**Offshore “O”-lay pipe laying.**

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**Abstract**

The pipe laying technique described here is very different from the common technique used at present. The operational production costs can be reduced compared to the existing general methods of pipe laying and the pipe laying operations can be faster than other methods used today. Experts say that pipe laying as fast as 15 to 25 km per day is obtainable with this method. The main reason for this high speed has to do with the bottleneck of welding and testing which is not a procedure that is part of the laying itself anymore.

The main difference between the new, state of the art, “O”-lay system and the existing systems is that the total length of the pipe is welded and tested onshore on an site that is near the waterfront and that the pipeline will be transported as a whole, in a huge floating spiral to the location where it will be laid.

Depending on the local situation, series of “pipe pieces” with a length of 50 to 1000 meter are produced and temporarily stored in the pipe yard.

The “pipe pieces” are welded together in the final pipe line string and then transported into the water. They will be kept afloat with the help of floatation devices. A spiral will be formed with the floating pipe with a diameter that is sufficiently large to prevent the pipe from deforming in its plastic area. Normally the diameter of the floating circle is 500 times the pipe diameter (Example: A pipe with OD 20 inch will form a spiral of 250 meter diameter). The spiraled pipe can form a total length of more than 100 km pipeline.

When the pipe spiral has reached its predetermined length, the whole spiral can be transported (towed by tugboats) to the place where the laying has to be done.

When the spiral has arrived at the location where the pipe will be lowered, the spiral shall be unwound and with the help of a special prepared vessel it will be lowered to the seabed. This method of pipe laying is especially interesting for water depths where S-lay methods are used.

Several tests in laboratory and under real conditions have shown that the method described is feasible for pipelines of all diameters.
History

The first "offshore" pipeline was constructed by Brown & Root 1954 in the Gulf of Mexico. It was a 10 inch, concrete coated gas pipeline of 16 kilometer length which was laid at a depth of 4 to 10 meters. The speed of laying was approximately 800 meters per day and the crew worked only during daylight. Later Brown and Root made adaptations like building a ramp to allow the pipeline to approach the ocean floor more gently. This was further developed with a "stinger" used in today's offshore pipeline operations.

The first purpose build lay barge was built in 1958, also by Brown and Root.

Submarine Pipelines Ltd. was responsible for the development of controlled flotation pipe laying technology--pulling the pipeline out from shore supported by pontoon barges.

The fixed reel pipe laying barge was developed in 1961. The development of the reel ship in 1975.

These three inventions come together in the “O”-lay method with the added technical feature that the pipeline will be bend in its elastic area into a spiral for easy transport to the new pipeline location.

![Figure 1. The “O”-lay Method. The floating spiral being laid.](image-url)
The “O”-lay Method.

The method of “O”-lay pipe laying was introduced as “state of the art” technique for laying pipe of all diameters at depths of only a few meters up to several thousands of meters. The system is a combination of some already known technologies with some new ideas. The enormous advantage of the system is that pipe is not being constructed and welded on a lay barge at the position where the pipe will be lowered on the seabed. Instead the pipe is fully prepared at predefined lengths on an onshore location and stored in a floating “O” shaped model in front of the construction yard.

The system of laying the pipe roughly consists of 5 stages.

1 Pipeline production stage
2 Pipeline spiralisation stage
3 Transportation stage
4 Unspiralisation stage
5 Laying stage

**Pipeline production stage**
The pipes with a standard length of approximately 12 meter are delivered to the location where the construction is done. On arrival at the construction site the pipes will be measured, calibrated (to see if the pipe is not oval or dented during the transport) and cleaned.

After the inspection the pipe ends will be beveled by pipe facing equipment and welded into double joints. The double joints are best welded with submerged arc stations which can do 2 or more passes depending on wall thickness. Then the pipes will be constructed into quadruple joints also using submerged arc welding. Depending on the layout of the yard and the logistic possibilities the pipe joints can be extended further before they will be moved to the firing line.

The pipe welds have to be tested before they will be lined up in the firing line.

In the firing line the quadruple joints will be welded with gas metal arc welding, preferable with a computerized system, the welds will be inspected and the coating will be fixed in place.

The production method can differ from the one described since the layout of the production site can be modified to the choice of the production manager depending on its settings, the available equipment and personnel.

In case the pipe is so heavy that it will sink by itself (in most circumstances this will be the case) a floater will be mounted to the pipe to assure that the pipe will stay afloat during the spiraling and transport stage.

These floats will be of the type that can be easily attached and released in a short time. The design will be of a secure fit so that they cannot get loose during transport.

Relocation of the welding and inspection of the pipeline from the weather sensitive and remote location offshore to the relatively friendly onshore site is very attractive.
due to the lower costs and good approachability to the work site for all kind of services and supply of material which are needed to produce the pipeline.

Pipeline spiraling stage.

