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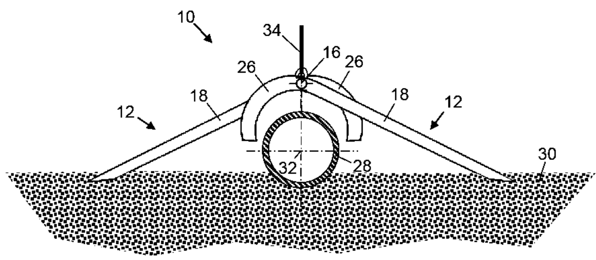
(54) Title **Controlling movement of subsea pipelines**

(57) Abstract

A weighting clamp (10) for holding a pre-installed subsea pipeline (28) against movement relative to the seabed, such as walking driven by thermal cycling. The clamp comprises jaws (26) that are movable toward each other into a pipeline engagement position, and foundation panels (18) that are also movable relative to each other. The jaws are connected to the foundation panels to move into the engagement position in response to relative movement between the foundation panels on contact with the seabed (30). Pivotable connections between the jaws and between the foundation panels are made about a common pivot axis (16) between the jaws and the foundation panels connected to those jaws.



Controlling movement of subsea pipelines

This invention relates to subsea pipelines and in particular to the problem of such pipelines moving transversely to their longitudinal axis during their operational life.

Oil and gas are present in subterranean formations at elevated temperature. On production of oil or gas from subsea fields, the hot production fluid emerges from a subsea wellhead, flows in a subsea pipeline across the seabed and eventually flows up a riser to the surface.

During transportation along the pipeline, the production fluid has to be kept hot enough to ensure a sufficient flow rate across the seabed and up the riser. Various measures are therefore taken to ensure that the internal temperature of the pipeline remains high when in operation, typically above 65°C and in some cases above 200°C.

Pipelines must occasionally be shut down for maintenance. During a shutdown, hot production fluid no longer flows through the pipeline. The pipeline will therefore cool down due to thermal exchange with the surrounding seawater, which is much colder than the production fluid. For example, seawater typically has a temperature of just 4°C below a depth of 1000m.

It follows that a subsea pipeline is subjected to substantial thermal cycling between successive periods of operation and shutdown. Consequently, over time, the pipeline may experience several successive cycles of thermal expansion and contraction. As a subsea pipeline is commonly several kilometres long, potentially tens of kilometres long, thermal cycling can result in significant elongation and shortening between the ends of the pipeline or between intermediate anchoring points.

To avoid over-stressing a pipeline due to thermal cycling, it is desirable to allow and to accommodate axial movement of the pipeline relative to the seabed, along the central longitudinal axis of the pipeline. However, friction and cohesion between the pipe and the seabed soil resist such axial movement and so give rise to axial compressive forces. Unless the pipeline is constrained within a trench and covered along its length, for example by heavy concrete mats or by a berm of dumped rocks, these axial compressive forces could cause horizontal or vertical deflections of the pipeline and may result in buckling, especially where the pipeline is subject to high pressures and temperatures.

It is expensive and time-consuming to bury a pipeline in a trench, and may not be practical in deep water or where the seabed soil is soft or silty. In those circumstances, pipelines may be laid across the seabed and supported at intervals by foundations such as mudmats. Mudmats may particularly be required under heavy accessories incorporated into the pipeline, such as in-line or terminal structures. However, mudmats are challenging to install simultaneously with a pipeline and are difficult to install and to couple to a pipeline if they are installed separately from the pipeline, either before or after the pipeline is laid on the seabed.

As pipelines do not follow straight paths and may include loops or other curves to reduce the risk of buckling, axial forces are commonly accompanied by components of lateral force in directions transverse to the central longitudinal axis. Over time, these lateral forces tend to shift sections of the pipeline sideways across the seabed. This effect is known in the art as ‘walking’.

Unrestricted pipeline walking is undesirable. If not limited or discouraged, walking could eventually cause a pipeline to clash with nearby subsea structures or equipment or to adopt shapes that over-stress the pipeline. For example, walking has been known to initiate buckling of a pipeline in a loop, particularly where the pipeline is hot and is subject to massive hydrostatic pressure at great depth. In shallow water, there is also a risk that storms or currents could displace a subsea pipeline away from its intended path.

Numerous prior art solutions exist to address the problem of pipeline displacement or at least to mitigate its effects. However, such solutions often require undesirable modification of the pipeline installation method. Other known solutions are not easy to retrofit to a pipeline that has already been installed on the seabed.

