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Installation of Steel Flowlines from a Diving Support Vessel

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SYNOPSIS

As early as 1982/83 the need had been recognized to move away from conventional pipelay installation by barges and utilize the new breed of heavy diving support vessels for construction duties. The trend towards marginal field developments in the 1980s encouraged by government forces in the U.K. sector of the North Sea and an increase in the number of subsea completions spurred on the development of diving support vessels for use as general construction vessels. A feasibility study was initiated in 1983 to evaluate the use of dynamically positioned diving support vessels for laying small diameter rigid steel flowlines. After confirming the technical feasibility, a project involving the installation of flowlines and other subsea construction activities was undertaken. A full pipelaying system was developed in modular form and installed on the diving support vessel Bar Protector. A number of lessons were learnt during the preparation for and execution of this project but the attractiveness and effectiveness of this new concept in pipelaying was confirmed. A summary of the evaluation of pipelay from diving support vessels is presented herein.

INTRODUCTION

In the present climate of recession caused by the depressed oil prices throughout the world, exploration and field development are in decline. Marginal field developments, which had been on the increase between 1983 and 1986, are now becoming more and more questionable. Operators are turning to new techniques for offshore field development, some technically innovative and others technically inferior but economically attractive. This, of course, has created cut-throat competition, forcing many contractors to look for cheaper and more efficient construction processes and systems.

A number of new technologies have appeared, even in the traditional methods of pipelaying. For the installation of subsea flowlines a number of new methods such as control-depth-tow, reel lay and flexible lay have evolved and been used in various field developments. The increase in flexible composite flowlines has arisen as a result of quick installation times and the ability of dynamically positioned diving support vessels (DSVs) to work in and around congested areas. High initial material costs and permeability problems for gaseous hydrocarbons detract from the suitability of this technique.

Pipelay barges and more particularly semi-submersible lay barges are all expensive to operate. The cost of a large crew and heavy support equipment means that mobilization costs can substantially exceed installation costs for minor flowlines. Alternative techniques are clearly needed if contractors are to gain the edge in an already highly competitive market.

In the declining market all sectors of the construction industry are affected, leaving lay vessels, derrick barges, drilling rigs and diving support vessels idle all over the world. Many shipowners have had to look to other areas in order to provide (sometimes loss making) work for diving support vessels. There are now over fifty diving support vessels in the offshore construction market, and most of these vessels are regularly used for alternative work to that of providing a safe working base for diving activities.

This paper is directed at the efforts required to modify and prepare such a DSV for the installation of rigid steel flowlines. Many problems are posed when using a dynamicaly positioned ship shape hull form vessel for the laying of steel flowlines. Not just in providing a stable platform on which to carry out welding, NDT (non-destructive testing) and field joint coating work, but also in moving forward steadily along a predetermined route in small increments and, most importantly, controlling the tension in the pipeline while maintaining station in irregular wind and wave conditions. These problems and ways of overcoming them are presented in this paper together with the experiences gained during the installation of a welded 2.375 inch diameter flowline in the Irish Sea during the 1985 work season.

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BACKGROUND FEASIBILITY

It was recognized as early as 1982/83 that there would be a surplus of DSVs and an increase in marginal field developments. Hence, possibilities would exist for the utilization of DSVs in flowline installation activities. At this time the poten-

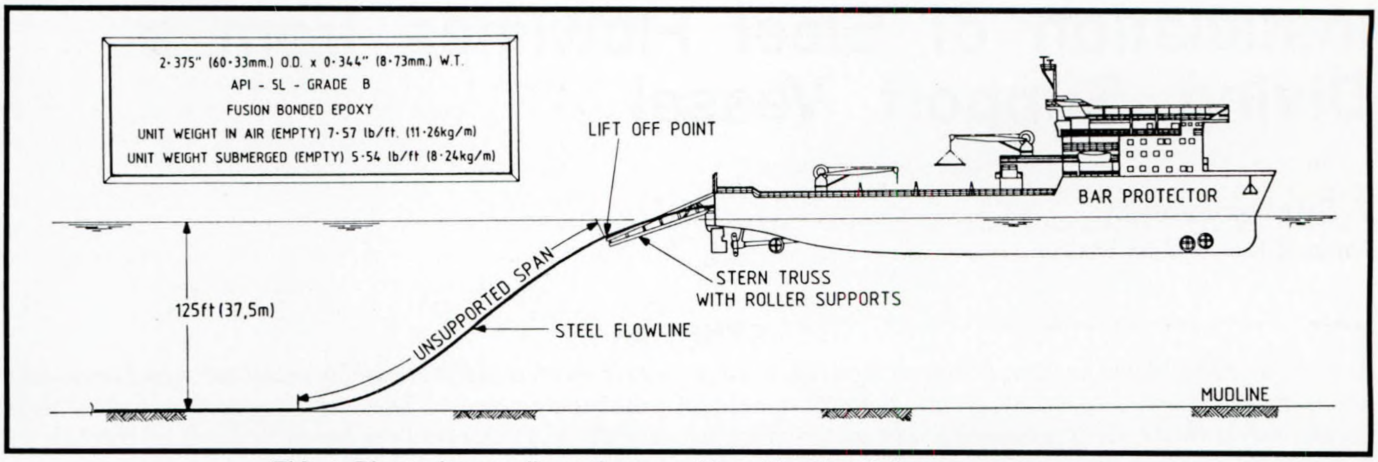


FIG. 1: Pipelaying configuration considered for the diving support vessel

tial for one contractor to undertake a total subsea development with a single vessel was recognized, when previously a characteristic of the subsea market had been that operators would involve several contractors and vessels with expertise in different activities in the installation of each subsea field.

In view of this, a study was commenced to evaluate the feasibility of installing steel flowlines from a DSV while maintaining its characteristics. The study objectives were established as follows.

1. Conceptual design of a modular pipelay system which required a minimum of vessel modifications.
2. Retain a minimum capability as a multi-purpose DSV.
3. As far as possible the system was to be self-contained.
4. Mobilization and demobilization times to be minimized.
5. Establish vessel stability.
6. Define maximum sea state for pipelay operations.

As the DSV would use a conventional S-lay technique the immediate problem became one of productivity with the limited deck length available. Onshore double jointing was considered essential to prove the technique economically viable.

In summary, it was established that pipe diameters of up to 8 inch could be layed in water depths of up to 300 ft with a limited sea state of Beaufort 5. Having established the feasibility of the technique, the opportunity arose to demonstrate the versatility of a DSV for the installation of steel flowlines.

