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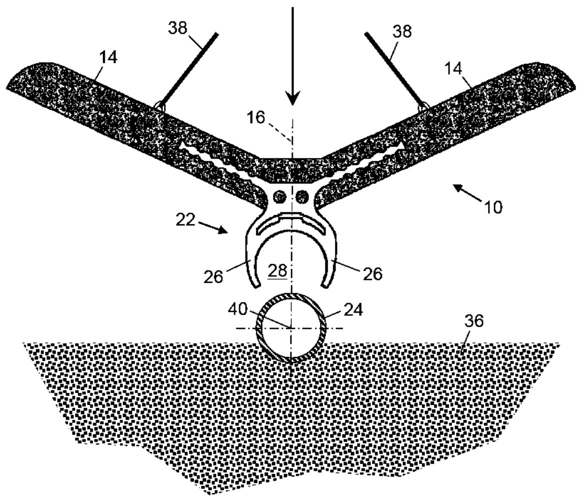
(54) Title **Controlling movement of subsea pipelines**

(57) Abstract

A weighting clamp (10) for a subsea pipeline (24) comprises laterally-extending wings (14) and jaws (26) suspended beneath the wings. The jaws are arranged to embrace a pipeline that extends along a central longitudinal plane (16) of the clamp in use. The wings may be in dihedral relation, inclined above a horizontal plane. The clamp is lowered onto the pipeline from above to engage the jaws with the pipeline. Lowering the clamp further applies weight of the clamp to the engaged pipeline to embed the pipeline further into the seabed (36) and to bring the wings into contact with the seabed. This forms a trench in the seabed that has a cross-section corresponding to, and at least partially containing, the wings.



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: wings extending laterally from a central longitudinal plane, for example in substantially mirrored relation about the central longitudinal plane; and engagement formations suspended beneath the wings, the engagement formations being arranged to embrace a pipeline that extends along the central longitudinal plane in use.

The engagement formations may be substantially bisected by the central longitudinal plane and may be spaced apart along the central longitudinal plane.

The engagement formations suitably comprise at least one pair of downwardly-extending jaws that hang beneath the wings. In that case, a downwardly-facing opening may be defined between free ends of the paired jaws.

Conveniently, the jaws may be movable resiliently to admit and to engage a pipeline in use. For example, the jaws may be formed of a polymer material. In that case, two or more jaws may be moulded together as parts of a unitary frame. Such a frame may further comprise anchor extensions that extend laterally into, and engage with, the wings.

The jaws preferably have substantially part-circular curvature on at least an inner side. For example, each jaw may curve around more than 90º of arc. Each wing may extend in a plane, in which case the curvature of the jaws may be substantially centred on an axis that is substantially parallel to that plane.

The wings may be in dihedral relation, inclined above a horizontal plane.

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

The wings may be cast in concrete, in which case the engagement formations may conveniently be embedded partially in the concrete. The wings may, for example, be cast together in the same monolithic block.

The inventive concept embraces a corresponding method of holding a pre-installed subsea pipeline against movement relative to the seabed. The method comprises: lowering a weighting clamp onto the pipeline from above to engage the pipeline with engagement formations suspended beneath laterally-extending wings of the clamp; and lowering the clamp further, applying weight of the clamp to the engaged pipeline to embed the engaged pipeline further into the seabed and to bring the wings into contact with the seabed.

The wings may be at least partially embedded into the seabed. For example, further lowering of the clamp may form a trench in the seabed, the trench having a cross-section that corresponds to and at least partially contains the wings. Thus, if the wings have dihedral inclination, the trench may have a V-shaped cross-section.

Embedment of the engaged pipeline into the seabed may be limited by engaging the wings with the seabed. Elegantly, the engagement formations may be engaged with the pipeline automatically in consequence of lowering the clamp, for example by snap-fitting the engagement formations onto the pipeline.

In summary, the invention provides a post-installed wing-shaped concrete element with a pipeline clamp that increases the resistance to movement of a pipeline relative to the seabed, especially in horizontal or lateral directions. The clamp is landed and automatically locked on the pipeline.

