A method and system for laying an underwater pipeline from a barge-mounted reel which supports a coil of elasto-plastic pipe. The coil contains many layers, each formed by a plurality of variable-diameter convolutions. To make the effectiveness of the system substantially independent of the diameter of the convolution from which the pipe emerges, and to facilitate the threading through the system of the pipe span emerging from the reel, the curved emerging span is reverse-bent beyond its elastic range to a predetermined radius sufficient to prevent buckling the span. Subsequently, the reverse-bent pipe is passed through a straightener for imparting to the pipe a substantially rectilinear configuration.
METHOD AND SYSTEM FOR LAYING A PIPELINE FROM A REEL BARGE

CROSS-REFERENCE TO RELATED APPLICATIONS

Particular pipe processing tools which are useful to this invention are described and claimed in co-pending patent application Ser. No. 5,842, and now U.S. Pat. No. 3,680,342, assigned to the same assignee.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to the field of laying underwater pipelines from a barge-mounted reel.

2. Description of the Prior Art

A known and presently used system for laying small-to-medium diameter pipelines from a barge-mounted reel is described in U.S. Pat. No. 3,237,438. In general, the known system involves, on one hand, pre-bending and winding the pipe, and on the other hand, unwinding and reverse-bending the pipe.

The pre-bending and winding phase is accomplished by advancing straight sections of pipe toward a work station, joining the sections together as they progress through the work station to form a continuous pipeline, plastically pre-bending a span of the pipeline leading to the reel, rotating the reel preferably about a vertical axis, and winding the pipeline on the reel into a multi-layer coil.

The unwinding and processing phase involves reverse-bending the span of pipe emerging from the reel and suitably guiding the straightened pipe from the barge to the floor of the body of water.

In particular, for a better understanding of the known system, a detailed description will now be given using the reference characters of the drawings in said patent. The emerging span of pipe 13 from reel 11 has its curvature removed by reverse-bending in a straightener 17 which is provided with two pairs of end rolls 41, 43 and a center pair of working rolls 42. Between the centers of rolls 41 and 43 is defined a horizontal path line. The amount of straightening or reverse-bending of the emerging pipe span is determined by the horizontal distance from the center of working rolls 42 transverse to the horizontal path line. Straightener 17 is mounted on a platform 18 and is supported for reciprocal vertical movement on vertical posts to allow the horizontal path line to become in vertical alignment with each pipe convolution as it unwinds from reel 11.

In the operation of the above known system, one finds that the radius of curvature of the emerging pipe span from reel 11 varies from a minimum radius, corresponding to the innermost pipe layer, to a maximum radius, corresponding to the outermost pipe layer. Since the transverse horizontal distance from the working rolls 42 to the horizontal path line is generally maintained constant, the amount of reverse-bending is also constant, irrespective of the reduction in the diameter of the unwinding coil and, hence, irrespective of the curvature in the curvilinear pipe span emerging from reel 11. Since the transverse horizontal distance is selected on the basis of the average curvature of the emerging pipe span, it is appreciated that the spans of pipe emerging from the outermost convolutions of reel 11 and from the innermost convolutions may not be completely straightened by straightener 17. Incomplete straightening may leave some residual bending stresses and strains within the pipeline as it emerges from straightener 17. While the residual curvatures can be overcome, as by the proper application of axial or longitudinal tension in the pipeline, they cannot be completely removed by such applied tension.

To alleviate the residual stress problem, an operator, in carrying out the known method, could continuously manually adjust the transverse horizontal distance between the working rolls 42 and the horizontal path line by an amount which is correlated with the instantaneous diameter of the coil as it unwinds.

But, at the rate it is desired to lay the pipe, such a continuous manual adjustment would be a most difficult job, even if a skilled operator could determine, by observation or from instrumentation, the optimum amount of required adjustment.

It may be also contemplated to provide, for the working rolls 42, automatic adjusting and positioning means, but the cost, complexity and lack of reliability for continuous use of such automatic adjusting means make such a solution rather unattractive.

Another consideration in the practice of the above method stems from a variable angle of entry into the pipe straightener 17. The above-mentioned horizontal path line is selected so as to be tangent to a middle layer in the coil, that is, to approximately bisect the angle sustained by the diameter of the full coil from the entry point to the straightener. Hence, the curved pipe span emerging from the outermost pipe layer on the coil will be at a maximum working angle of one polarity relative to this tangent in a horizontal plane, and when emerging from the innermost layer it will be at a maximum working angle of the opposite polarity. Consequently, if the pipe's path line remains stationary in a horizontal plane, this working angle will decrease as the diameter of the unwinding coil becomes reduced. If the horizontal path line were made movable transversely to follow the reduction in the coil's diameter, it would be necessary to mount the straightener both for reciprocal horizontal movement, as well as for reciprocal vertical movement. A straightener so mounted would require a wide span in a horizontal plane on the deck of the barge, as well as cumbersome support structures which are normally coupled to the barge for guiding the pipe onto the floor of the body of water.