ENGINEERING AND DESIGN

Although the feasibility of installing steel flowlines was confirmed from the initial study, it was necessary to carry out detailed engineering and design in order to build the various components of the pipelay system. The three major activities carried out in the detailed engineering phase were pipelay configuration evaluation, stern-truss design and dynamic pipelay analysis.

Pipelay configuration evaluation

A conventional pipelay system was used on the DSV where double-jointed sections of pipe were welded together on the vessel to make a continuous pipe string and, after radiography and field joint coating, passed over the stern-truss. As the vessel moved forward, the pipe was lowered to the sea bed. A hydraulic tensioning machine on the vessel applied a horizontal force to the pipe. Its purpose was to control the curvature of the pipe in the suspended span between the lift-off point at which it lost contact with the stern-truss and the touchdown point on the sea bed.

The design of such a system took into account many factors to eliminate the possibility of high stresses being induced as the pipe passed over the last roller or through the sag bend. The configuration was determined by the interaction between the flexural stiffness of the pipe, its own weight and the forces applied to it by the roller supports and the tensioner, and by the sea bed itself.

The pipelaying configuration considered for the vessel is illustrated schematically in Fig. 1.

A computer program, TIEIN, was used to analyse the pipelay configuration. The program uses a large-deflection three-dimensional finite-element pipe model with linear or non-linear material properties. The pipelay configuration was analysed by modelling the lay vessel and stern-truss roller supports, location and heights.

The effect of varying tension at the lay vessel was investigated for various water depths together with a lateral current velocity of 3.12 ft/s (0.95 m/s). An optimum pipelay configuration was found which minimized the effect of currents, maintained vessel tension at an acceptable level, and kept the stinger to a manageable size and weight whilst controlling the induced pipe stresses to the allowable levels.

Stern-truss design

The primary function of the stern-truss was to support the flowline in the overbend region and so reduce the stress during the pipe lay operation. It was also required to be:

1. as light as possible and easy to handle;
2. operable during the worst sea conditions anticipated for the pipelay;
3. able to be hoisted out of the water on hinges and be tied back during transit;
4. capable of withstanding all loading regimes including wash from the main propeller, and have an adequate number of adjustable roller supports;
5. suitable for attachment to the existing vessel without structural modifications;
6. modular and require minimum fixing.

During the execution of the project for DSV pipelay, the short period of time allocated for design, fabrication and installation of the stern-truss was a major consideration and it had a considerable effect on the final configuration and member sizes. For this reason the following constraints were adopted.

1. Priority was given to simplicity of welded connections to decrease time and improve fatigue characteristics.
2. Materials were restricted to those readily available.
3. Dynamic loading due to vessel motions was also considered.

In considering the dynamic loading due to vessel movements API 'Recommended Practice for Planning, Design and Construction of Fixed Offshore Platforms 1982' was consulted for guidance. The two relevant Clauses are 2.4.2c and 2.4.4 covering 'installation from a floating vessel in open, exposed sea' and 'forces during transportation', respectively. The first clause gives a minimum dynamic load factor of 2.0 to be applied to the calculated static loads. The transportation clause, however, suggests that vessel response to predicted sea conditions must be evaluated and the loads deduced from that.

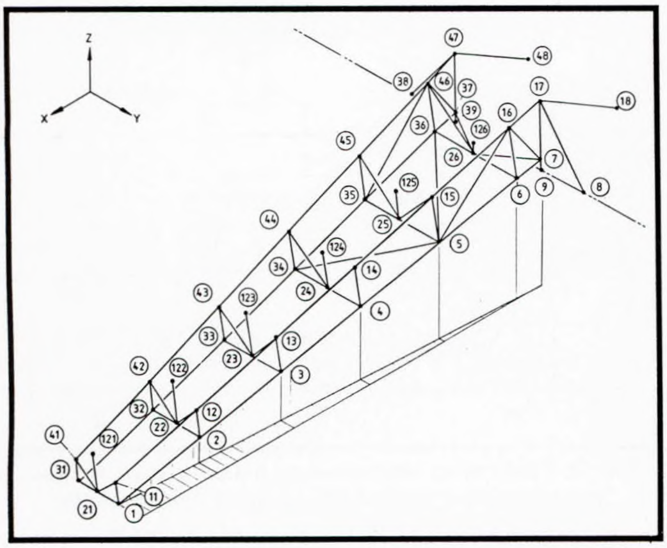


FIG. 2: Computer stick model used for the stern-truss design analysis

It was considered that the hoisting of the truss out of the water was an 'installation' and during the pipelaying it was in 'transportation'. The vessel motion response analyses, however, could not commence until a preliminary design had been carried out. Hence, a factor of 2.0 was used for most of the analyses.

A computer program, BARMOT, was used to determine the motion responses of the pipelaying system. The motion response of the vessel for five wave headings from head seas through to following seas was considered in the analysis. It was found that the maximum acceleration of the tip of the stern-truss was 0.36 *g* in a significant wave height of 4.0 m and zero crossing period of 8.5 s.

A structural computer program, DAMS, was used to model the truss together with punching shear at the nodes. The computer program is designed to perform linear elastic analyses of three-dimensional structural models. The program has a wide range of both static and dynamic capabilities and is specifically tailored for marine structures. The structural program includes a sub-routine program, JAMS, for punching shear calculation. This program provides an analysis and design of simple tubular joints in accordance with the API RP2A and/or Det Norske Veritas code. Based on geometrical information and maximum member forces and moments obtained from a static analysis, joints were proportioned according to the punching shear criteria.