In GB 2081414, for example, a pipeline is anchored to foundations. In WO 2014/147354, sleepers are installed to initiate buckles at pre-determined locations whereas in EP 1358420, loops are created deliberately for the same purpose. In BR PI0803572, rollers mounted on a pipeline at predetermined locations also control the appearance of buckles.

Another approach involves increasing frictional or mechanical engagement between a pipeline and the supporting seabed soil. For example, US 2014/044489 proposes mounting spiked clamps on the pipeline.

EP 0672856 teaches laying pairs of ballast blocks on the seabed, one on each side of a pipeline, the blocks being connected together by a pliant bridging link that straddles the pipeline. Similarly, in GB 2242251, a mattress-like clamp is installed on the pipeline during installation in order to increase the area of contact with the seabed for stabilisation. Again, the clamp comprises pairs of ballast blocks, one on each side of a pipeline, which are also connected together by a pliant link that crosses the pipeline. In this case, each ballast block is longer in the longitudinal direction than in the lateral direction. In both cases, the pipeline remains free to slide longitudinally relative to the pliant link once installed.

WO 2017/070289 develops the principle of paired ballast blocks with pipe-clamping blocks that are shaped to self-lock around a pipeline.

It is against this background that the present invention has been devised. In one sense, the invention provides a weighting clamp for a subsea pipeline. The clamp comprises jaws that are movable toward each other into a pipeline engagement position and foundation panels that are movable relative to each other. The jaws are connected to the foundation panels to move into the engagement position in response to said relative movement between the foundation panels.

For example, there may be a pivotable connection between the jaws and a pivotable connection between the foundation panels. In that case, the pivotable connections between the jaws and between the foundation panels may elegantly be made about a common pivot axis. The pivot axis is preferably disposed between at least one jaw and one of the foundation panels connected to that jaw.

The jaws may be spaced along the pivot axis. For example, jaws connected to one of the foundation panels may be interdigitated with jaws connected to another of the foundation panels.

At least one of the jaws may be in fixed relation to one of the foundation panels connected to that jaw. For example, each foundation panel may extend in a plane and jaws in fixed relation to that foundation panel may curve out of that plane, preferably around more than 90º of arc. The jaws suitably have part-circular curvature on at least an inner side.

More generally, the jaws may have inner curvature that is substantially centred on a pipeline engagement axis. In that case, the planes of the foundation panels suitably intersect on a line that is substantially parallel to the engagement axis.

When the jaws are in the pipeline engagement position, the foundation panels may be in anhedral relation or in dihedral relation, respectively inclined below or above a horizontal plane, or may be in substantially horizontal orientation.

Gripping formations may be positioned on an underside of the foundation panels to improve engagement with the seabed soil.

The inventive concept extends to a corresponding method of holding a pre-installed subsea pipeline against movement relative to the seabed. The method comprises lowering a weighting clamp toward the pipeline from above to place jaws of the clamp on opposite sides of the pipeline and to bring foundation panels of the clamp into contact with the seabed. First contact between the foundation panels and the seabed may occur before or after the jaws first straddle the pipeline. Lowering the clamp further causes resistance of the seabed to move the foundation panels relative to each other and, by virtue of that relative movement, to move the jaws into engagement with the pipeline. The jaws are connected to the foundation panels for this purpose.

The foundation panels may, for example, pivot relative to each other in response to resistance of the seabed. In that case, the jaws may conveniently pivot relative to each other into engagement with the pipeline. The jaws and the foundation panels preferably pivot about a common pivot axis. Elegantly, the jaws and the foundation panels may move in the same angular direction about the pivot axis on opposite sides of the pivot axis.

The foundation panels may be at least partially embedded into the seabed. Advantageously, the weight of the clamp may be applied to the pipeline to embed the pipeline further into the seabed. However, embedment of the pipeline into the seabed may also be limited by engaging the foundation panels with the seabed.

In summary, a post-pipelay buckling prevention clamp of the invention is landed on a pre-installed subsea pipeline. The post-installed buckling prevention clamp is landed on the pipeline in an open position. The clamp is sufficiently heavy that the pipeline will start to penetrate the seabed under the additional weight.

As the clamp penetrates the seabed, the seabed bears upwardly against a pair of wings that act like lever arms to close the clamp. This is possible due to a bolt or other pivot that connects the two wings. Each wing comprises at least two fingers.

