OTC 3739

NEW SOLUTIONS AND IMPROVEMENTS TO PIPELAYING DEVELOPED DURING CONSTRUCTION OF VERY DEEP WATER SEALINES WITHIN TRANSMEDITERRANEAN PROJECT

by Stefano Bianchi, Stefano Cao, and
Vincenzo Oliveri, Saipem S.p.A.

This paper was presented at the 12th Annual OTC in Houston, Tex., May 5-8, 1980. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

ABSTRACT

This paper describes the main problems, at times unexpected, faced during the Messina crossing project, completed successfully in 1979 using for the first time the new generation semisubmersible pipelayer SAIPEM CASTORO SEI, whose features are mentioned in OTC 1979 paper 3502. Three 20 in. lines have been laid from Favazzina on the Italian mainland to Mortelle, Sicily. This is part of a gasline system - under construction - from Algeria through Tunisia, across the Mediterranean to Sicily then to the Italian mainland northward to Bologna for a total of about 2,500 km.. Problems faced and solutions adpted contribute to feasibility of future projects in deep waters, namely:

- fatigue stresses induced on free spans by oscillations due to currents require high quality pipes and stricter welding specifications,
- extreme laying accuracy in deep waters has been consistently achieved: ± 5 mt. (at special points only 1 mt.),
- manned submersible has been proven as laying tool to monitor and guide touch-down,
- effects of current layers on pipe being laid: 5 knots in 340 mt. W.D. with 1,300 mt. span-relevant solutions,
- required high pulls cause residual tension on the line: implications (longer free spans etc.). This and other new findings suggest specific tension limitations for future deep water projects.
- Operational limits of advanced layvessels versus those of supporting crafts: problems and solutions in difficult environment,
- development and betterement of automatic pipelaying control resulting from Messina operations with special reference to pipe safety, laying accuracy and productivity,
- validation and calibration of new computations and ensuing operational techniques: laying and A/R programmes, touch down computation, tridimensional pipe programme.

MESSINA CROSSING MAIN PARAMETERS

- length: 14 km. in a continuous bend
- 2 lines: longitudinally welded X65 grade, w.t. 17.48 mm. (and 5 cm. concrete coating) up to 280 mt. of water and 20.62 mm. (with 4 cm. concrete) in deeper waters, with resulting submerged weight of 126 and 137 kg/mt respectively; 10 cm. of concrete has been applied on the shore approach sections, buried.
- 3rd line: seamless, X52, w.t. 23.83 mm., with concrete coating on the shore approaches only, thence bare pipe with polyethylene anticorrosion coating-submerged weight 86 kg/mt.

The maximum depth was 360 metres by far the deepest sealine laid to date. The route profile has a steep slope up to 22 degrees to reach the deepest part when gradually raises towards the Sicilian coast. The sea-bottom nature is extremely variable from the initial rocky section to mixed rocks and sand, then a long sandy section with sand waves, caused by strong currents. The route crosses many submarine telephone cables. There were also many wrecks just off route interfering with anchor handling. Because of these hazards, six mooring cables were broken during the first line, one during the second and none on the third. The vageries of the Sicilian winter season, albeit mild in tempe-

---

References and illustrations at end of paper.

rature, added to the difficulties encountered by Castoro Sei.

Main operational problems and their solutions

A) Welding

B) Lay accuracy

C) Submarine guided-lay

D) Currents

E) High applied pulls

F) Limitation of support crafts

G) Development and improvement of the automatic control systems

H) Operational computing programmes

***

A) The nature of the rough sea-bottom made freespans unavoidable. Under the currents effect, these freespans might well start oscillating considerably, and cyclic fatigue stresses might be induced. Such stresses become extremely dangerous if there are defects for fracture initiations. From these initiations, fatigue failure might later propagate. Similar fatigue problems could arise with the pipeline remaining long enough, in free bend configuration in presence of currents or bad weather. As a consequence the welding specs were very restrictive, largely exceeding API requirements. Semiautomatic CO_2 has been used on board Castoro Sei. Thus 100% ultrasonic inspection has been added to the usual x-ray. Welding procedures have been meticulously drawn up also to achieve high impact resistance and low hardness. Consequent retraining of welders and foremen was required. Nevertheless the high specifications resulted at the beginning in more frequent repairs, reducing the productivity. This experience is invaluable for future project with similar specifications. The bet solution will certainly be a very good quality automatic method.