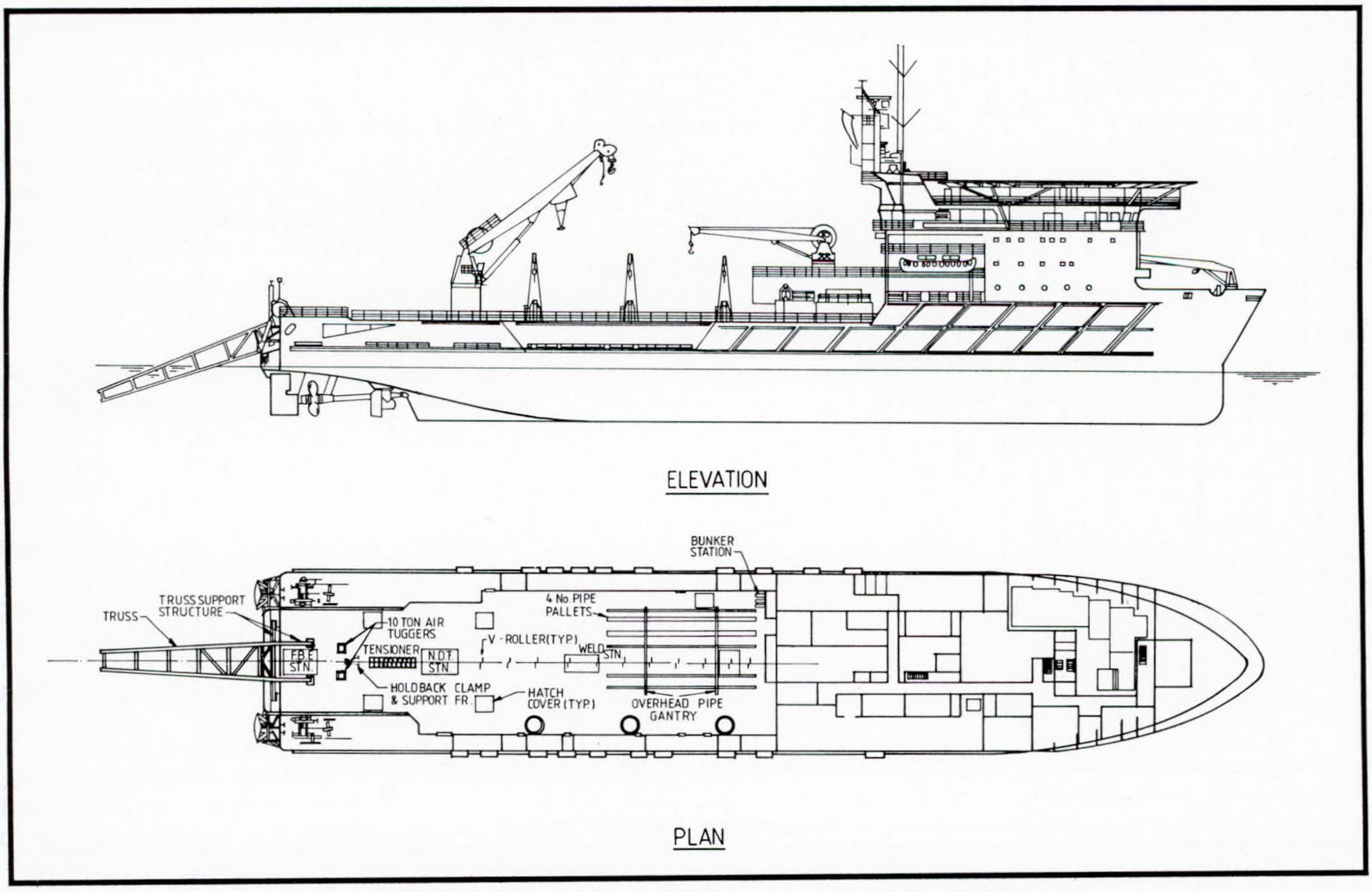


FIG. 3: General arrangement of the diving support vessel pipelay system

The stern-truss was analysed for the normal lay case with the main chord at 18.5° from the horizontal, supporting the flowline on a 250 ft radius. The computer model used in the stern-truss analysis is given in Fig. 2. The stern-truss was also analysed for the case where the truss is being lifted out of the water by slings from deck mounted winches. The horizontal position was considered to be the governing stern-truss orientation for the lift and the computer model was therefore rotated for this analysis using the additional facilities given in the computer program. The general arrangement of the diving support vessel pipelay system is given in Fig. 3.

Dynamic pipelay analysis

When pipeline installation continues under bad weather conditions, the entire pipelay system responds dynamically and induces dynamic stresses in the pipeline. The dynamic stress amplitudes are over and above those induced by the regular handling process. If the magnitude of the dynamic stress amplitude is significant, then there is a risk of overstressing the pipeline. It therefore becomes quite important to consider the influence of dynamic stresses prior to developing the final construction procedure and establishing abandonment criteria.

A frequency domain dynamic pipelay analysis was carried out using a computer program, DAMP, considering the effect of wave and current on the DSV pipelay system. The computer program is a three-dimensional finite element computer code capable of performing the following types of analysis for the conventional S-lay or any other specified configuration.

1. Static analysis of initial pipeline configuration.
2. Eigen value analysis.
3. Frequency domain dynamic analysis.
4. Time history dynamic analysis.
5. Post-processing of the results including calculation of transfer function and fatigue life elevations.

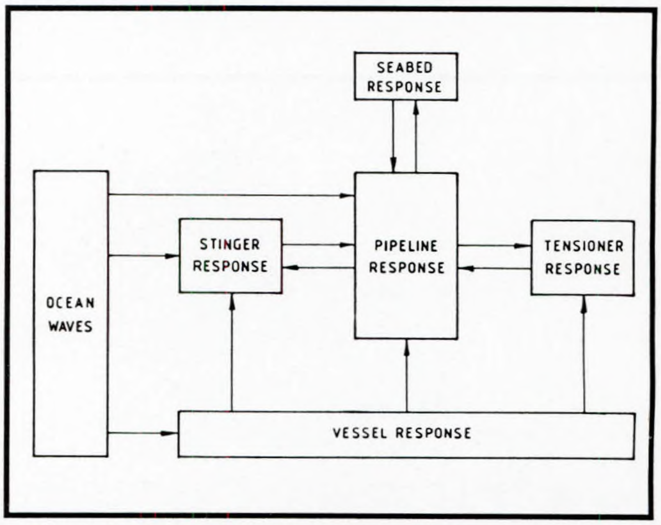


FIG. 4: Schematic illustration of a pipelay system and the interactive behaviour between the elements