The post-installed buckling prevention clamp gains resistance against horizontal movement from the embedded pipe and also from the enlarged interface area in contact with the seabed soil. This is especially effective for a clay seabed, where resistance to movement is dependent on the area of the interface.

Embodiments of the invention provide a weighting clamp for an underwater pipeline, the clamp comprising: at least two wings to be in contact with the seabed; and a hinge between the wings, each wing extending across the hinge into a respective hook that straddles the pipeline.

Embodiments of the invention also implement a method for preventing walking or buckling of a subsea pipeline, the method comprising: installing the pipeline on the seabed; installing a claw-shaped weighting clamp on the pipeline, where two clawed wings of the clamp are in contact with the seabed and the claws are around the pipeline; and leaving the weight of the clamp to push the pipeline down into the seabed and to close the claws.

Thus, the invention provides a weighting clamp for holding a pre-installed subsea pipeline against movement relative to the seabed, such as walking driven by thermal cycling. The clamp comprises jaws that are movable toward each other into a pipeline engagement position, and foundation panels that are also movable relative to each other.

The jaws are connected to the foundation panels to move into the engagement position in response to relative movement between the foundation panels on contact with the seabed. Pivotable connections between the jaws and between the foundation panels may be made about a common pivot axis between the jaws and the foundation panels connected to those jaws.

In order that the invention may be more readily understood, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1 is an exploded end view of a clamp of the invention;

Figure 2 is an exploded plan view corresponding to Figure 1;

Figure 3 is a schematic plan view of the clamp of Figures 1 and 2, assembled and gripping a subsea pipeline;

Figure 4 is a schematic end view of the clamp of Figure 3 being lowered toward a subsea pipeline previously laid on the seabed;

Figure 5 corresponds to Figure 4 but shows the clamp bearing against the seabed while approaching the pipeline;

Figure 6 corresponds to Figure 5 but shows the clamp now engaged with the pipeline and embedded partially in the seabed; and

Figure 7 corresponds to Figure 6 but shows a variant of the clamp.

Referring firstly to the exploded views of Figures 1 and 2 and the assembled view of Figure 3, a weighting clamp 10 comprises a pair of wings 12 that can be coupled together by a hinge pin 14. When coupled together in this way, the wings 12 can pivot relative to each other about a mutual pivot axis 16 defined by the hinge pin 14. The pivot axis 16 is substantially horizontal in use.

Each wing 12 comprises a foundation panel 18 on an outer side that is cantilevered from hinge formations in the form of fingers 20 on an inner side. The foundation panel 18 is substantially planar but may have a tapered, upwardly-curved or upwardly-inclined outer edge portion as shown.

In this example, a pair of fingers 20 extend from the foundation panel 18. The pair of fingers 20 is offset laterally with respect to the foundation panel 18 and the fingers 20 of the pair are spaced apart from each other. The resulting gaps 22 beside the pair of fingers 20 and between the fingers 20 of the pair are wider than the width of either finger 20 in the lateral direction, parallel to the pivot axis 16.

It will be apparent from the plan views of Figures 2 and 3 that, advantageously, the wings 12 are identical. One wing 12 is simply reversed relative to the other wing 12 to bring their fingers 20 into alignment and engagement with each other. Specifically, the fingers 20 of the wings 12 interdigitate in alternating, staggered relation, with the fingers 20 of one wing 12 being received in the opposed gaps 22 of the other wing 12.

Interdigitation of the fingers 20 brings into mutual alignment a series of through-holes 24 that extend laterally through each finger 20. The through-holes 24 of the wings 12 align on the pivot axis 16 to receive the hinge pin 14 as shown in Figure 3.

Returning to Figure 1, it can be seen that initially the fingers 20 extend from the foundation panel 18 in the plane of the foundation panel 18. Then the fingers 20 curve downwardly out of that plane with part-circular curvature around more than 90º of arc. The resulting curved claw portion 26 of each finger 20 has an inner radius of curvature that is selected to match the outer radius of curvature of a subsea pipeline 28, shown gripped between the claw portions 26 in Figure 3.

In each wing 12, the foundation panel 18 and substantially all of the claw portions 26 of the fingers 20 are on opposite sides of the through-holes 24 and hence are on opposite sides of the pivot axis 16. Consequently, rotation of a wing 12 in a given angular direction about the horizontal pivot axis 16 causes the foundation panel 18 and the claw portions 26 to move in opposite vertical directions.