B) The difficult profile has required extreme laying accuracy especially over some sections. In the steepest parts of the Calabrian slope, the rocky sea-bottom had to be blasted in order to clear a narrow corridor in which to lay all three lines and eventually a future fourth one. Maximum width of the corridor is 45 metres only. Here pipelaying has been guided by submarine using a previously laid cable as reference for the first line; the latter served as reference for the following two lines. In this section of one kilometre, the water depth varied from 50 to 200 metres and the length of the unsupported spans from 180 to 600 metres. Well, such accuracy was achievable with a correct computation of the ships movements with respect to the touchdown points and with and extremely accurate control of the ship's heading and position, even in bad environmental conditions. This was done with an almost online computation (the scientific computer was continuously operating) working in parallel with the automatic control system of Castoro Sei. Then, if the submarine, which was monitoring touchdown point, wanted a correction to that point or to its angle, the pipe was realigned as follows:

1. The submarine retreated to a safe distance;
2. The pipe pull was increased to length and straighten the free configuration, consequently the touchdown point moved back from the previous position;
3. The ship was moved and rotated and the pipe allowed to settle in its new path on the sea bottom;
4. Finally the pipe was released again to the previous tension values and the submarine checked the new configuration.

This happened a cople of times. As a result there are now three lines within ten metres each from the other and ample room for another inside the same corridor.

C) As previously noted, one of the most useful tools for the success of the Messina Straits crossing has been a manned submarine, the Perry PC 16; it will be an essential for all future deep water projects to perform a variety of functions (installation of supports for the freespans, preparations for blasting). The submarine has also performed conventional survey functions. It made vertical and horizontal as built profiles, essential reference for later lines. When the submarine has guided the bridge, the following procedure was adopted:

1. direct link between Castoro Sei and submarine by hydrophonic telephone,
2. during welding the submarine went to the touchdown point measuring the distance between the pipe and the guide cable by means of its underwater positioning system or sonar (for the first line) or between the lines (for the second and third line),
3. if the position was acceptable, the submarine stood off the line to await the next check,
4. if the touchdown point position had to be corrected, the correction was made as already explained, with a subsequent re-check.

This experience suggested SAIPEM to add to its spread a new submersible mother ship, the "Ragno Due", and an improved version of Perry submarine. A further essential capacity of the Castoro Sei system is to have the actual configuration computed with the reaction between pipe and support so knowing the stress on the pipe and to check it with the measured values coming from vertical and horizontal load cell on the ramps.

D) The shortest route between Calabria and Sicily had been rejected for the sea-bottom profile and for the prohibitive currents. Nevertheless very strong currents have been met along the chosen route. There were current layers with variable depth profiles as well as cyclic variations due to tidal components. During one night, a very strong current developed athwartships in half and hour. At that time Castoro Sei was laying the first line in 340 meters of water: a surface current of five knots was measured, where, only the night before (one kilometre back), there had been nothing! The most evident effect of the current was observed in the free configuration. Pipeline started oscillating, first with short vertical movements and, later, with jumps of 1.5 metres at the period of maximum current. The T.V. camera showed all these movements; at the same time, the reaction of the last vertical roller continued to increase because of the lateral push of current. The pipe pull was now 130 tons, the length of the unsupported span was 1,300 metres and the pipe pull oscillation was substantial. The desirable rotation and movement were now given to the ship to reduce the pipe transverse stress at the last vertical roller of the external ramp. This was the only unexpected emergency causing some damages to the concrete because of the buffeting, as apparent from the survey done the following day; no other pipelay system could have prevented major mishaps under such extreme current conditions. That night on board the old belief in the legendary monsters, Scilla and Cariddis almost revived. Mythology has it that they inhabited the Straits and menaced navigators. Nowadays, modern computation and operational techniques were perfected to minimize the antics of Scilla and Cariddis; they have been no longer able to cause any significant damage.