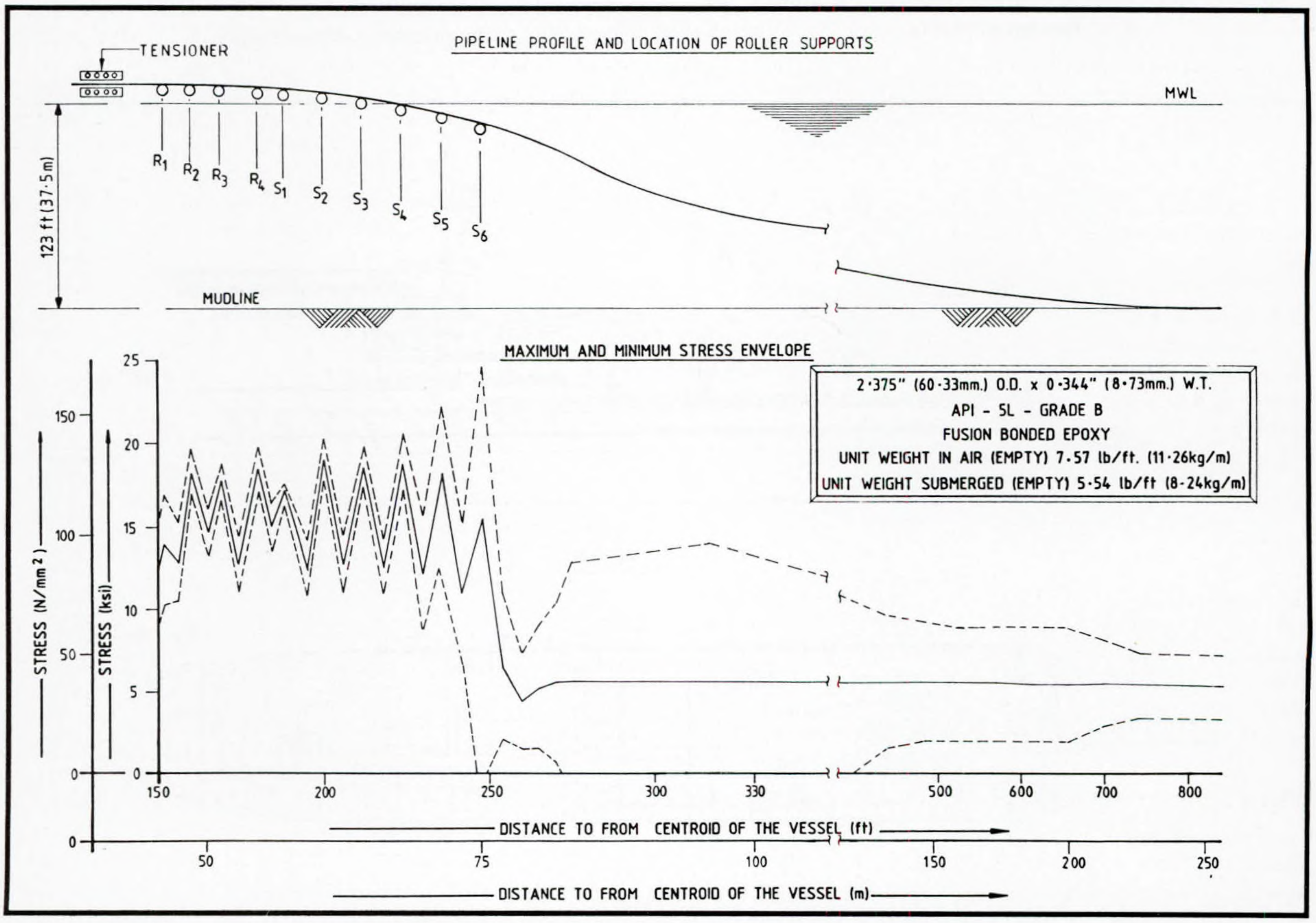


FIG. 5: Flowline configuration and dynamic stress envelope for a sea state of 7.36 ft (2.25 m) significant wave height with 5.0 s period and current velocity 3.12 ft/s (0.95 m/s)

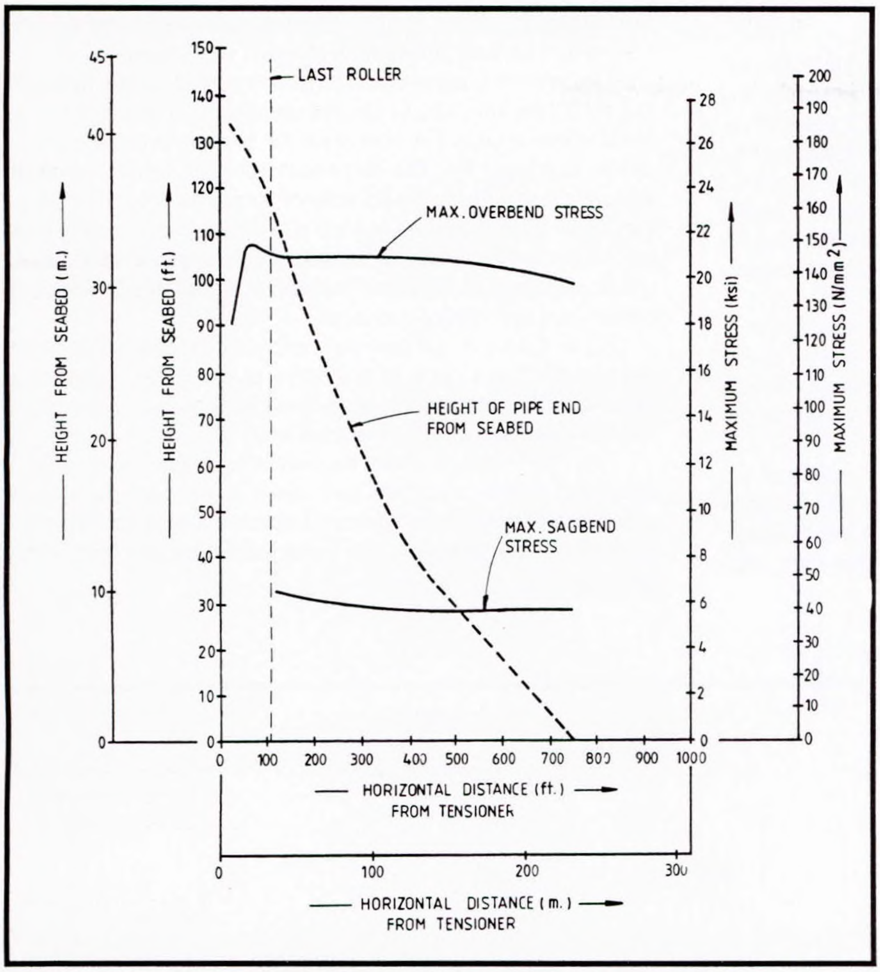


FIG. 6: Flowline configuration and stresses induced in the pipe during start-up

The pipelay system and the interactive behaviour between the system elements used in the computer program is shown in Fig. 4.

