed during installation of some pipelines in the UK Sector of the North Sea. The technique is ideal for deepwater installations and long distance towing and, in addition to offering all the advantages of the off-bottom tow method, also provides the benefits that:

- The entire system of pipeline and chains is lifted off the seabed, totally freeing it of the problems related to the bottom configuration and potential obstructions such as ship wrecks, rock outcrops and other pipelines or cables.

- Selection of the tow route is easier, and a less rigorous and probably less expensive survey is necessary before and during transportation than for the bottom tow method.

- Smaller tow forces are required than for tow methods where the pipeline is in contact with the seabed: also, smaller longitudinal stresses can be guaranteed.

It has been demonstrated by, among others, Reid [14] in 1951, and Brando and Sebastiani [15] in 1971, that for a submerged slender lightweight pipeline subjected to a large axial tension, the stiffness of the line may be neglected, enabling it to be treated as a catenary. Acceptable limits for the validity of catenary equations with a suspended pipeline have been established as a function of pipe stiffness, length, tension and negative buoyancy.

For the purposes of formulation, the pipeline and link cables may be considered as combined catenaries, symmetrical about the mid-point of the pipe. For a given tow speed, the increased drag force of the suspended system is added to the cable tension at the tow vessel. The bending stresses in the pipe may be determined from the curvature of the line.

To prepare tow procedures and monitor the tow-out and pipeline installation, tow parameters are calculated listing pipe geometry, the position of the line relative to the seabed, and tow and holdback cable lengths for different tow speed and tension forces at the tow and holdback vessels. Results observed during actual installation by the CTD method have been found to be comparable to forecast data using the catenary approach.

Finite element techniques or rod theories [13] may be used for analysis of undesirable or extreme conditions as regards insufficient tension, too heavy a pipeline, or exessive bending. If the reliability of the catenary analysis in safeguarding the integrity of the pipeline is accepted then, when using the CTD method of installation, a more general formulation [16] may not be necessary.

SECOND END CONNECTION

The second end, or trailing end connection technique may be employed with single or bundled pipelines where there is a relatively short distance between the two structures to be connected, such as between a wellhead and/or platform, SPM or central manifold, etc. Not considered here are second end connections which require the use of a swivel connection [17] or flexible pipe comprising alternate layers of plastic and steel. While some of the design difficulties have been presented before [9, 18] , the following is intended to emphasize the more prominent design and construction prerequisites for the safe accomplishment of pipeline connection and operation.

To perform first and second end connection, it is preferable to have a light and flexible pipeline system to assist in minimizing pipe pull forces and bending loads [4]. By virtue of their use of a stable system, elevated off the seabed and in contact with the bottom via chains uniformly distributed along the length of the pipe, the CTD and off-bottom tow methods both offer these benefits during the connection phase. By contrast, the other tow techniques require costly in-place preparations.

For tow-out, submersibles and diving support are helpful in providing route selection and survey data: for first and second end connections, the assistance of such equipment is invaluable. Here, their functions may include:

- As-built survey and inspection of the pipeline before, during and after connection.
- Subsea installation of rigging needed for connection of the line, and attachment and disconnection of tow/pull cables.
- Inspection of the seabed as regards soils, scour, pipe spans etc.
- Sand bagging of the line
- Emergency services.

The pipe geometry and pull forces are very sensitive to soil characteristics, seabed configuration, chain properties, pipe buoyancy, and survey accuracy. The acquisition of data relating to these various elements - which is not always easy - and their subsequent modeling, must be performed with great care to avoid the use of incorrect boundary conditions in turn leading to incorrect solutions. It is also important to check the operating conditions that will obtain when the pipeline is in its second-end connection configuration as these can interact with the prior design phases.

A theoretical analysis can assist in identifying the optimum construction procedures, and in specifying the types of equipment needed to perform the tow/pull-in connections of the pipe ends. The advantages of this method have already been emphasized.

CONCLUSIONS

The four tow techniques are each technically feasible. For a given location, selection of the installation method to be used should be based on a thorough evaluation of the likely alternative construction procedures. As outlined in this paper, each method has its own advantages and limitations, and the best solution may be found when these are related to the known boundary conditions of the particular installation. A technical assessment and cost estimate will indicate the feasibility of, and risks attaching to, each of the tow techniques, and in some instances will identify positive reasons promoting a particular method.