E) Another problem due to the difficult profile was long freespans, with relevant implications. On similar lines and identical seabed profile, different laying tensions and residual tensions on the lines will cause a variation on free span length and geometry, as apparent between the two X65 lines and the third X52 line, where the longest freespans have been found: this is a point to be thouroughly considered at engineering stage.

F) The high operational limits designed into Castoro Sei were soon in evidence in this first project, but, unfortunately, the limits of the supporting crafts did not match. They were lower, especially for anchor handling and supply vessels which had to stop much earlier than Castoro Sei during a storm with 17 ft. waves.

It is worthwhile to mention some tension values applied during the job:

- 308 kips for the first line in 340 mt. of water (w.t. 20.62 mm.)
- 277 kips for the second line in 240 mt. of water (w.t. 17.48 mm.)
- 330 kips for the third line in 340 mt. of water (w.t. 23.83 mm.)

Peak tension as high as 420 kips has been applied on emergency, without causing any undesirable effect.

G) Automatic pipelaying control

Before starting work on the Messina Straits crossing, the automatic pipelaying control system of Castoro Sei (BINIPS) had been tested in a series of sea trials. During these tests, the system design concepts were verified with automatic station keeping and move-ups from one position to another. These tests gave very encouraging results, but they were only the beginning of the long verification, adjustment and calibration eventually produced throughout the job. Several problems soon emerged, all gradually solved, with a dramatic improvement of performance and reliability of the system.
Main automation problems were related to:

G.1) Pipelaying
G.2) Sensors
G.3) Actuators.

G.1) Pipelaying.

Accurate station keeping and moving-up soon have been found not sufficient to insure good automatic pipelaying control. Primarily the ship's velocity must be controlled carefully during move-ups for the operator to select the desired maximum speed. This velocity control also enables the operator to perform the following special operations carefully:

- pipe pull transfer from tensioners to the tensioner winch and viceversa, and also pipe head motion through the tensioners and over the ramp during abandonment or recovery operations,
- small adjustments of pipe position on the ramp, when pipe sections are not of uniform length,
- allowance for pipe sections with variable external diameter to go carefully through the tensioners,
- reduction of move-up velocity when peculiar sea-bottom might cause oscillation of pipe tension.

Furthermore, if exact positioning of the pipe with respect to the ramp at the end of the move-up is desired, it is not enough to command a ship's displacement equal to the length of pipe to be layed. The necessary ship's displacement may be significantly different from the pipe length and this is not known before move-up commencement, because it is a function of the friction between the pipe and the ramp, and also of the sea-bottom characteristics.

Ship overshoots during move-up must also be controlled carefully to produce smooth and precise motion of the pipe with respect to the ramp. This is more difficult because of the variable mooring system response time, a function of water depth and pre-tension level.

Finally, pipelaying in strong sea current or in a curved path requires automatic heading adjustments to minimize pipe lateral stress against the external ramp. All these factors led to a gradual redesign of the control system of Castoro Sei.

In its present form, the control system now has three interrelated levels of control:

- velocity control
- ship's position control
- pipe stress and position control

(Fig. 1)

Velocity control.

The velocity control system controls ship's surge, sway and heading velocity, the velocity commands may be given directly by the operator using a joystick (in semi-automatic mode), but they usually come from the ship's position controllers. The velocity feed-backs are generated by the navigation section of the control system, mixing and filtering signals coming from the navigation sensors. The ship's velocity controllers command correction forces to both the mooring and thruster systems.

Position control.