For a better understanding of the problems which may be encountered with prior art systems, as well as of the advantages of the system of the present invention, a simplified review will be given of the bending stress-strain relationship within a pipe made from an elastoplastic metal.

In the elastic or "straight-line" range the stress is proportional to the resulting strain. When the stress is released, the strain returns to its original balanced value or zero curvature. The limit of the elastic range is reached when the strain no longer returns to zero curvature. This limit corresponds to the greatest stress the pipe's material can withstand without producing a residual deflection or curvature.

Beyond the elastic range, that is in the plastic or "flat-line" range, the applied bending stress exceeds the pipe's elastic limit, and the proportional stress-strain relationship no longer holds. For a small increase in ap-
plied bending stress, there now is obtained a substantially greater increase in resulting curvature. The boundary between the elastic range and the plastic range is commonly referred to as the yield point.

As one continues to bend the pipe past its yield point, the bending stress or moment increases relatively slowly toward an ultimate value. The pipe's curvature on the other hand increases to a critical curvature at which buckling impedes. Although most of the mathematical theories of plasticity deal with "ideal" plastic materials, most commercially available line pipe metals deviate somewhat from the ideal. It is therefore best to experimentally establish design parameters and to measure the critical moment required to bend the pipe to its critical curvature. The critical moment is a function of the pipe's diameter, wall thickness and grade.

A material which is plastic becomes elastic when the applied stress is reduced in magnitude below the yield stress. Experimental curves show that upon progressively reducing the applied moment from any point on the "flat" plastic curve, there follows a descending elastic straight line substantially parallel to the original elastic line. The residual curvature is that curvature which remains after the applied moment is reduced to zero. The progressive re-application of the moment to the pipe will follow an ascending elastic straight line from the residual curvature. This ascending line initially is substantially parallel to the original elastic line, and subsequently joins the plastic line after the yield point of the pipe's material is reached.

**SUMMARY OF THE INVENTION**

It is an object of the present invention to overcome the above-mentioned prior art shortcomings and to provide a new and improved method and system for laying pipelines from reels. The system requires a minimum of adjustments, hand labor, complex instrumentation, deck space and pipe support structures.

These and other readily apparent objects are accomplished in accordance with a broad aspect of this invention by: reverse bending the pipe span emerging from the reel preferably to a constant radius of curvature sufficient to prevent buckling, and subsequently straightening the reverse-bent pipe. In accordance with a specific aspect of this invention, said constant radius is made substantially equal to or greater than the minimum radius required to prevent buckling of the greatest diameter pipe anticipated to be wound on and unwound from the reel.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a top view illustrating a preferred embodiment of the invention; and

FIG. 2 is a side elevation view of the embodiment shown in FIG. 1.

Referring now to the drawings, wherein the showings are for the purpose of illustrating the preferred method and system of the invention only, and not for the purpose of limiting same, a suitable barge 10 supports a reel 12 for rotation about a vertical axis 11. Reel 12 winds and unwinds a continuous length of pipeline 16. While reel 12 is shown mounted for rotation about a vertical axis, it is appreciated that it could be equally mounted for rotation about a horizontal axis, but with appropriate changes in the positions of the pipe processing elements.

Pipeline 16 is preferably made of an elasto-plastic steel material of a suitable grade and may have a relatively large diameter, say between 4 to 12 inches, and even higher. For example, a standard X-Grade pipe could be a 12 inch line pipe, Schedule 20 through 90, API 5L, Grade B, seamless, or a 6 inch line pipe, Schedule 20 through 180. For underwater applications, pipeline 16 is ordinarily covered with a suitable protective coating, although such coating is not essential.

It has been found, contrary to what might be expected that neither the coating nor the pipeline becomes damaged by the consecutive bending and reverse-bending operations contemplated by the method of this invention.

Reel 12 can be rotated by any known suitable means. During the winding and unwinding operations, a span of pipeline 16 passes through a system 14 which includes a combined bending-and-level wind apparatus 18 and a tension-control mechanism 42. System 14 is mounted on a frame 24 which is reciprocable vertically on a plurality of posts 26.