****

REFERENCES

1 Gombert, D.W., "Huge Subsea Pipe Bundle Installed from Shore" The Oil and Gas Journal, August 4, 1975, pp 60-64

2 Menezes, P.F. de, "Emissario Submarino de Santos, Brazil: Operaçao Puxamento", DAE Journal, No 116, 1978, pp 24-27

3 Staff reporter, "Bottom-tow Holds Influential Impact", Offshore, July 1977, pp 48-53

4 Brown, R.J., "Pipeline Stabilization and Automated Connection", paper presented at the "1980 European Seminar, Offshore Oil and Gas Pipeline Technology", London, 1980

5 Staff reporter, "R.A.T. Pipelaying Method Passes Test in North Sea", Pipeline & Gas Journal, October 1977, pp 49-52

6 Staff reporter, "Tomorrow's Frontiers - Today's Experience", Noroil, May 1980, pp. 111-116

7 Potyondy, J.G., "Skin Friction Between Various Soils and Construction Materials", Geotechnique, Vol. XI, The Institution of Civil Engineers, 1961, pp 339-353

8 Kullemberg, B., "Shape of Trawling Cable", Report of the Swedish Deep Sea Expedition, Vol. III, No 2

9 Fernández, M.L. and Carlson, W.O., "Theory and Practice in Deep Water Pipe Laying", paper presented at the "1980 European Seminar, Offshore Oil and Gas Pipeline Technology", London, 1980

10 Mesloh, R., Johns, T.G. and Sorenson, J.E., "The Propagating Buckle", Proceedings Boss '76, The Norwegian Institute of Technology, 1976, pp 787-797

11 NASA TND-1510, "Collected Papers on Instability of Steel Structures", Langley Research Center, Virginia

12 Kermel, L. and Chauvaux, G., "Laying Underwater Pipelines by Float and Chains Method", Ocean Resources Engineering Journal, April 1978