The ship's position controller has either the task of maintaining the centre of the ship at a desired geographical position and ship's heading at the desired value, or, of bringing the ship to a new position. The position set points may be given directly by the operator (with control in the navigation mode), however they usually come from the pipe controllers. The position feed-backs are computed by the navigation section of the control system. The ship's position controllers command ship's velocity to the velocity control loops. The velocity commands insure straight ship motion and never exceed the limits imposed by the operator. This mode has been very convenient for special operations, for example when all safety checks on the pipe are taken over by the operator, or, when a sharp route correction is needed.

Pipe control.

The pipe controllers have to keep pipe tension, lateral forces and pipe position with respect to the ramp at the values requested by the operator. Pipe controller output forms the ship position commands for the position control system. During station keeping, the pipe is held steady with respect to the ramp by the tensioners, which allows the pipe tension variation within given tension limits ("dead zone"); the pipe controllers adjust ship position set point along a given ground track and also ship's heading set point to keep pipe stress at the desired value. During move-up , the pipe controllers adjust the ship position set point along the ground track as a function of pipe length and pipe velocity, while the tensioners provide pipe tension control. The ship position set point must be adjusted continuously in order to insure precise and smooth move-up. The pipe controllers also turn off and on the tensioners "dead zone" at the beginning and end of the move-up. The gains in velocity, position and pipe controllers have to be adjusted as a function of the mooring system response time and of the pipe spring constant. The gains must also be adjusted as a function of the number of thrusters in auto control and as a function of the ship position sensors noise level.

G.2) Sensor problems.

The following are the main sensors used by BINIPS:

- radio positioning systems
- doppler systems
- gyrocompasses
- vertical gyro
- mooring line angle sensors
- mooring line length sensor
- mooring line tension sensors
- pipe tension sensors
- ramp load cells
- pipe length and velocity sensors
- wind sensors

Some of these sensors presented quite a few problems which had to be solved in order to achieve reliable pipelaying control.

Radio navigation.

The radio navigation system used for the Strait of Messina crossing was the Decca trisponder. A special confidence test was designed for this device to ignore unreasonable measurements. In the event of a too high percentage of unreasonable radio fixes BINIPS automatically switches to other navigation modes to return to the original mode as soon as possible. The measurements of the radio systems are always mixed with the doppler measurements in order to use the better part of both. This provides stable ship's position and velocity information for the control system.

Doppler system.

The doppler system, Sperry SRD-301, measures ship's velocity with respect to the water. Any bias due to water current is removed by mixing it with the radio navigation system data. The doppler system is capable of measuring high ship velocity; accurate calibration and tunings were necessary to obtain the required accuracy in the range of velocities produced by Castoro Sei, typically no more than one knot when pipelaying. The doppler transducers had to be mounted so as to avoid interference from the four thrusters, but some interference was still noticed when a supply vessel came alongside Castoro Sei. This problem was solved shifting the mixer's crossover frequency towards the radio or towards the doppler as adequate.

New line length navigator
(Dead reckoning system).

Ship's position changes can be measured using the variation of mooring line length, angle, and tension. This algorithm was designed to provide position information when a reliable radio measurement was not available. The algorithm may be affected by several factors, such as cable angle errors, anchors dragging, friction in fairleaders and pulleys. Reasonability checks on the measurements overcame such contingencies.

Vertical gyro.

Good vertical gyro data are necessary to correct radio measurement errors due to ship's roll and pitch (the radio antennae on the Castoro Sei are installed at about 60 to 70 metres above water level). For particular water depths and ship deck loads a resonance effect may occur between mooring and ship roll if radio measurements are not corrected with the vertical gyro.

G.3) Actuator problems.

Up to twelve winches and up to four thrusters are the actuators used by BINIPS. The winches are the basis of the control system, with thrusters used as an aid to the winches. BINIPS is also thought to be quite effective using only thrusters for complete pipelaying control, although such an application has never been tested as under normal conditions, there is a lack of back-up in emergency. The minimum number of actuators is four winches (one per corner) and two thrusters (any combination).