To facilitate the winding of pipeline 16, the core 28 of reel 12 is made frusto-conical. A preferred construction of reel 12 and the manner of its operation is fully described in copending application Ser. No. 5,840, and now U.S. Pat. No. 3,630,461, assigned to the same assignee. Pipeline 16 is wound into a multi-layer coil 30. Each pipe layer includes several pipe convolutions 32. The radius of curvature of the pipe's span 34 when emerging from the innermost layer 36 has the smallest radius of curvature and when emerging from the outermost layer 38 has the largest radius of curvature. Also, within each layer, the radius of curvature decreases as the pipe span 34 emerges from the bottom convolution to the top convolution.

As can be seen from FIG. 1, when the pipe span 34 emerges from the outermost layer 38 it is at a relatively small angle A from a transverse horizontal line B, and when it issues from the innermost layer 36 it is at a relatively large angle C from line B. Thus, the emerging pipe span 34 has a variable angle of entry into the bending apparatus 18. The instantaneous magnitude of the angle depends on the diameter of the particular convolution 32 from which pipe span 34 emerges.

The exact configuration of the emerging pipe span 34 between reel 12 and apparatus 18 depends on the physical characteristics of pipeline 16 and the stresses within the pipe. An inflection point 40 occurs within the emerging pipe span 34 between reel 12 and bending apparatus 18. Before reaching point 40 from reel 12, the span 34 has a positive curvature, and following point 40 a negative curvature. The terms positive and negative have been arbitrarily selected only for ease of description. As herein employed, a positive curvature is a curvature the radius of which has a center below the path of span 34 (as shown in FIG. 1) and, conversely, a negative curvature has its center above the path of span 34.

In mathematical terms the radius of curvature of a segment of a curve is the reciprocal of the curvature K, that is 1/K, in which K is equal to the change in the direction of the curve per unit length of arc. The radius of curvature of a straight line is infinite and that of a circle is the radius used to generate the circular curve. The radius of curvature of a complex curve is a variable which depends upon the curvatures of the in-
finitesimally-long circular arcs located at adjacent points on the curve. The inflection point 40 is therefore a point where the pipe's curvature changes signs. The bending apparatus 18 is adapted to receive the emerging span 34 at a variable angle of entry and at a variable curvature, and to automatically bend the pipe so as to render it substantially free of residual stresses and strains for subsequent use during the pipe-laying operation.

To better appreciate the present invention, each of the basic components of the system will be discussed in some detail; however, it is understood that various structural changes may be made in some or all of these components without departing from the scope of the present invention. The detail structure of the components forming the system is fully described in said U.S. Pat. No. 3,680,342. Hence, only a brief description thereof, sufficient to understand the present invention, is given herein.

The bender 18 is designed to compound-bend the merging pipe span 34. For simplicity of construction, a "three-roll" compound bender is employed which includes three tools 50, 52 and 54 positioned at spaced locations relative to each other and to reel 12. Pipe span 34 is extended through these tools, as shown. The peripheral face of each tool has a movable chain bearing resilient blocks that are arcuately shaped to receive and closely engage against one side of the pipe span. The radius of curvature of each chain in each of tools 52 and 54 is adjustable from an infinite radius of curvature (flat) to a minimum radius sufficient to prevent pipe buckling, thereby allowing the variation of the amount of curvature imparted to or removed from the pipe span 34. The bending tool 50, on the other hand, applies a transverse force in a horizontal plane which is operable to impart to pipe span 34 a negative curvature corresponding to the radius of curvature of its peripheral face in engagement with the pipe span 34.

During the winding operation, pipeline 16 is plastically bent by yielding the metal of the pipe beyond its elastic range to set therein a positive curvature in each convolution 32. During the unwinding operation, bending tool 50 stresses the emerging span 34 as it passes through bender 18 to thereby yield the pipe's material and to plastically bend span 34 beyond its elastic range to a negative curvature having a constant radius sufficient to prevent buckling the pipeline.

Accordingly, the emerging pipe span 34 exiting from bending tool 50 at a tangent point 56 will have a constant negative plastic curvature, irrespective of the diameter of the unwinding coil 30. Hence, the pipeline, when entering bender apparatus 18, has a non-uniform curvature, and, when exiting from tool 50, has a uniform curvature, irrespective of the diameter of the unwinding coil. Therefore, bending tool 50 may be considered as a stress uniformizer and as a curvature uniformizer.