13 Konuk, I., "Higher Order Approximations in Stress Analysis of Submarine Pipelines", ASME paper No 80-Pet-72, 1980

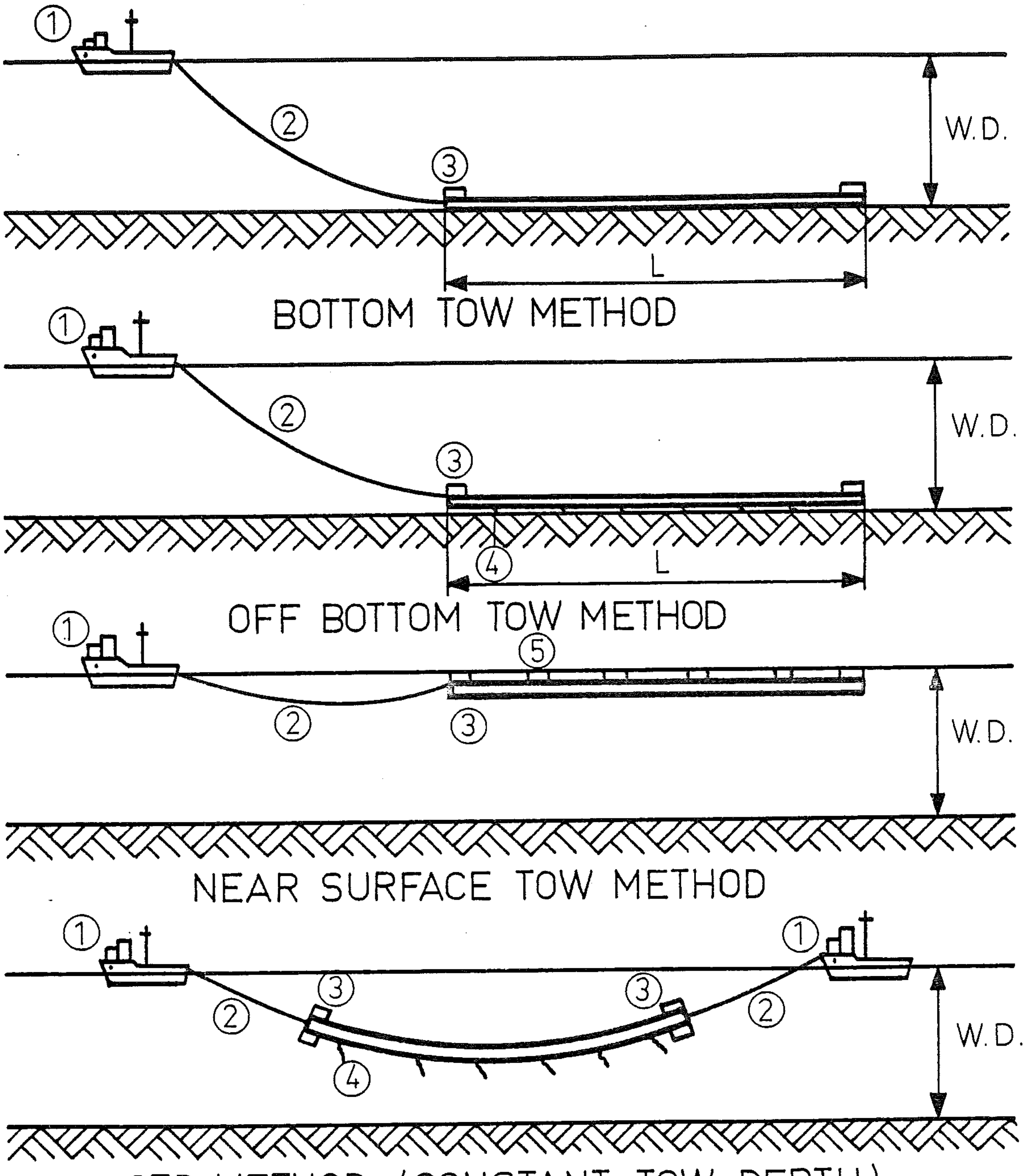
14 Reid, R.O., "Some Oceanographic and Engineering Considerations in Marine Pipeline Construction", Proceedings Second Conference on Coastal Engineering, Chapter 28, 1951, pp 325-393

15 Brando, P. and Sebastiáni, G., "Determination of Sealines Elastic Curves and Stresses to be Expected During Laying Conditions", Proceedings of the Offshore Technology Conference, Paper OTC 1354, 1971

16 Kan, W.C. and Healey, A.J., "Finite Element Analysis with the State Variable Transfer Matrix and Geometric Non-linearity for Marine Pipelines in Sub Surface Tow", ASME Paper No 80-Pet-47, 1980

17 Pras, S., Levellois, E. and Gouraud, O., "Second End Flowline Connection Without Length Adjustment", Proceedings of the Offshore Technology Conference, Paper OTC 3074, 1978

18 Hibbitt, H.D., Becker, E.B. and Taylor, L.M., "Non Linear Analysis of Some Slender Pipelines", Computer Methods in Applied Mechanics and Engineering, Vol. 17, North Holland, 1979, pp 203-225