Winches.

The ship control by winches presents a few problems:
- response time is extremely variable with water depth;
- tension regulation may be affected by problems such as anchors dragging or cables snapping.

Tests capable of quickly and reliably detecting anchors dragging and snapped cables have been therefore made. BINIPS automatically reacts to these problems by reallocating cable tensions and actuating thrusters when they are in stand-by. The reaction of the system is so fast that the ship's motion due to a dragging anchor or a snapped cable is not more than a few metres. Many measurements are supplied by the winch system to BINIPS so that it was necessary to design tests in order to avoid reaction to false alarms. The optimum force allocation among any number of winches (between four and twelve) is not an easy problem; a linear programming algorithm had to be used. Difficult priority levels are given to the allocation of requested forces among the winches; the highest priority is for the forces needed to react to the environment and to hold the pipe tension; lower priority is given to the control of ship's position and velocity and to the pretension forces.

Thrusters.

The use of thrusters as aid to the mooring system did not give any big problem. An adjustment of the control loop gains was sufficient to achieve very good performances. Such adjustments are done automatically as a function of the number of actuators in use. The thrusters were of considerable aid to ship control because of their quick response at any water depth. For deep water pipelaying (over 300 metres water depth) is of the essence to combine thrusters with the mooring system.

H) Operational computing programmes

One of the two main computers, a SEL 32/55, was mainly directed, for off-line purposes, towards the developments of computing programmes as tools to meet every contingency likely to crop up on the Messina crossing as well as on the trials carried out earlier and later in 600 metres off the Calabrian coast, southern Italy. The computers were instrumental in checking the criteria, the mathematical models and instrumentation for controlling the pipelaying. Experience so acquired has contributed significantly to base the Sicilian Channel project on reliable pipelaying assumptions.

The serious difficulties encountered on the rugged seabed of the Messina crossing suggested special attention to:

a) The minimization of the maximum difference between the actual strains and design strains on each ramp roller, or in the sagbend, if in shallow water.

b) Pipe contact with as many rollers as possible.

c) Maximum flexibility in adjusting (hydraulically) the height of the rollers, especially those at the ramp end, and this at all times.

d) Reduction of the length of freespans on the rough seabed.

As can be seen above, aim a) sets out to minimize the pull of the tensioners and aim c) to maximize the roller contact at all stages of the pipelay. So in the preliminary stage the basic aim was to determine the optimum geometric ramp/roller configuration and the pull with the consequent strains on the ramp along the pipeline profile. At the operational stage it was esential to know the minimum allowable pull in order to assign a correct value to the "dead zone" of the tensioners, and to preassess the maximum allowable reactions on supports for each point of the profile. The A/R operation required to minimize the move up distance of abandonment while remaining within the allowable stresses in the sagbend. In rising seas, anchor handling tugs have to stop working much earlier than Castoro Sei does and much before than the pipe begins to move appreciably. Thus, instead of abandoning, it is possible to wait for better conditions to enable an earlier restart; pipelaying continues at a lower rate to prevent significant buffeting. Time for abandonment is only reached when approaching the limits of anchor cables to perform the operation without anchors repositioning. To achieve this the operation was split into two parts: for abandonment, it was first at constant pull and then at constant cable length; for recovery the two phases are reversed - constant cable length, followed by constant pull.

In the first phase it was sought the minimum pull on the cable which, when the cable was paid out, would enable the vessel to go astern without causing the maximum actual strain in the sagbend. This strain must never exceed the allowable strain.