The clamp may be made of a plastics material and may be cast into the concrete element. The concrete element is suitably V-shaped in cross-section. This increases penetration into the seabed until equilibrium is reached. Penetration increases resistance of the pipeline to horizontal movement and therefore helps to prevent buckling of the pipeline.

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 clamping means to lock the wings onto the pipeline. The clamping means may, for example, comprise snap self-locking clamps, clamping to the pipeline by virtue of elasticity of their members.

The wings are suitably made of concrete and may form a monolithic concrete block.

At least one wing may make an angle with a horizontal plane, for example an upward angle.

A surface of the wings may be adapted to provide high friction with the seabed soil.

Embodiments of the invention also implement a method for preventing walking or buckling of an underwater pipeline, the method comprising: installing the pipeline on the seabed; and installing a V-shaped weighting clamp on the pipeline, wherein the clamp comprises two wings in a V-shape and a clipping clamp.

Thus, the invention provides a weighting clamp for a subsea pipeline, which clamp comprises laterally-extending wings and jaws suspended beneath the wings. The jaws are arranged to embrace a pipeline that extends along a central longitudinal plane of the clamp in use. The wings may be in dihedral relation, inclined above a horizontal plane.

The clamp is lowered onto the pipeline from above to engage the jaws with the pipeline. Lowering the clamp further applies weight of the clamp to the engaged pipeline to embed the pipeline further into the seabed and to bring the wings into contact with the seabed. This forms a trench in the seabed that has a cross-section corresponding to, and at least partially containing, the wings.

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 end view of a clamp of the invention;

Figure 2 is perspective view of the clamp shown in Figure 1, aligned with a subsea pipeline that can be engaged by engagement formations of the clamp;

Figure 3 corresponds to Figure 2 but shows a variant of the clamp;

Figure 4 is a schematic end view that shows the clamp of Figures 1 and 2 being lowered toward a subsea pipeline previously laid on the seabed; and

Figure 5 corresponds to Figure 4 but shows the clamp now engaged with the pipeline and embedded partially in the seabed.

Referring firstly to Figures 1 and 2 of the drawings, a weighting clamp 10 has an elongate body 12 that is substantially rectangular in plan view. The body 12 is apt to be cast in concrete but could be fabricated from other suitably dense and rigid materials such as steel.

The body 12 comprises a pair of laterally-extending foundation panels or wings 14 that are substantially symmetrical in mirror-image about a vertical central longitudinal plane 16. Each wing 14 has a substantially flat underside 18 in this example.

The wings 14 are conjoined via a central root 20 that is bisected by the central longitudinal plane 16. In this example, the wings 14 are inclined upwardly above the horizontal from the root 20 to form a shallow V-section. Adopting an aeronautical analogy, the wings 14 therefore have dihedral inclination with respect to the root 20.

The clamp 10 further comprises engagement formations 22 for embracing and engaging a subsea pipeline 24, which is shown aligned with the engagement formations 22 in Figure 2. The pipeline 24 is then bisected by the central longitudinal plane 16.

The engagement formations 22 shown in Figures 1 and 2 are arranged to snap fit around the pipeline 24, in effect allowing the clamp 10 to be clipped onto the pipeline 24 simply by being lowered onto the pipeline 24 from above.

In this example, engagement formations 22 hang in mutual alignment in a row under the root 20 of the body 12. The engagement formations 22 are also symmetrical in mirror-image about the central longitudinal plane 16.

The engagement formations 22 are exemplified here by downwardly-extending pairs of jaws 26 that define a downwardly-facing opening 28 between their free ends. The jaws 26 have an inner radius of curvature that matches the outer radius of curvature of the pipeline 24.

The free ends of the jaws 26 are spaced apart by slightly less than the outer diameter of the pipeline 24. Consequently, the jaws 26 must splay apart to admit the pipeline 24 through the opening 28 and must then move back together to grip and engage the pipeline 24. In this example, the jaws 26 splay apart and snap back by virtue of their resilience. In other examples, the jaws 26 could pivot or slide relative to the body 12 as part of an engagement mechanism, to open and close as required.