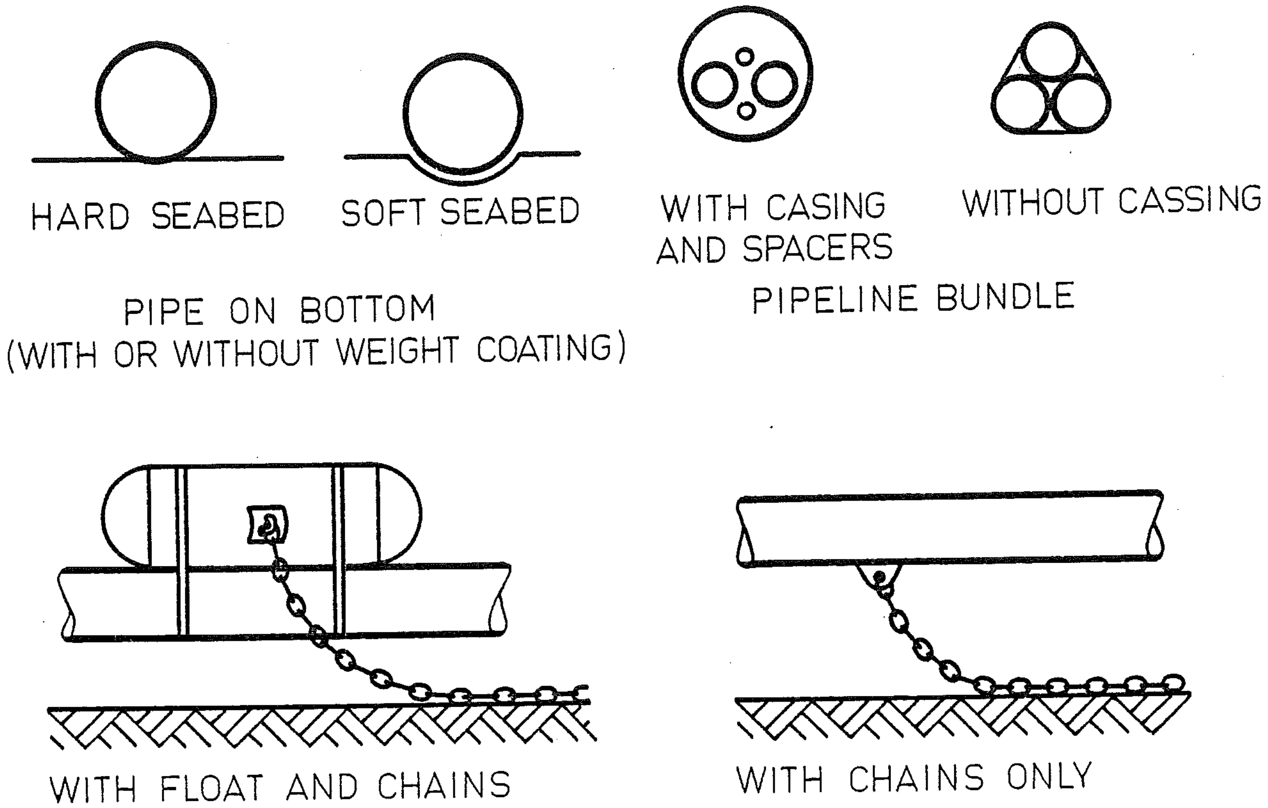


LEGEND :

① SEAGOING TUG
② CABLE
③ PULL HEAD
④ CHAINS
⑤ FLOATS
L = PIPELINE LENGTH

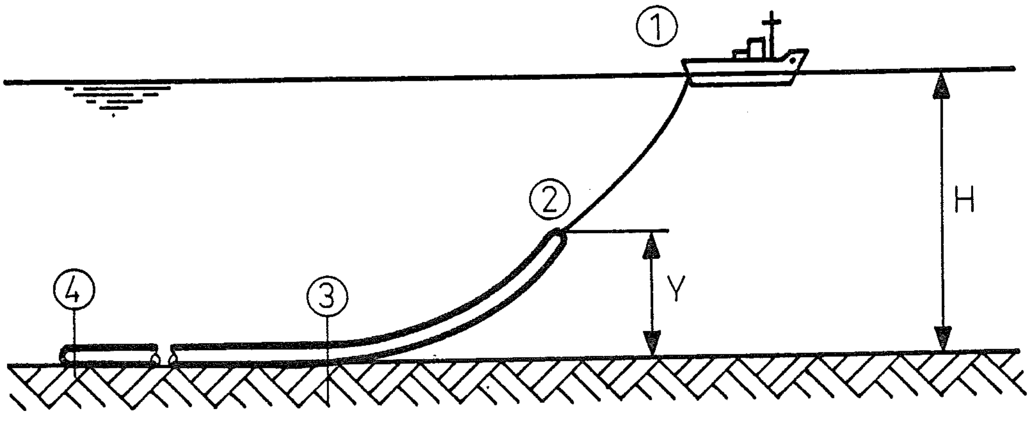
FIGURE 1

FERNÁNDEZ



PIPELINES OFF THE BOTTOM

FIGURE 2



MODIFIED BOTTOM TOW METHOD

FIGURE 3