Another problem in the A/R operations was due to the rigidity of the ramps on Castoro Sei, as the pipe entering or leaving the external ramp was at an angle tangential to the ideal curve along support tops. In this situation extremely dangerous moments, due to the lifting of the pipehead, would develop during the time in which the pipehead was above the external rollers at the end of the ramp. It has been possible to minimize the angle difference between the pipehead and the cable. In this operation, the pull in A/R is higher at every stage than the corresponding one during pipelay (in Messina, this difference reached 25% between the two conditions), as the pipe does not feel the effect of the bending moment imparted by the ramp. To avoid this pull increase in Messina, as in the following trials in 600 metres depth, an alternative was developed, in abandonment for example, by taking the pipe head to the innermost support of the external ramp and then, by lowering this ramp (holding the pipe at pipelay pull value) the pipe curvature passed from negative to positive. In geometrical terms this showed as a change from an "s" to a "j" configuration. Right away the pipelay pull could be further decreased to abandonment pull and operation was continued.

The computer programmes for pipelay deal with the pipe in the three dimensions and are based on the numeric integration, by the finite difference methods, of differential equations that tie the curvatures of pipe. The differential equations are so transformed in an algebric non-linear system: the solution of this system, that guarantees the equilibrium of the pipe at every point, is solved with a Newton-Raphson method. The congruence with the data of the problem is reached with linear iterative methods. The result of this is an extremely compact computer programme.

The ramp rollers are taken as points in the design stage, this is done so as to be on the conservative side. The current is considered to be acting in a plane parallel to the sea surface. The configuration of the pipe on the bottom, to determine the displacement of the touchdown point, is obtained continuing the integration of the elastic line on the bottom. Thus the bottom curvature is established.

The schematic of the loads acting on the pipe resting on the seabed depends both on the assumptions of the seabed behaviour and by the evaluation of the friction coefficient.

The programme accepts in each node, changes in diameter, weight, stiffness, etc. It returns the vertical and lateral loads on the ramp rollers; they are used to monitor the actual strains on the pipe on the ramp.

The computing algorithm for A/R operations is based on the same numerical integration of differential equations used for the pipe laying programme. The cable, in fact, is assumed as a pipe with negligible stiffness. This programme too, as with the pipelay programme, gives the possibility to evaluate the current effect during this operation. This effect can influence the final position of the pipe head in very deep water. The connection between pipe head and cable is assumed behaving as a spheric hinge.

During the Messina job and other trials, tests were done to validate design criteria and pipeline control systems. Invaluable help was given by submarine monitoring to depths of 360 meters. The first was in 180 metres depth off Calabria on a current - free flat bottom. Design pull was applied and roller reactions checked; the submarine both reported and recorded the pipe's elastic configuration from seabed to ramp. The result was a maximum error of one diameter of pipe in height. Subsequently a series of tests on touchdown point positions was done, while laying the first sealine. This check was done to compare theoretical and actual freespans at the given pull. The test proved the accuracy of the mathematical model to within one to three pipe lengths, depending on depth involved. Additionally, these tests were used to determine the effect of ramp friction on the tensioner pull. Owing to an irregular bottom the accuracy was reduced.

Post check was constantly done to observe whether any torsional effect was generated during pipelaying. Lines painted on the top of each pipe-length were checked on the seabed, and found always on the top clear evidence of no rotation. Thus the pipe is considered as having been in the elastic condition, as intended.

For A/R operations the correspondence of theoretical and actual move-up distance for each value of pull and cable length has been constantly checked. This test was done to verify the monitoring instrumentation and the relevant mathematical model. Later the test was repeated with a 20 in. pipe in 600 metres water depth. An accuracy of 2.2% was found in abandonment; in recovery it was different the accuracy being 5% on the move-up distance; this was attributed to the variation in ramp friction between the two operations.