Pipe span 34, as it exits from bending tool 50, is curvilinear. It is the function of the other remaining tools to transform this curvilinear profile of pipeline 16 into a rectilinear profile. For this purpose the center bending tool 52 applies a moment to pipe span 34, which moment imparts to it a positive curvature. This is accomplished by plastically bending pipe span 34 beyond its elastic range to a particular positive curvature. Thereafter, as the pipe moves past device 52 and toward device 54, the induced bending moment in span 34 is unloaded along a linearly elastic path, resulting in a pipe profile which is substantially rectilinear and which is characteristic of a state of substantially zero net moment in pipeline 16.

The tension-control mechanism 42 maintains the emerging pipe span 34 under tension while it is being compound-bent by bender apparatus 18. The tensioner 42 in the preferred embodiment includes two opposed track chains 46, 48, at least one of which is powered for rotation. Each chain also bears resilient blocks having a groove therein so shaped as to receive and snugly engage one side portion of the pipe. The chains move in the direction indicated by the arrows 49 during the unwinding operation, and they also assist in pulling the pipe off reel 12.

Tool 54 defines with the center line of the tensioner 42 a horizontal path line 60, and the amount of working or bending by tool 52 is determined by the adjustable, transverse, horizontal distance from the periphery of tool 52 to this horizontal path line, as will be appreciated by those skilled in the art. It will also be apparent that the pipe span 34 between tools 50 and 52 sustains a sign reversal in its curvature and has a second inflection point 62 near bending tool 52.

The system of this invention is effective for pipes of different diameters. While, in operation, relative horizontal position adjustments of tools 50 and 54 are not required, it is appreciated that such adjustments are required, they could be easily provided for either tool, or in a manner as to move the tools through a single control.

As stated, the tensioner 42 is suitably supplied with motive power. On the other hand, the tensioner may be eliminated, for example, by securing one end of the pipe to the seabed and pulling the barge by tugs and the like along the lay line, so that the pipe would be pulled off reel 12 by the motion of the barge.

Moreover, though only one reel is shown mounted on barge 10, it will be evident that more than one reel could be employed. In fact, such reels could be stacked one above the other and used to pay out a plurality of pipelines simultaneously or sequentially.

Each of tools 50, 52 and 54 may be a wheel or a portion of a wheel. The peripheral face of each of tools 52 and 54 may vary from a straight line to a relatively short radius of curvature. To allow for the processing of pipes of different diameters, the constant radius of curvature for the bending tool 50 is selected so as to prevent buckling of the largest diameter pipe expected to be processed by bending apparatus 18 and so as to prevent "ovaling" of the pipe. The curvature of the peripheral face of the center or working tool 52 is adjustable to accommodate pipes of varying diameters through the bender 18.

One or more guide structures or stanchions, generally designated as 70, carry supports 71 for guiding the rectilinear pipeline 16 which exits from the tensioner 42 along a vertically inclined, pipe-processing path 72 to facilitate the pipe's entry into the body of water.

Any suitable means 74, which may be cam operated and controlled, may be employed to reciprocate vertically the supports 71 as well as the platform 24 on
which are mounted tools 50, 52, 54, and tensioner 42. The reciprocation is synchronized with the rotation of reel 12.

The preferred system 14 of the present invention allows the unwinding of a pipeline from a reel at a relatively high rate of speed without the need to continuously manually or otherwise adjust the bending tools of conventional benders. The system accepts pipes of varying diameters and is especially beneficially employed with relatively-large diameter pipes, up to 12 inches and higher. The emerging curvilinear pipe from the reel is rendered substantially rectilinear without unbalanced residual moments remaining therein. Also, the system is substantially independent of the prior loading history of pipeline 16.

While the description has been so far particularly directed to a preferred apparatus, it will be appreciated that other known tools can be employed for carrying out the novel steps of this invention. For example, a “three-roll” bender of known design, such as is disclosed in U.S. Pat. 3,237,438, can be used after the pipe span 34 exits from the bending tool 50.

While the operation of the disclosed apparatus was particularly directed to the unwinding phase, it will be appreciated that the winding phase can be equally accomplished with the apparatus of this invention. In addition, the compound bending of the pipe, during the winding and unwinding operations, is also effected by vertical movement of the entire frame 24. This vertical movement is effected by the power means 74. Power means 74 can be hydraulically-operated cylinders which could also be useful in moving the various tools 50, 52, 54 and 42 relative to each other in a conventional manner.

During the winding operation, sections of pipe in standard lengths are moved through a welding station and joined together to form the pipeline. The pipeline is then bent and wound onto the reel 12 during this joining operation. The prebending is to a curvature depending on the diameter of the reel employed and on the diameter of the pipe.

It will be therefore obvious that many other modifications may be made in the apparatus particularly disclosed herein. The invention is therefore not to be considered limited to the preferred embodiments shown in the drawings, but rather only by the scope of the appended claims.