Bending steel pipe.
Considering that, within limits, everything can be deformed in an elastic way. Steel pipe can be deformed in its elastic area and return to its original form after the applied forces are taken away.
For the spiraling pipeline it is interesting to find the constraints of this elastic bending.

Due to the limitless tests that have been performed on steel and especially on pipeline it is easy to predict what the constraints for bend pipeline will be. As we can see in the diagram the pipe will deform from the yield point onwards in a way that the steel pipeline will change irreversible its form. Besides that the structure of the steel will change and harden, the round form of the pipe will become oval.
When the pipeline roundness deformation becomes to large the inspection tools and pigs that will be utilized in a later stage could have problems passing the deformed parts of the pipeline.
For the pipe’s integrity it is best that deformations remain in the elastic area.

Plastic yield occurs when:

\[ \frac{r}{R} > \frac{Y}{E} \]

where \( r \) = outside pipe radius
\( R \) = spiral radius (more exact, from center of first layer to the pipe axis)
\( Y \) = yield stress of the steel
\( E \) = modulus of elasticity or Young's Modulus

For a pipe the values of \( r \), \( E \) and \( Y \) are known. Therefore the \( R \) can be calculated.

Example:
For a pipe (API 5L) with OD of 508 mm, \( E = 2,06*10^{6} \text{ N/mm}^2 \), \( Y = 450 \text{ N/mm}^2 \).
The first winding of the spiral will be minimum \( 508 \times 206000 \div 450 > 233 \text{ meter} \).

On average you can say that the diameter of the first layer of the spiral should be roughly 500 X the diameter of the pipe.
As long as the pipeline will stay within its own elastic area the pipe will not get into an oval shape. Ovalisation will occur when a pipe is bend beyond the boundaries of elastic deformation. Excessive ovalisation is not acceptable due to the fact of its incompatibility with the use of pigs and TFL tools in a later stage.
With the 'O'-lay method it is possible to prepare any diameter of pipe to lay on the sea-bed. The advantage of this method is that pipeline will not be plastically deformed during spiralisation and the pipe will always return to its original form after the applied forces are taken away from the pipe.

Creating the spiral.

The spiral is created with the help of a central point (or central mooring system) which is secured with anchors to the seabed to which some centre lines are attached see figure 1. This central point (or central mooring system) will act as a pivot in a later stage of creating the spiral.

![Figure 3. The "O"-lay Method . First part of the floating spiral being laid.](image)

First a long piece of the pipe will be pulled in the water past point A in figure 3. When a sufficient part of the pipeline has been pulled past point A, (let's say a little more than half the length of the circumference of the spiral diameter) the pipe will be connected, at point A, to the centre line and anchor line in such a way that it cannot move sideways. The end of the pipe should than be pushed by a small support boat in the direction of the central point in such a way that the pipe will be orbiting the centre point at a predefined radius it will pass point B in figure 1. Here again the pipe will be attached to the centre and anchor line. This way the pipe parameters are fixed and the first circle of the spiral will not become too small and the deformation will stay
in the elastic area due to the restriction of the anchor lines in the outer periphery.
The pipeline will be pushed further with the small motorboats around the centre point.
At point C the pipe will be attached to the centrelines and to anchor lines in the outer periphery of the spiral to be.
When the pipe reaches point D the centreline should be attached. From the moment that the small support boat has brought the length of pipe in the semi circumference and the centre line is attached the anchor lines in the outer periphery at A, B en C can be released. These anchor lines could form a restriction to circle the pipe around the centre point

Figure 4. Small watercraft are used to form the spiral or “O”

While the tensioner, which is located onshore, is feeding pipe into the system the pipe will circle around the centre point of the spiral, increasing the amount of pipe that is in the spiral. This way many layers of pipe can be produced, all floating in the plane of the surface of the water.
It is possible to create more than 100 km of pipe in one piece while the band of floating layers is still workable by the boats creating the spiral. When the total length of the pipeline has been created into a floating spiral, the pipeline should be prepared for transport.
Transportation Stage.

Consider the pipeline has been spiralled over its complete length. It has been secured with some “transport” ropes to reduce the tension in the pipeline during its voyage.

The pipeline shall be attached to a minimum of two tugboats (See figure 5). A third tugboat could be kept available in the near vicinity to help out in case of an unexpected event occurs. The anchor lines should be detached from the centre point and the spiral can be towed to the new location.

Although the spiralled pipe can withstand rough waves (the spiral can stand waves up to 4-5 meter) it is always good to consider the weather forecasts when the pipe is being transported. For logistic reasons it is recommended to choose a pipe yard that is in the vicinity of starting point of the laying location since the speed of travel is relatively low.
Unspiralisation stage and laying stage.

Due to the length of the pipe in the spiral the unwinding and the laying of the pipe will occur at the similar time. To have no constraints in laying, the free end of the spiral should have a minimum length. This length depends on the pipe diameter, the number of windings in the spiral, the water currents and the speed at which the lay barge can lay the pipe. The free pipe between the barge and the spiral works as a work buffer for the lay barge in case the spiral unwinding for some reason is delayed for a while.