From the design, the angles of the ramps were adjusted as well as were the heights of the supports. Fine adjustments were made as a third step; support heights were changed to meet the computed support reactions. Relatively speaking, these reaction adjustments were minute, in the order of one to five centimeters in roller heights. Each change of depth, pull, thickness, etc., demands that this adjustment be made. Particular store was set by the reaction of the extremity roller. In fact this reaction gave an indication on the pull set point; if it was over-loaded, then the pull was too low, and viceversa. Repeated checks with the required theoretically determined set point (determined in the knowledge of precise ship position and touchdown points) revealed remarkable agreement. Henceforth, the pull set point could be imposed without knowing those two precise positions. These positions were, in fact, known, but used solely as backup checks. This was, and indeed is, extremely valuable when laying in very deep waters, where the friction on the ramp, the system's inertia, and any "dead zone" on the tensioner combined with the pipe's tremendous flexibility in deep water, make it very difficult for the tensioner to react to the vessel's movement. Thus the tensioner sometimes remained inactive but the ramp loadcells displayed reaction changes indicative of a change of strain. So, at this point, the movement of the ship was used as tensioner, that means a change in vessel position set-point in order to meet the design strain of the ramp. This has been possible because of the outstanding manouvrability and accuracy of Castoro Sei movements.

The Messina crossing very steep slopes have required great accuracy on pull and ramp reactions: in fact, it was neccessary not only to keep ramp strains within allowable tolerances, but also to be sure that the touchdown point strain was within acceptable limits.
It has also been tried to shorten freespans whenever possible, to reduce the number of supports to be used during the testing of the pipe (the pipeline water filled is much heavier). For such conditions the seabed has been simulated by computer as a series of points with a known height and distance in order to compute the contact points of the pipe and their strain levels.
It is then possible to act on tensioner pull inside the allowable limits to reach the optimum value. A submarine was in continuous attendance during laying because an extremely accurate profile of the bottom was necessary.

The possibility of very strong currents on the Messina crossings, suggested to find a method of computing a countering ship's manouvre.
Two possible dangerous bending moments could develop in the transversal plane of the pipe, one at the ramp's extremity and one at the seabed. The latter depends essentially on the load that the current imparts to the pipe and on the friction coefficient that restricts the pipe movement on the seabed. The other, on the ramp extremity, depends not only on the current but also on the ship's heading.
Castoro Sei has on board instrumentation devoted exclusively to current analysis. It automatically processes the data from a currentmeter rapidly lowered to various depths obtaining the current profile. From this profile, from ships position and heading it is computed:

1. The angle of rotation of the ship to compensate the transverse bending moment induced by the current at the end of the ramp.
2. The movement of touchdown point and the maximum bending moment induced on the pipe section resting on the seabed beyond touchdown point.
3. The transverse reaction corresponding to the layvessel rotation. This value is passed to the ship's automatic control system ("pipe control mode") as a transversal reaction set-point on the last support.

This kind of operation on the Messina crossing permitted to continue pipelaying with surging currents of five knots and free configuration of 1,300 mt. To be true, another phenomenon came out in a dramatic way due to currents inducing "vortex shedding" with a great and extremely rapid oscillation of the pipe, as described before.
The average pull was only partly affected by the current running transversally to the pipe. Instead, with these high levels of currents, the touchdown point displacement was really sizable.

REFERENCES

1. P.Brando and G.Sebastiani: "Determination of sealines elastic curves and stresses to be expected during laying operations"
   OTC 1354 (1971)
2. A.Silvestri & P.Brando: "Deep water pipelaying"
   World Energy Conference, Detroit (Sept.1974)
3. A.Silvestri and R.Matteelli: "Trial crossing of the Messina Straits"
   Offshore Technology Conference, London (Oct. 1974)

4. P.Brando: "The automatic positioning system for a new generation semisubmersible lay vessel" IFAC/IFIP Symposium, Bergen (Norway) (June 1976)
5. A.Silvestri: "Pipelaying experiences 'Lay trials in the Sicilian Channel in 2,000 ft. of water' OTC 2910 - Houston (May 1977)
6. A.Silvestri and G.Rosa: "Successfull pipelaying experience in 600 mt. of water with Castoro Sei" - Offshore Brazil Conf. (June 1978)
7. V.Oliveri and H.C.Thomson: "A navigation and positioning system for pipelaying barge" OTC 3502 - Houston (May 1979)