Fig. 5 shows a schematic illustration of the pipeline profile and the location of the roller supports together with the maximum and minimum stress profiles predicted by the program for the sea state of 7.38 ft (2.5m) significant wave with 5.0 s periods and current velocity of 3.12 ft/s (0.95 m/s) at the water surface.

INSTALLATION ENGINEERING

As is normal for all pipelay operations specific installation stress analyses and procedures have to be carried out before the mobilization of the pipelay vessel. For the DSV pipelay project J-tube start-ups were required and as the pipelay were terminated with J-tubes at either end a welded above-water tie-in was needed in a suitable flowline route.

Pipelay start-up with J-tube pull

There are various methods of pipelay start-up including deadman anchor, sheave start-up and J-tube pull. Pipelay start-up with J-tube pull was applicable for the first steel flowlines installation project from the DSV.

For the J-tube start-up, the pipelay vessel was positioned at the required distance from the platform. The pull-in wire was then connected to the pipeline pull-head and pipelay commenced by using the platform pull-in winch to pull the pipe from the stationery vessel. One double joint would be pulled from the vessel at a time, similar to normal lay.

However, the stresses induced in the pipeline would be different from the normal lay since the pulling cable cannot provide the same stiffness as the pipe. Therefore, a step by step analysis was carried out by using the computer program TIEIN. The pipeline configuration and stresses induced in the pipe during the start-up are shown in Fig. 6.

A separate analysis was carried out using a computer program, JTUBE, to predict the pull-in force required at the platform winch and stresses induced in the flowlines during the J-tube pull.

The JTUBE program calculates the strains and forces in a pipe being pulled through a J-tube assembly. The pipe and J-tube geometrical properties are input to the program. As output, the program calculates contact forces between the J-tube and the pipe and the tension required to pull the pipe through the J-tube. The solution procedure of the program starts with the pipe pulled to an initial J-tube angle and repeats in steps as the angle is increased by pulling the pipe until it clears the J-tube.

The pipe was divided into a number of elements and linear bending theory was used to formulate a finite beam element analysis. An average constant elastic modulus was assigned to each pipe segment based on the maximum bending in the segment. Stiffness variation, ovalization and reverse loading were considered in solving the problem. The required pull-in forces at the platform winch predicted by the program for J-tube pull are given in Fig. 7.

Abandonment and recovery

The flowline has to be laid down at the end of the laying operation. It may also be necessary to abandon the flowline if weather conditions deteriorate beyond the workable limits.

Therefore when the decision to abandon the flowline is made, a temporary abandonment head is welded to the end of the flowline. The tension on the flowline is transferred from the tensioner to the A/R winch and the abandonment of the flowline begins.

The vessel is moved ahead a sufficient distance to allow the abandonment head to come to rest on the sea bed. This procedure is applied in reverse order when the decision is made to recover the flowline from the sea bed.

During abandonment and recovery operations, although the flowline follows approximately the same route as normal lay, the stresses induced in the flowline will be different from the normal lay because of the changes in stiffness and configuration of the abandonment cable. Hence, a comprehensive analysis was carried out for the abandonment and recovery of the flowline. The flowline configuration and stresses induced during the abandonment and recovery operations are shown in Fig. 8.

Above-water tie-in

As the flowlines started with J-tubes at each platform, the two halves of each pipeline were laid separately necessitating a mid-point tie-in to complete each system. For the above-water tie-in, the flowlines were laid with ends overlapped by approximately 44 ft. The vessel was then positioned as required and both ends of the flowline raised approximately 10 ft above the water level using four davit lines and one tension line on each side. The flowline ends were cut and the welded connection made.

The vessel was moved laterally approximately 65 ft before the flowline was finally lowered to the sea bed to avoid overstressing the flowline under compressive forces which would have developed because of the increased length in the weld configuration.

A comprehensive analysis was carried out for each of the steps involved in the above-water tie-in operation, and the steps analysed included right- and left-hand side vertical pick-up, above-water welding configuration, lateral move-over, and lowering to sea bed. The flowline configuration and stresses induced during the critical operation of above-water welding are shown in Fig. 9.

PIPELAY EQUIPMENT

The equipment was of a modular configuration enabling a very short mobilization period. In practice it took less than 48 h to load, seafasten and test all of the pipelaying equipment on board the vessel. The equipment was positioned on the vessel deck as recommended by the detailed engineering study.

Pipe storage was in four interlocking pipe racks. The racks were designed so that they could be lifted into place by the vessel crane and moved when empty. The stern-truss was supported by a simple braced frame mounted over the vessel's stern bulkhead.

The pipelay system used a rubber-wheeled hydraulic tension machine for maintaining tension during the normal pipelay operation. The tension machine was fitted with a caliper breaking system but external pipe slips were used as a further safety feature to prevent losing the pipe in the event of system failure.

The firing line was centrally located with three work stations, the first being a welding station, the second for NDT and the third a field joint coating station. The tension machine was located between stations two and three.

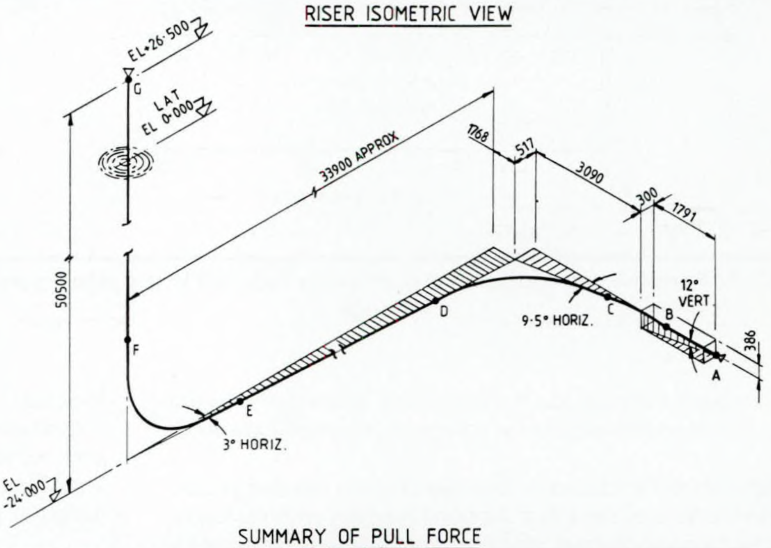
For 4, 6 and 8 inch diameter pipes the feasibility study had recommended that four stations were adopted, i.e. the first two being welding stations to improve the overall cycle time. This would have been feasible if the pipe was supplied in 12 m double random lengths, but for the DSV flowline lay project pipe was supplied in 8 m lengths. After double jointing, the pipe lengths were 16+ m and so only three work stations were feasible.