Thus, as the foundation panel 18 swings up about the pivot axis 16, the claw portions 26 will simultaneously swing down about the pivot axis 16. In doing so, the claw portions 26 of the opposed wings 12 will swing together about the pivot axis 16 to embrace and grip the pipeline 28 between them in the manner of opposed clamping jaws. In this respect, a greater angle between the foundation panels 18 of the opposed wings 12 corresponds to a smaller opening between their respective claw portions 26.

Turning next to Figures 4 to 6, this sequence of drawings show how the clamp 10 may be installed on a pre-installed subsea pipeline 28 already laid on the seabed 30. The pivot axis 16 is aligned above the central longitudinal axis 32 of the pipeline 28 throughout. In each drawing, the clamp 10 is shown suspended from a wire 34 hanging from a winch or crane of a surface vessel. However, part of the weight of the clamp 10 is transferred to the seabed 30 in Figure 5, and all of the weight of the clamp 10 may be transferred to the pipeline 28 and to the seabed 30 in Figure 6.

It will be noted from Figures 4 and 5 that the soil of the seabed 30 is soft and that the pipeline 28 has therefore embedded slightly into the seabed 30 under its own weight. However, the depth of embedment is insufficient to restrain deflection of the pipeline 28 that characterises walking or buckling.

Figure 4 shows the clamp 10 being lowered through the water column and approaching the pre-installed pipeline 28. At this stage, the wings 12 of the clamp 10 hang with a relatively small angle between their foundation panels 18 about the pivot axis 16. Consequently, there is a relatively wide opening between their respective claw portions 26.

When the lowermost level of the clamp 10 defined by the free edges of the foundation panels 18 encounters and engages the seabed 30 as shown in Figure 5, the foundation panels 18 begin to splay apart about the pivot axis 16 under the unsupported weight of the central part of the clamp 10. This swinging apart of the foundation panels 18 causes the claw portions 26 of the opposed wings 12 to swing together about the pivot axis 16, hence beginning to embrace the pipeline 28 as shown.

Figure 6 shows the clamp 10 now landed fully on the seabed 30 and in a state of equilibrium. The wire 34 can then be detached from the clamp 10 and recovered to the surface. The weight of the central part of the clamp 10 is bearing down on the pipeline 28 beneath. This has driven the pipeline 28 down to embed more deeply into the soil of the seabed 30, a process that could continue over a further period of time if equilibrium had not yet been reached. The free edge portions of the foundation panels 18 have also embedded further into the soil of the seabed 30.

As the foundation panels 18 have splayed further apart in Figure 6, the claw portions 26 of the opposed wings 12 have consequently swung together to embrace and grip the pipeline 28 and to lock the clamp 10 to the pipeline 28. In this respect, it will be noted that the claw portions 26 together extend more than 180º around the pipeline 28. The inner curvature of the claw portions 26 is now substantially centred on an engagement axis that is coincident with the central longitudinal axis 32 of the pipeline 28.

Elegantly, therefore, the weight force of the clamp 10 bearing on the seabed 30 is employed to drive together the claw portions 26 into engagement with the pipeline 28 without the complexity of a separate drive mechanism acting on the claw portions 26. Instead, the claw portions 26 are simply in fixed relation to the respective foundation panels 18. Thus, the claw portions 26 move with the foundation panels 18 in the same angular direction about the pivot axis 16, but on opposite sides of the pivot axis 16, in response to reaction forces from the seabed 30.

The deeper embedment of the pipeline 28 shown in Figure 6 combines with the weight of the clamp 10 and the large interface area with the soil of the seabed 30 to resist movement of the pipeline 28 relative to the seabed 30. Movement of the pipeline 28 is primarily resisted in lateral and vertical directions orthogonal to the central longitudinal axis 32, which deflections characterise walking or buckling.

The geometry of the arrangement shown in Figures 1 to 6 is such that the foundation panels 18 of the wings 12 are inclined below the horizontal when the claw portions 26 have gripped the pipeline 28 and so the wings 12 cannot swing further about the pivot axis 16. Adopting an aeronautical analogy, the wings 12 have anhedral inclination with respect to the pivot axis 16.

Other arrangements with different geometry are possible. For example, the foundation panels 18 of the wings 12 could lie closer to the horizontal on encountering the seabed 30 and/or could pivot beyond the horizontal as the pipeline 28 embeds further into the seabed 30 under the weight of the clamp 10. This may require the claw portions 26 of the fingers 20 to extend around a slightly smaller arc than is shown in Figures 1 to 6.