Figure 6 Lay barge laying pipe from spiral.

Compared to the conventional ways of laying larger diameter pipe the speed of laying can be considerable higher. The basis for this is that no welding or ultrasonic inspection has to be performed on the pipe while the pipe is being transferred over the lay barge since these procedures have been done in the onshore pipeline construction yard.

The motive that the lay barge is being employed is that at the point where the pipe submerges, there is a need for guarded buoyancy so the pipe can be launched in the water in a controlled way. Depending on the positioning system, the size of the tensioners, type of stinger and floating capacity of the barge the pipes can be lowered
to a certain depth. The higher the capacity of the barge the more depth can be reached.

The barge is relatively simply in its lay out. It consists of a barge with a lifting crane, a minimum of two tensioners (one at the bow and one at the stern), an abandonment and recovery system, a positioning system (mooring winches or preferable is a dynamic positioning system), barge stabilise and ballast system, a small workshop and living accommodations.

It might be an option to have a single welding station and coating station on the barge in case the pipeline to be laid is for a project with a longer distance. As a consequence the pipeline can then be delivered in several lengths (more spirals).

When arrived at the location where the pipe has to be laid the spiral will be unwound. The unwinding and laying consists of the following (simplified) stages:

1. Unlash the pipe end
2. Unwind the first meters so that the lay barge can pick up the pipe end.
3. Winch the pipe through the tensioners in the firing line of the lay barge
4. Connect the spooler, riser, sub sea wellhead or other sub-sea structure where the pipe has to be connected to.
5. Lower the connected sub-sea structure and pipe while the lay barge slowly moves away and feeds pipe from the tensioners.
6. Secure the sub-sea structure on its destined location.
7. Start laying the pipe by feeding it to the sea bed in a controlled way.

Figure 7. Model of lay barge with open supply ends for “endless” pipeline strings
The speed of laying the pipe is independent of the diameter of the pipe or on the depth of the seabed. However a very good cooperation between the lay barge crew and the team unwinding the spiral is of high importance. Specially the unlashing of the links which keep the layers on the spiral together should keep pace with the speed of laying. Therefore several small workboats are engaged to keep the operations running smooth. These workboats are also used to rotate and unwind the spiral at the speed required. Speeds of laying can be expected to reach 20 to 25 kilometres per day.

An option can be to connect workboats on the inside of the spiral where they will work as an outboard motor to circle the pipe spiral.

Flotation devices which are used to keep the spiral afloat during storage and transport have to be released before the pipe enters the lay-barge. They will be stored and shipped back for storage to be re-used on a following operation.

**Economics.**

Using the the “O”-lay method has on top of some logistical and technical advantages also huge economical advantages.

Physical pipe handling and logistical management is less complicated when we compare the the “O”-lay method with the conventional method of pipe laying using the S-lay.

The pipeline is constructed on a land base pipeline construction yard. The construction of pipeline in a pipe yard has a considerable advantage compared to construction at sea. Personnel cost due to lower transportation costs, cheaper accommodations, less expensive living cost and finally but not the least important lower wages.

Equipment is not as expensive as the conventional lay barges with complete pipe management systems, large storage places for pipes, several welding stations, inspection stations and coating stations. The “new” type of lay barge will be less complicated and smaller, therefore they can be build for a specific project or for multiple projects in the same range of pipe or area.

Transport of the spiralised pipeline only needs three or four tugboats and a rigid lashing system which is part of the central mooring system of the spiral.

Figure 8. One of the tugboats pulling the big “O”.

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The offshore operation takes only a fraction of the time of that what it normally would take to lay the pipe with conventional lay barges. From literature is known that pipe lay operation with reel lay barges will lower the cost of operation 50 to 70%. The maximum diameter at this moment for reel laying is 18 inch. It is plausible that economical advantages with the “O”-lay method would be even better.

Risk.
Using new systems and procedures in any industry entail always a certain risk. Specially in the offshore industry this risk has to be calculated because there can be large consequences. With this system a large part of the procedures have been moved from offshore to land based operations, therefore we expect smaller risks at a smaller operational cost. New procedures should be looked at with great effort. Financial, ecological and possible future failure should be looked at. In this paper we have not looked specifically at these risks. Nonetheless it is well believed that this new method will have a great future.

Conclusion
Since the “O”-lay method is expected as a relatively high speed method of laying pipeline in water depths from several meters to several thousands of meters. Speed of laying is estimated to be up to 20 to 25 kilometres per day. Therefore offshore operations time can be limited to a minimum and advantage can be taken from a relatively small weather window with optimal conditions for the pipe lay operations.

Due to its high operation speed at sea, the relatively low capital expenditure and the mainly land based operations the costs of pipeline laying will be reduced enormously.

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