The pipe was supported by rubber-coated rollers throughout the firing line and as the maximum roller reactions were always less than 5 t it was possible to use readily available nylon bearings. For the stern-truss double roller, carriages were used to reduce the effects of local bending. The roller carriages were mounted in threes and fours on a single plate providing further modularization. Mobilization was therefore quick, requiring each unit to be positioned and fixed to the deck rather than each roller carriage.

All of the work stations were elevated at least 1.5 m above the vessel's work deck to provide a suitable pipe supporting system in the overbend region. Each station was completely modularized and a self-contained unit.

The NDT station was surrounded by a thin layer of lead shielding which absorbed any stray X-ray radiation. Each individual X-ray unit had its own lead casing which reduced the costs of overall shielding and provided for greater mobility of the unit.

RISER ISOMETRIC VIEW



SUMMARY OF PULL FORCE

CRITICAL LOCATIONS		APPROX DISTANCE FROM BELLMOUTH (metres)	DESCRIPTION OF GEOMETRY	MAXIMUM PULL FORCE REQUIRED (kN)	
				COEFFICIENT OF FRICTION = 0·25	COEFFICIENT OF FRICTION = 0·30
BELLMOUTH	A	0·0		26·00	26·00
			STRAIGHT		
BEGINNING OF FIRST BEND	B	1·50		26·00	26·00
			12° BEND		
END OF FIRST BEND	C	3·25		30·25	30·90
			0·0		
BEGINNING OF SECOND BEND	C	3·25		30·25	30·90
			77·5°		
END OF SECOND BEND	D	7·31		52·31	53·30
			STRAIGHT		
BEGINNING OF THIRD BEND	E	34·85		54·75	56·25
			90°		
END OF THIRD BEND	F	39·56		84·82	95·80
			STRAIGHT		
TOP OF JACKET	G	86·87		88·38	100·10

FIG. 7: Pull-in forces predicted by the JTUBE program for a typical J-tube pull

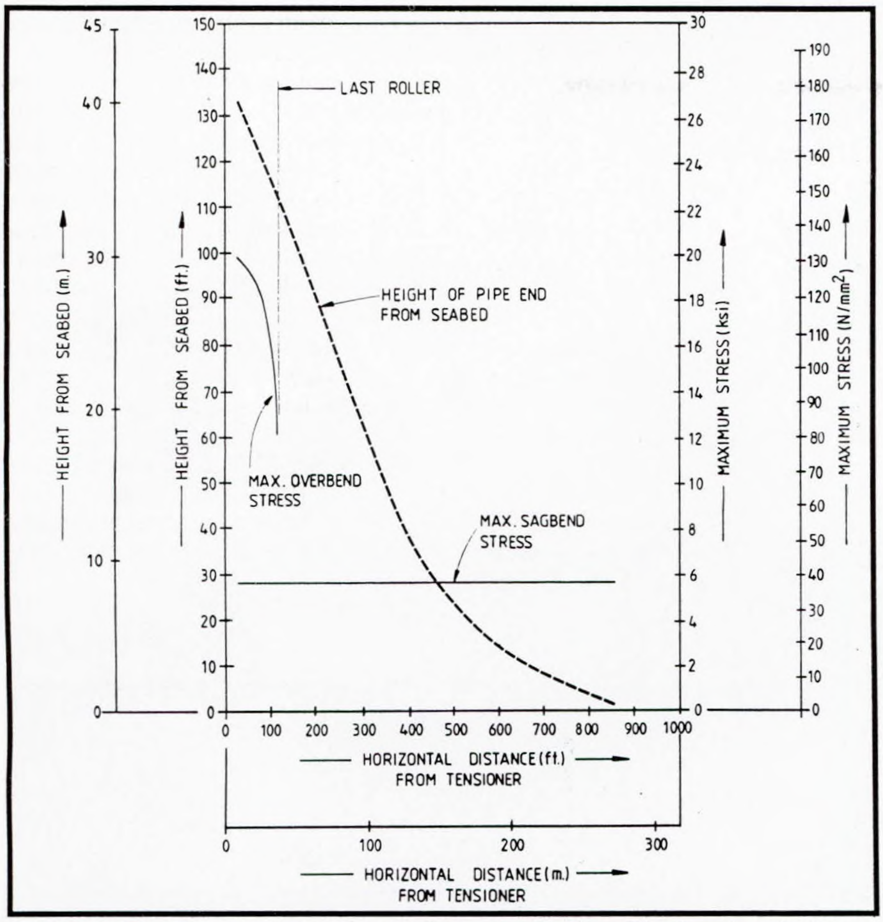


FIG. 8: Flowline configuration and stresses induced in the pipe during abandonment and recovery

OFFSHORE PIPELAY OPERATIONS

Start-up

As noted previously, J-tube start-ups were required. The DSV was set up on station a predetermined distance from the J-tube bellmouth and the flowline pull head was attached to a pull line from a platform-mounted winch. There were no significant problems with this operation other than those associated with new equipment being used for the first time.

Normal pipelay

After completing the operations in each work-station on the pipelay vessel, a button was depressed in each individual station. When all buttons were depressed, i.e. all the work had been completed, a green light showed in the bridge and the vessel would be moved forward the required distance.

As the vessel had to move forward approximately 16 m under control of the DP (dynamic positioning) computer and stop at exactly the right place, problems could have arisen. Prior to starting the actual pipelay operations a series of DP trials took place. The DP software was written around keeping the vessel on