The result could be as shown in the variant clamp 10 of Figure 7. Here, the foundation panels 18 are inclined above the horizontal when the claw portions 26 have gripped the pipeline 28, to form a shallow V-section. Continuing the aeronautical analogy, the wings 12 now have dihedral inclination with respect to the pivot axis 16.

If the seabed 30 is sufficiently soft, the effect of the variant shown in Figure 7 is to embed the pipeline 28 more deeply into the seabed 30 and to increase the interface area with the soil of the seabed 30, hence to resist lateral or vertical deflection of the pipeline 28 more effectively. The partially-embedded foundation panels 18 of the clamp 10 form a correspondingly V-shaped trench 36 in the seabed 30 in which the clamp 10 is engaged, hence further improving lateral location of the pipeline 28 engaged by the clamp 10.

In all variants, the engagement between the foundation panels 18 and the soil of the seabed 30 prevents the pipeline 28 becoming embedded too deeply in the seabed 30. In this respect, being buried too deeply could also result in over-stressing of the pipeline 28 and could hinder inspection and maintenance operations.

Figure 7 also shows another optional feature of the invention, namely gripping formations 38 positioned on the underside of the foundation panels 18 to engage the seabed 30. Those gripping formations 38 may, for example, comprise downwardly-facing spikes or longitudinal ridges. Of course, the gripping formations 38 could also be applied to the embodiment shown in Figures 1 to 6.

Claims

1. A weighting clamp for a subsea pipeline, the clamp comprising:

jaws that are movable toward each other into a pipeline engagement position; and

foundation panels that are movable relative to each other;

wherein the jaws are connected to the foundation panels to move into the engagement position in response to said relative movement between the foundation panels.

2. The clamp of Claim 1, further comprising:

a pivotable connection between the jaws; and

a pivotable connection between the foundation panels.

3. The clamp of Claim 2, wherein the pivotable connections between the jaws and between the foundation panels are made about a common pivot axis.

4. The clamp of Claim 3, wherein the pivot axis is disposed between at least one jaw and one of the foundation panels connected to that jaw.

5. The clamp of Claim 3 or Claim 4, wherein the jaws are spaced along the pivot axis.

6. The clamp of Claim 5, wherein jaws connected to one of the foundation panels are interdigitated with jaws connected to another of the foundation panels.

7. The clamp of any preceding claim, wherein at least one of the jaws is in fixed relation to one of the foundation panels connected to that jaw.

8. The clamp of Claim 7, wherein each foundation panel extends in a plane and the jaws in fixed relation to that foundation panel curve out of that plane.

9. The clamp of Claim 8, wherein the jaws curve around more than 90º of arc.

10. The clamp of Claim 8 or Claim 9, wherein the jaws have part-circular curvature on at least an inner side.

11. The clamp of any of Claims 8 to 10, wherein:

> the jaws have inner curvature that is substantially centred on an engagement axis; and
>
> the planes of the foundation panels intersect on a line that is substantially parallel to the engagement axis.

12. The clamp of any preceding claim, wherein the foundation panels are in anhedral relation, inclined below a horizontal plane, when the jaws are in the pipeline engagement position.

13. The clamp of any of Claims 1 to 12, wherein the foundation panels are in dihedral relation, inclined above a horizontal plane, when the jaws are in the pipeline engagement position.

14. The clamp of any preceding claim, further comprising gripping formations that are positioned on an underside of the foundation panels.

15. A method of holding a pre-installed subsea pipeline against movement relative to the seabed, the method comprising:

> lowering a weighting clamp toward the pipeline from above to bring foundation panels of the clamp into contact with the seabed and to place jaws of the clamp on opposite sides of the pipeline, the jaws being connected to the foundation panels; and
>
> lowering the clamp further to cause resistance of the seabed to move the foundation panels relative to each other and, by virtue of that relative movement, moving the jaws into engagement with the pipeline.

16. The method of Claim 15, comprising pivoting the foundation panels relative to each other in response to resistance of the seabed.

17. The method of Claim 16, comprising pivoting the jaws relative to each other into engagement with the pipeline.

18. The method of Claim 17, comprising pivoting the jaws and the foundation panels about a common pivot axis.

19. The method of Claim 18, comprising moving the jaws and the foundation panels in the same angular direction about the pivot axis on opposite sides of the pivot axis.