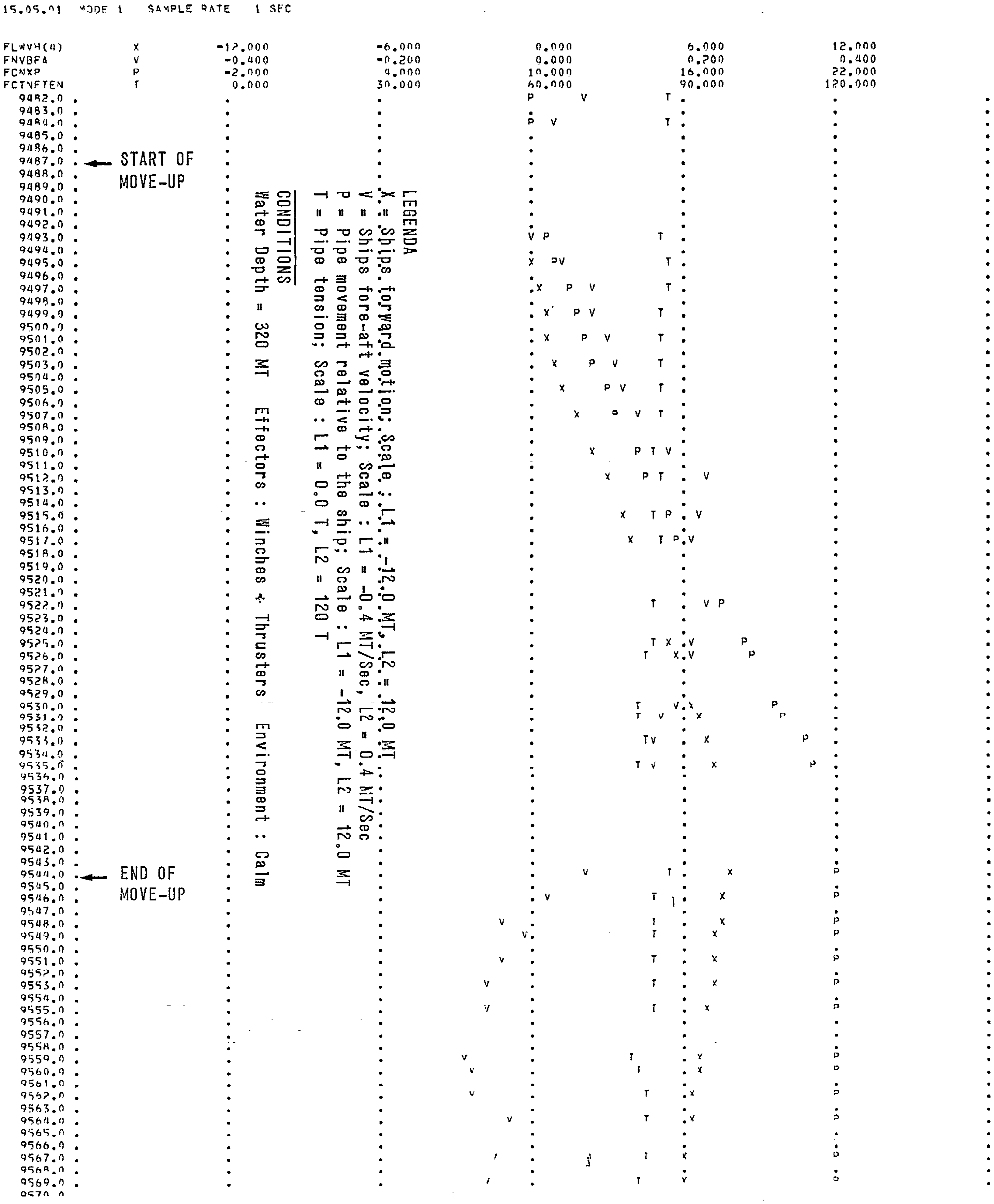

Fig. 1 - Typical Castro Sei move-up (12 mt joint) in 320 mt of water during Messina Strait crossing.