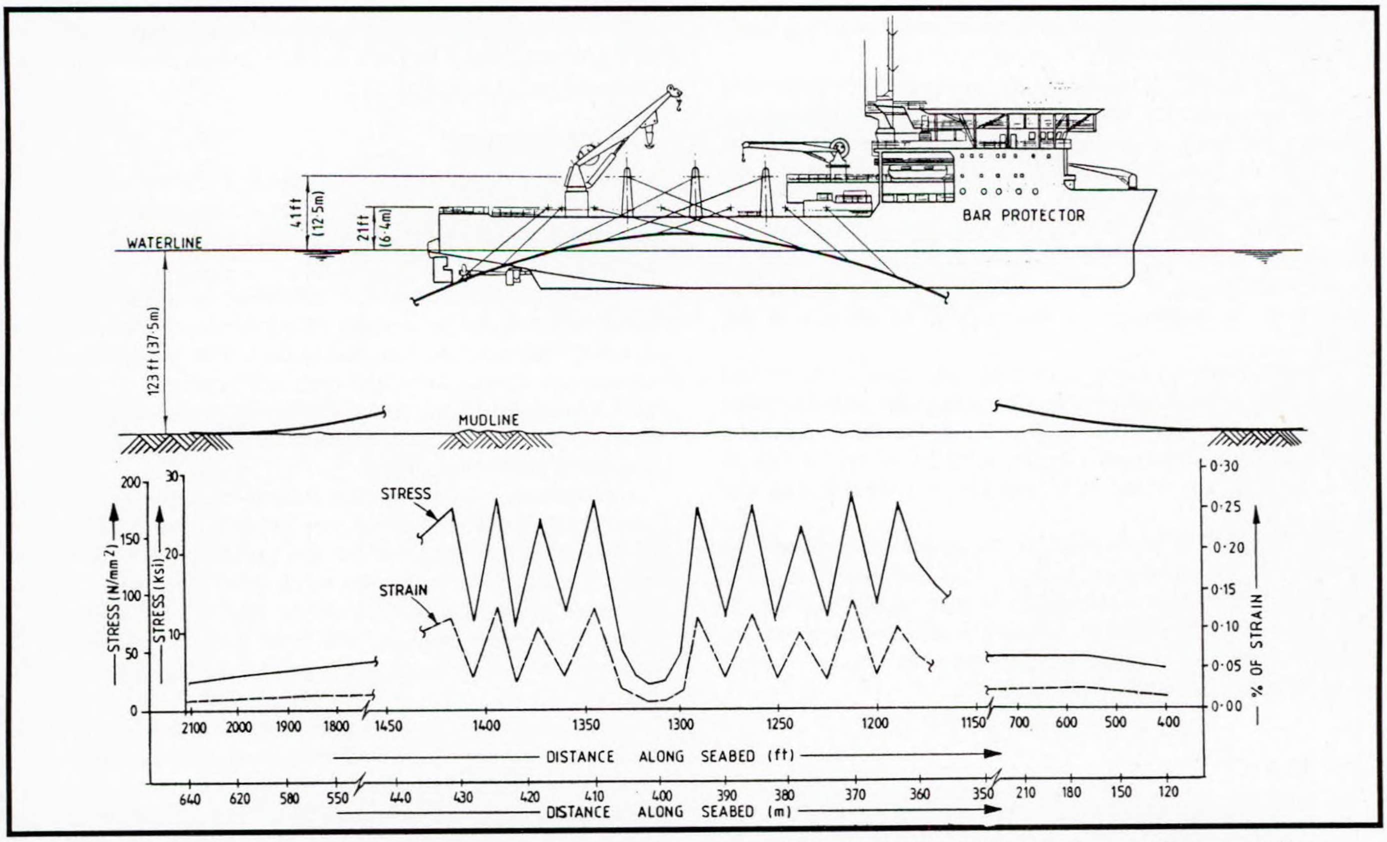


FIG. 9: The flowline configuration and stresses induced in the pipe during the above-water welding operation

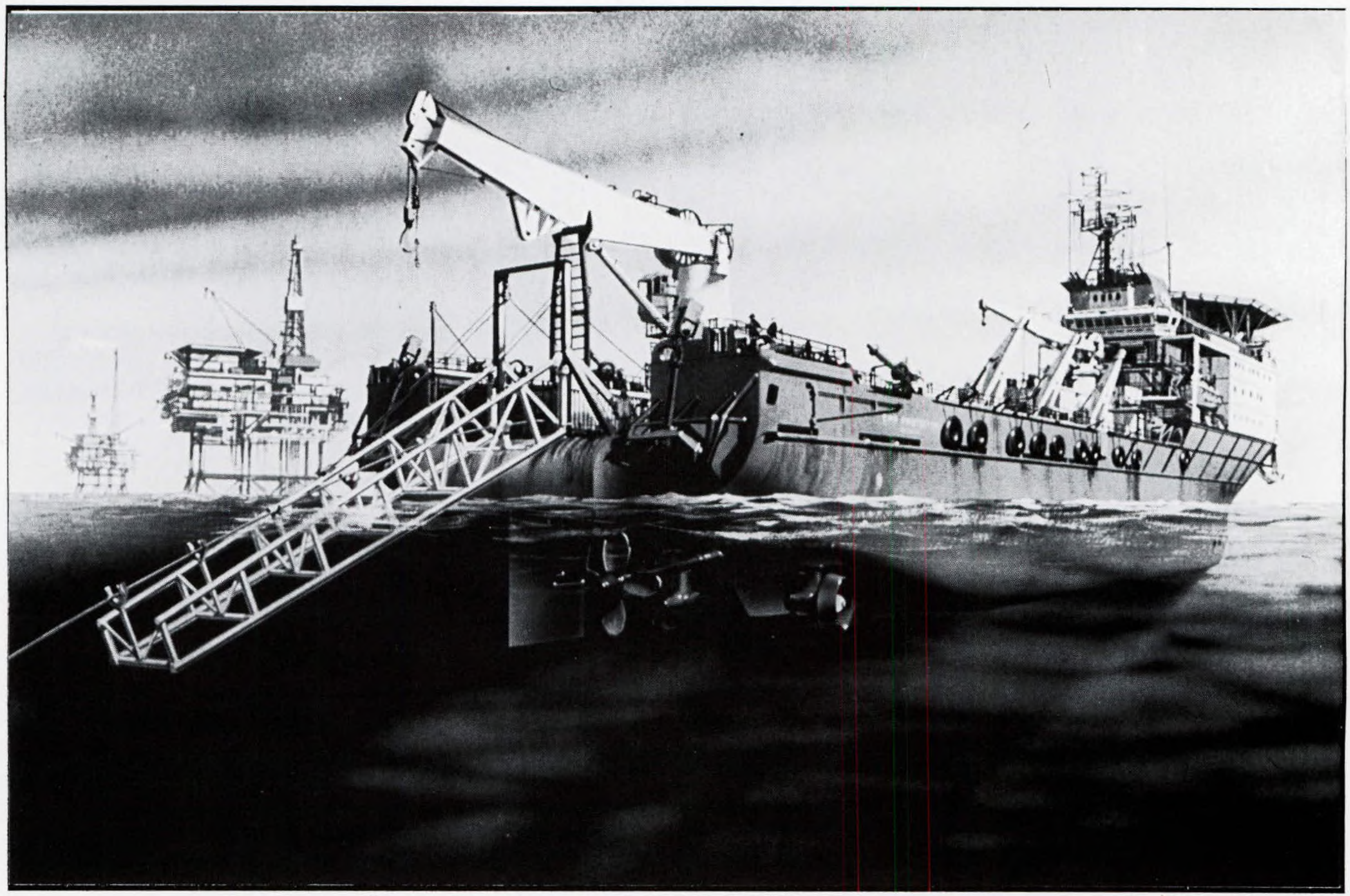


FIG. 10: Diving support vessel installing the steel flowline

station in one place during diving operations or moving along a predetermined course at a constant speed.