20. The method of any of Claims 15 to 19, comprising at least partially embedding the foundation panels into the seabed.

21. The method of any of Claims 15 to 20, comprising applying weight of the clamp to the pipeline to embed the pipeline further into the seabed.

22. The method of Claim 21, comprising limiting embedment of the pipeline into the seabed by engaging the foundation panels with the seabed.

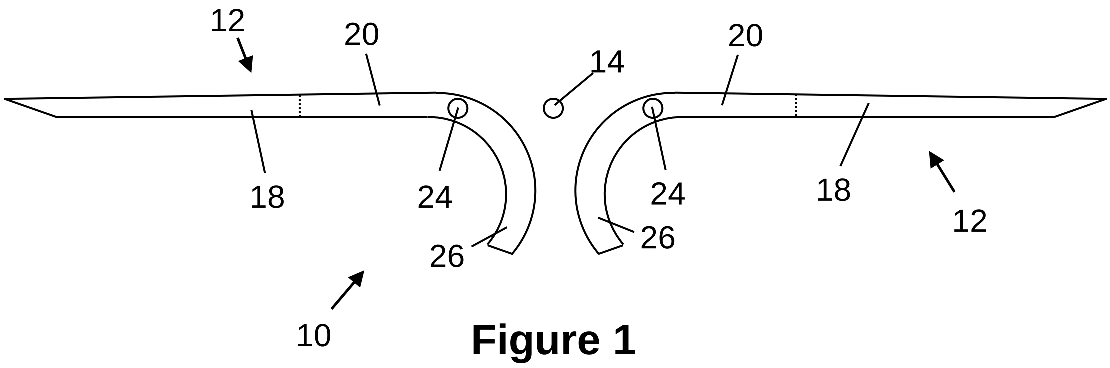


Figure 1

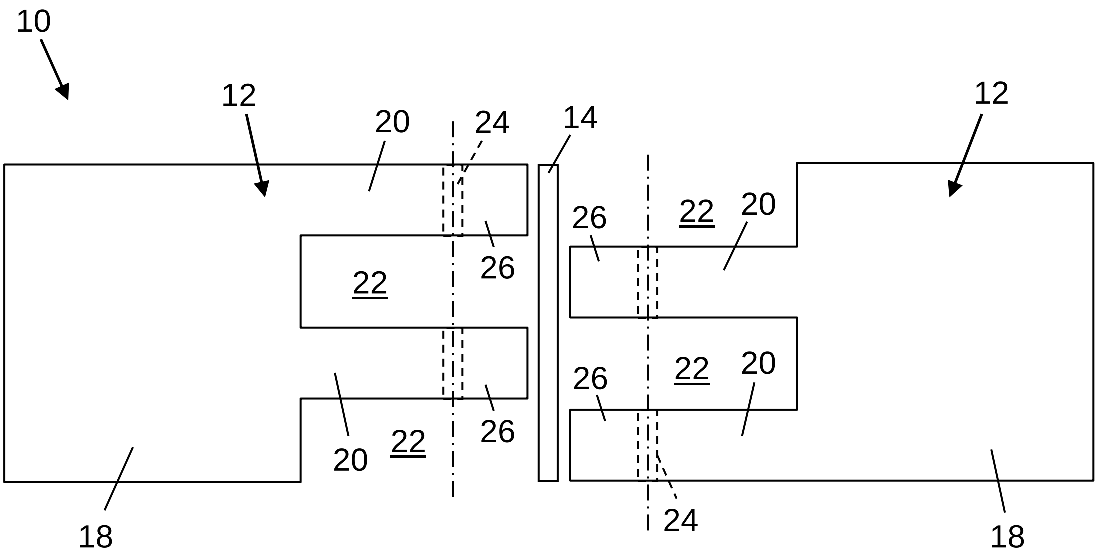


Figure 2