The jaws 26 are suitably formed of a polymer material to confer the required resilience. In that case, both jaws 26 are apt to be moulded together as parts of a unitary frame 30. The frame 30 is shown here partially embedded in the wings 14 and the root 20 of the body 12, which may conveniently be cast around the frame 30 if it is made of concrete. The frame 30 further comprises anchor extensions 32 that extend laterally into, and engage with, the wings 14 to transfer loads from the pipeline 24 into the body 12.

Figure 3 shows a variant of the clamp 10 in which the wings 14 extend substantially horizontally from the central root 20, all in substantially the same plane. Figure 3 also shows another optional feature of the invention, namely gripping formations 34 positioned on the underside of the wings 14 to engage the seabed in use. Those gripping formations 34 may, for example, comprise downwardly-facing spikes or longitudinal ridges. Of course, the gripping formations 34 could also be applied to the embodiment shown in Figures 1 and 2.

Figures 4 and 5 show how the clamp 10 shown in Figures 1 and 2 may be installed onto a subsea pipeline 24 already laid on the seabed 36. It will be noted from Figure 4 that the soil of the seabed 36 is soft and that the pipeline 24 has therefore embedded slightly into the seabed 36 under its own weight. However, the depth of embedment is insufficient to restrain deflection of the pipeline 24 that characterises walking or buckling.

Figure 4 shows the clamp 10 being lowered through the water column and approaching the pre-installed pipeline 24. Wires 38 suspend the clamp 10 in the water column from a winch or crane of a surface vessel. The central longitudinal plane 16 of the clamp 10 is aligned above the central longitudinal axis 40 of the pipeline 24. This aligns the engagement formations 22 along the pipeline 24, ready to admit the pipeline 24 through their downwardly-facing openings 28 defined between the free ends of their jaws 26.

All of the weight of the clamp 10 has been transferred to the pipeline 24 and to the seabed 36 in Figure 5, which shows the clamp 10 now landed fully on the seabed 36 and in a state of equilibrium. The wires 34 have been detached from the clamp 10 and recovered to the surface.

The pipeline 24 is now received snugly between the jaws 26 of the engagement formations 22. The inner curvature of the jaws 26 is substantially centred on an engagement axis that is coincident with the central longitudinal axis 40 of the pipeline 24.

In Figure 5, the weight of the clamp 10 bearing down on the pipeline 24 beneath has driven the pipeline 24 down to embed deeply into the soil of the seabed 36, a process that could continue over a further period of time if equilibrium had not yet been reached. Additionally, the wings 14 of the clamp 10 have partially embedded in the seabed 36, forming a correspondingly V-shaped trench 42 in which the clamp 10 is engaged. Thus, the cross-section of the trench 42 corresponds to, and at least partially contains, the wings 14.

Engagement of the clamp 10 within the trench 42 combines with the deep embedment of the pipeline 24, the weight of the clamp 10 and the large interface area with the soil of the seabed 36 to resist movement of the pipeline 24 relative to the seabed 36. Movement of the pipeline 28 is primarily resisted in lateral and vertical directions orthogonal to the central longitudinal axis 40, which deflections characterise walking or buckling.

In all variants, the engagement between the wings 14 and the soil of the seabed 36 prevents the pipeline 24 becoming embedded too deeply in the seabed 36. In this respect, being buried too deeply could also result in over-stressing of the pipeline 24 and could hinder inspection and maintenance operations.

Claims

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

wings extending laterally from a central longitudinal plane; and

engagement formations suspended beneath the wings, the engagement formations being arranged to embrace a pipeline that extends along the central longitudinal plane in use.

2. The clamp of Claim 1, wherein the wings are in substantially mirrored relation about the central longitudinal plane.

3. The clamp of Claim 1 or Claim 2, wherein the engagement formations are substantially bisected by the central longitudinal plane.

4. The clamp of any preceding claim, wherein the engagement formations are spaced apart along the central longitudinal plane.

5. The clamp of any preceding claim, wherein the engagement formations comprise at least one pair of downwardly-extending jaws that hang beneath the wings.

6. The clamp of Claim 5, wherein a downwardly-facing opening is defined between free ends of the paired jaws.

7. The clamp of Claim 5 or Claim 6, wherein the jaws are movable resiliently to admit and to engage a pipeline in use.

8. The clamp of Claim 7, wherein the jaws are formed of a polymer material.

9. The clamp of Claim 8, wherein two or more jaws are moulded together as parts of a unitary frame.

10. The clamp of Claim 9, wherein the frame further comprises anchor extensions that extend laterally into, and engage with, the wings.