The 'overshoot' when moving from one position to another was far too great for safe and efficient pipelay operations. Setting a move of 16 m on the DP computer meant that the vessel would overshoot at least 1 m or so dependent on the prevailing weather conditions.

However, being controlled by a computer meant that the vessel then backed up over a course of a minute or so to its programmed position, which could easily result in a buckled pipeline if the tensioner did not respond as quickly as the vessel.

To avoid this situation occurring, the vessel was in fact moved up in 14 m increments and then manually eased forward to the correct position. As well as being the safest mode of operation, this also proved to be the quickest. A typical view of the diving support vessel installing the steel flowline is given in Fig. 10.

For the size of pipe used in the operation the welding appeared to govern the cycle time. It is anticipated that for larger pipe diameters, radiography would control the critical path. The strict control of welding interpass temperatures meant that, on such a small diameter pipe, cooling time had to be allowed for between-welding passes.

Lay down

A 10 t constant tension air winch was used for abandonment, recovery and laydown. A specially machined abandonment head was attached to the pipe end and the pipe abandoned in the normal way. The DSV had to maintain smooth but rapid progress as the pipe was laid down.

Station keeping

No major modifications were made to the DP software for the pipelaying operation. For this project tension levels were a minimal 5 t which had only minor effects on the DP computer control.

However, these tension levels had to be maintained at all times and this did have some effect on the overall position-keeping characteristics of the vessel. The area where pipe laying was taking place had high tidal currents of the order of 3–4 knots across the vessel beam. The combination of wind force, current and pipe tension substantially reduced the powers of station keeping.

In practice, it seems that the station-keeping capabilities of most DSVs would shutdown pipelaying operations before the effects of vessel motions on the pipeline itself. This was experienced on one occasion when wind speeds of 35 knots combined with 3 knot cross currents had meant that the ship's power was operating at the 70% level. The decision was made to abandon the pipe until wind speeds had decreased to more tolerable levels.

It is interesting here to note that sea conditions did not deteriorate to more than 1–2 m seas and barely affected the vessel motions. If wind conditions were on the head of the DSV then pipelaying could have continued right up to the theoretical maximum, as dictated by the dynamic pipelay stress analysis.

EFFICIENCY

The size of crew for a DSV pipelay operation was small in comparison with that of a semi-submersible laybarge, thus substantially reducing the daily cost. The efficiency was correspondingly reduced, but the overall flexibility offered was significant. Within the same contract as this first welded DSV pipelay, the installation vessel also carried out electric power cable installation, support frame installation, jacket surveys, underwater welding and boat bumper installation, which clearly demonstrates the flexibility of DSVs.

CONCLUSIONS

The concept of installing offshore steel pipelines from a dynamically positioned diving support vessel was developed and the operability confirmed over the 1985 work season. During installation, it was clearly demonstrated that all the activities relating to the offshore pipeline installation, i.e. start-up with J-tube pull, normal lay, abandonment and recovery, laydown and above-water tie-in, can be carried out successfully.

This proven technology can be used world-wide, not only to reduce offshore pipeline installation costs, but also to install steel pipelines in congested fields without potential anchoring problems.

ACKNOWLEDGEMENTS

The author would like to take this opportunity to thank Brown & Root Construction and Engineering management for their encouragement and permission to publish this paper. Thanks are also due to colleagues for their valuable comments during preparation of this paper.

Discussion

S. SASANOW (Subsea Engineering News): Can the author please state the length of the flowlines and the amount of time it took to lay the lines? Also, since cost-effectiveness was a key element in this work, why didn't Brown & Root design the stern-truss so that it could be used for future work?

J. KENNEDY (Agip U.K. Ltd): Would the authors please outline the various options and possibilities they would envisage for diving and subsea support related to this kind of operation?

J. RIDEHALGH (Noble Denton Consultancy Services Ltd):
(1)Bearing in mind the quantity of pipe likely to be required to be stored on deck, were any special stability criteria required for the vessel, and if so, is this requirement likely to be a limitation on the operation?
(2)In the presentation, results of motion analysis were discussed for small size pipe (2.375 inch diameter). It was stated that the system could install pipe of up to 8 inches in diameter. Is there likely to be any significant difference in motion response for an 8 inch pipe compared with a 2.375 inch diameter flowline?
(3)The operation is obviously weather-dependent. Is the operation weather limit dependent on pipe size, and if so, to what extent?

Author's reply

In answer to S. Sasanow: The total length of the line was approximately 27 km and it took approximately 30 days to finish the lay.

The project was on a tight schedule regarding time and budget, hence we could not find the extra resources needed at that time to design a permanent truss to last for longer-term use to serve a variety of sizes of pipeline.

In answer to J. Kennedy: It is possible to use any subsea support- related vessel for this kind of operation provided it has enough deck space for pipeline storage and work space for the firing line. Also, the vessel should have the capability for dynamic positioning during the lay.

In answer to J. Ridehalgh: (1)In practice the quantity of pipe segments to be stored on the vessel is mainly dictated by the amount of space available on the deck area rather than vessel stability criteria. Stability checks on vessels have been carried out, and typically up to 3000–4000 tonnes of pipe weight can be used without significantly affecting vessel stability.

(2)The size of the pipeline itself is not likely to have significant effect on the vessel motion, however, vessel motion can greatly influence the pipeline and hence determine the pipe size that can be laid during a given sea state at a particular water depth. Larger diameter pipes can attract more environmental loading and visually require higher barge tensions to provide required configuration during installation operations.

(3)The allowable sea state is very much dependent on the pipe size and material. For allowable weather limit the pipelay stresses must not exceed the maximum specified stresses in the overbend and sagbend regions. Also, the maximum tension provided by tensioners on the vessel against environmental loading and self weight is dependent on the pipe size. Therefore, the maximum allowable sea states can vary according to pipe size, wall thickness and pipe material.