What is claimed is:

1. An apparatus for straightening a long line of elasto-plastic metal pipe wound on a reel including:
   means for unwinding the pipeline from the reel,
   means for reverse-bending said pipeline beyond its elastic range to a substantially uniform curvilinear configuration as it is being unwound, and
   means for again reverse-bending said pipeline beyond its elastic range to a substantially rectilinear configuration after said pipeline acquires said curvilinear configuration.

2. A method for straightening a long line of elasto-plastic metal pipe wound on a reel including the steps of:
   winding the pipeline from the reel,
   reverse-bending said pipeline beyond its elastic range to a curvilinear configuration as it is being unwound,
   subsequently reverse-bending said pipeline beyond its elastic range to a rectilinear configuration after said pipeline acquires said curvilinear configuration, and
   maintaining said pipeline under tension during the unwinding of said pipeline.

3. The method of claim 2 and further including:
   maintaining said pipe under tension during said unwinding step.

4. An apparatus for handling a relatively-inflexible metal pipeline, said apparatus including:
   a reel rotatable about its axis,
   means for rotating said reel in opposite directions for respectively winding pipe thereon and unwinding pipe therefrom;
   combined bending-and-level-wind means mounted adjacent said reel, said means comprising:
   a first, a second and a third surfaces, each surface being mounted for rotation about an axis extending substantially parallel to the axis of said reel,
   each pair of surfaces being at opposite sides of the line of travel of said pipeline,
   said surfaces being curved and being operable to engage longitudinally-spaced segments of a portion of said pipeline,
   means operatively coupled with said surfaces for maintaining and selectively moving said portion of said pipeline against said surfaces, thereby allowing said surfaces to exert on the engaged portion of said pipeline longitudinally-spaced, operating forces, while said pipeline is being wound on and unwound from said reel, and
   the radius of said first surface and the radius of said second surface being sufficiently great to bend and reverse bend said pipeline while said pipeline is being wound on and unwound from said reel beyond its elastic range.

5. The apparatus of claim 4 and further including:
   means for maintaining said pipe under tension while said pipeline being wound on and unwound from said reel.

6. The apparatus of claim 5 and further including:
   means for movably supporting said pipeline at spaced positions in a vertical plane, and
   said positions being adjustable to allow said pipeline to assume a progressively decreasing vertical elevation and to enter into a body of water along a downwardly-directed path.

7. An apparatus for uncoiling a relatively-inflexible metal pipeline wound on the hub of a reel rotatably mounted on a support, said apparatus comprising:
   means for unwinding the pipeline from the hub of the reel while maintaining the pipeline under tension;
   means for reverse-bending the pipeline beyond its elastic range, as it is being unwound from the reel, to a constant bending radius, thereby providing the pipeline with a substantially-uniform, residual stress distribution pattern at any cross section along its longitudinal axis; and
   straightener means for straightening the thusly bent pipeline.

8. A method of laying a pipeline made of metal from the deck of a floatable platform onto the bed of a body of water, comprising the steps of:
unwinding the pipeline from the hub of a reel which is rotatably mounted on said deck, reverse-bending the pipeline beyond its elastic range, as it unwinds from the reel, to a constant bending radius, straightening the thus bent pipeline and maintaining it under tension while it is being straightened, and moving the straightened pipeline into the body of water overlaying the desired location of the pipeline on said bed.

9. The method according to claim 8, wherein the pipeline, after it is reverse bent to said constant bending radius, acquires a uniform, residual stress distribution pattern at any cross-section along its longitudinal axis.

10. An apparatus for laying a pipeline made of metal from the deck of a floatable platform onto the bed of a body of water, said pipeline being wound into a coil around the hub of a reel which is rotatably mounted on said deck, said apparatus comprising:
means for unwinding said pipeline from said reel,
a bending member for reverse-bending the pipeline beyond its elastic range to a constant bending radius as the pipeline unwinds from said reel, a straightening member for straightening the pipeline after it has been bent by the bending member, and means for moving the unwound portion of the pipeline into the body of water overlaying the desired location of said pipeline on said bed.

11. The apparatus of claim 10, and a guiding member, disposed relative to the longitudinal axis of said pipeline on the opposite side of said straightening member and on the same side as said bending member, for effectively positioning and maintaining the moving pipeline on said straightening member.

12. The apparatus of claim 11, and a tensioner having at least two tensioning members oppositely disposed relative to the longitudinal axis of said moving pipeline to maintain said pipeline under tension while it is being straightened by said straightening member.