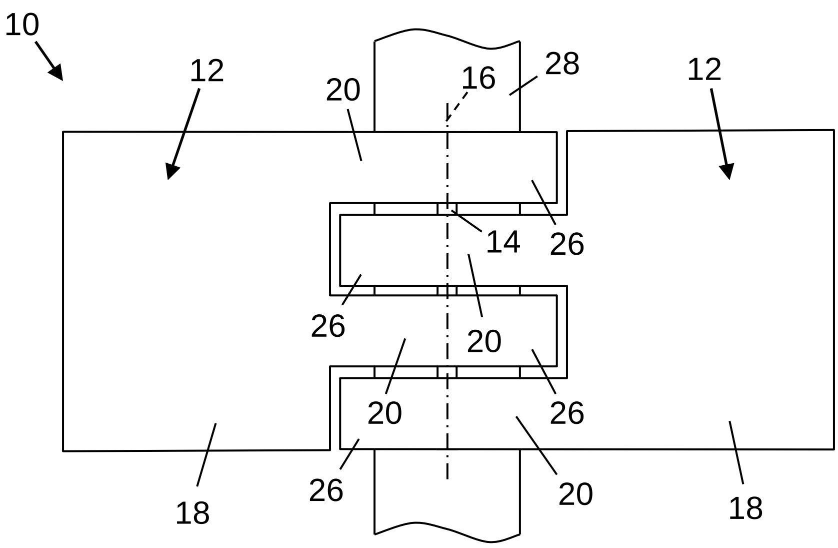


Figure 3

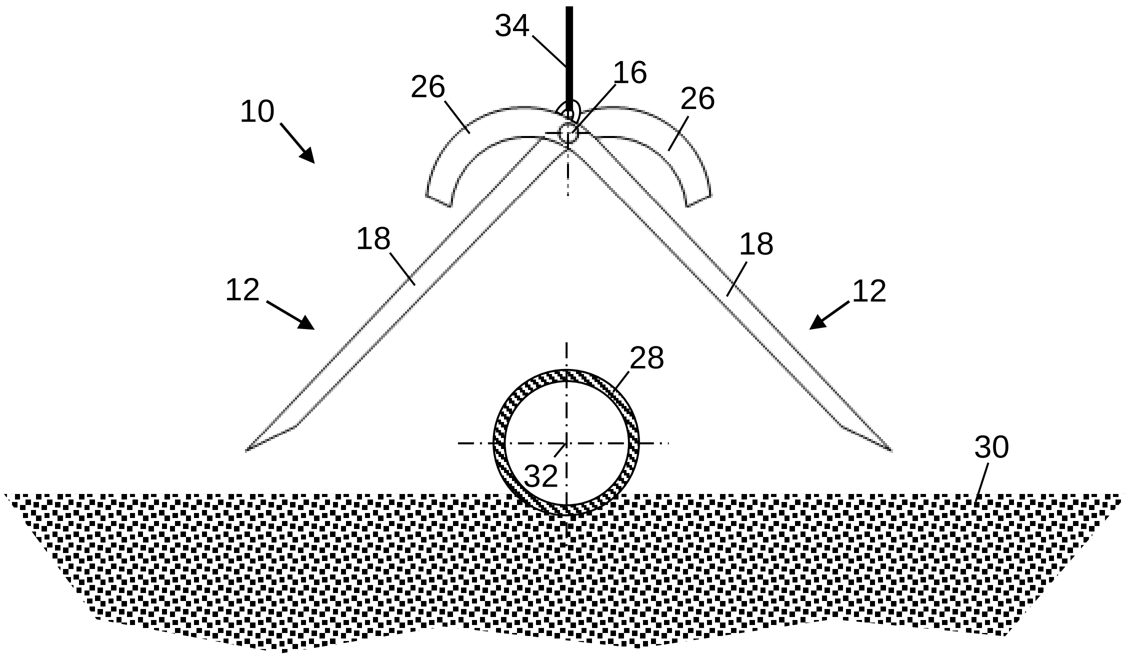


Figure 4

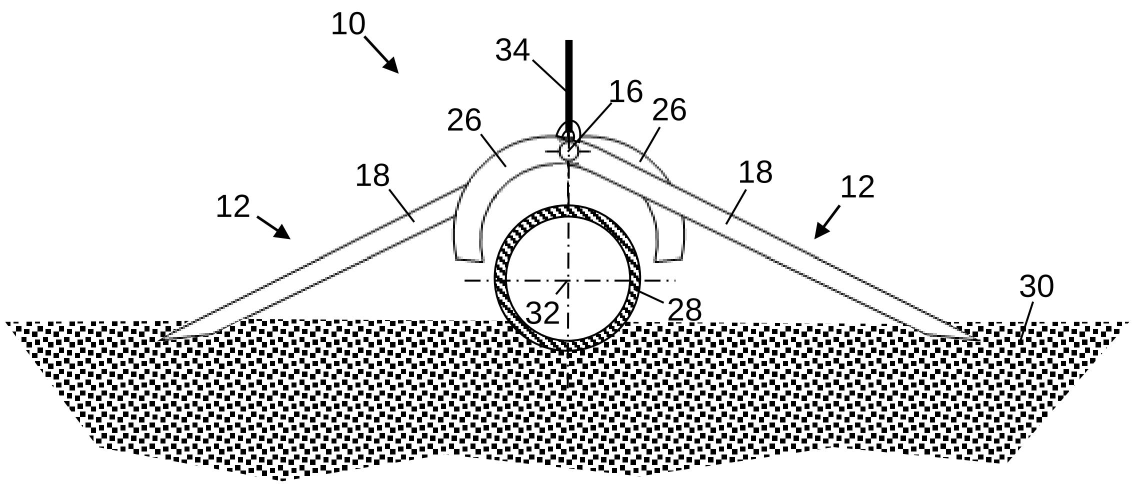


Figure 5

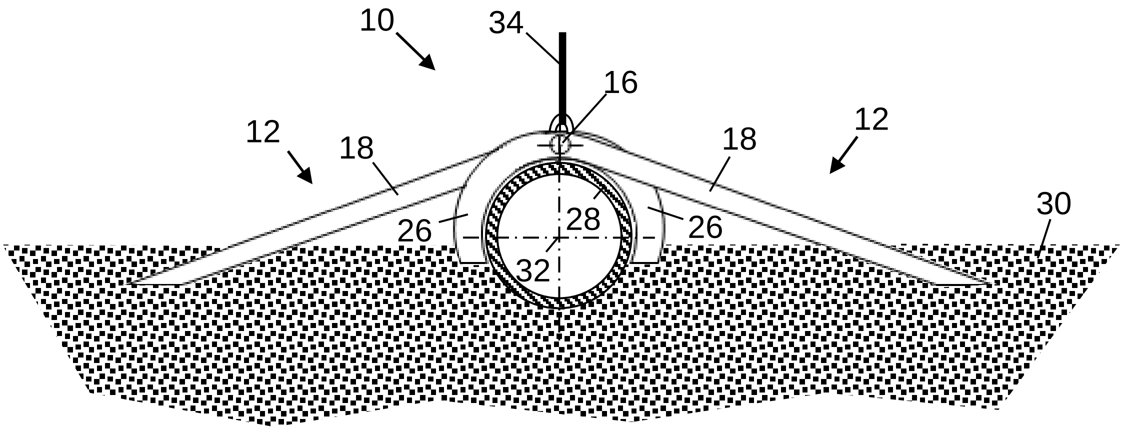


Figure 6

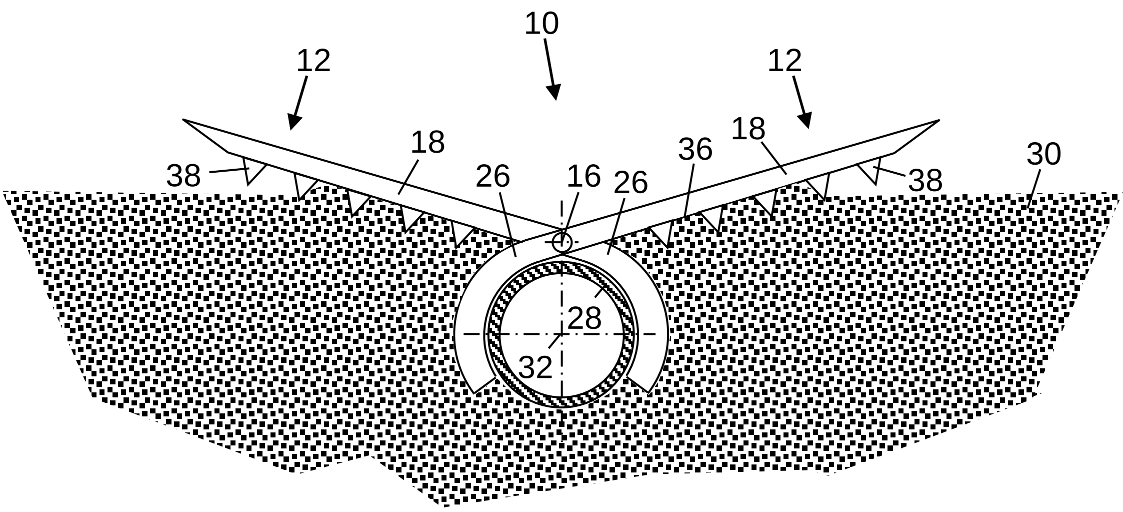


Figure 7