11. The clamp of any of Claims 5 to 10, wherein the jaws have part-circular curvature on at least an inner side.

12. The clamp of Claim 11, wherein each jaw curves around more than 90º of arc.

13. The clamp of Claim 11 or Claim 12, wherein each wing extends in a plane, and said curvature of the jaws is substantially centred on an axis that is substantially parallel to that plane.

14. The clamp of any preceding claim, wherein the wings are in dihedral relation, inclined above a horizontal plane.

15. The clamp of any preceding claim, further comprising gripping formations that are positioned on an underside of the wings.

16. The clamp of any preceding claim, wherein the wings are cast in concrete.

17. The clamp of Claim 16, wherein the wings are cast together in the same monolithic block.

18. The clamp of Claim 16 or Claim 17, wherein the engagement formations are partially embedded in the concrete.

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

> lowering a weighting clamp onto the pipeline from above to engage the pipeline with engagement formations suspended beneath laterally-extending wings of the clamp; and
>
> lowering the clamp further, applying weight of the clamp to the engaged pipeline to embed the engaged pipeline further into the seabed and to bring the wings into contact with the seabed.

20. The method of Claim 19, comprising at least partially embedding the wings into the seabed.

21. The method of Claim 20, comprising forming a trench in the seabed by said further lowering of the clamp, the trench having a cross-section that corresponds to and at least partially contains the wings.

22. The method of Claim 21, wherein the wings have dihedral inclination and the trench has a V-shaped cross-section.

23. The method of any of Claims 19 to 22, comprising limiting embedment of the engaged pipeline into the seabed by engaging the wings with the seabed.

24. The method of any of Claims 19 to 23, comprising engaging the engagement formations with the pipeline automatically in consequence of lowering the clamp.

25. The method of Claim 24, comprising snap-fitting the engagement formations onto the pipeline.

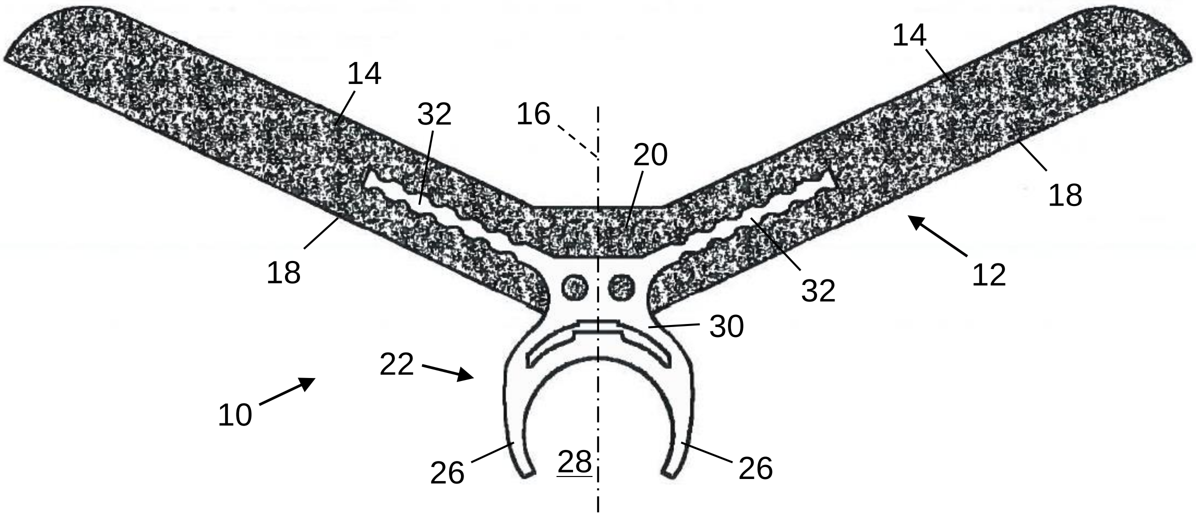


Figure 1

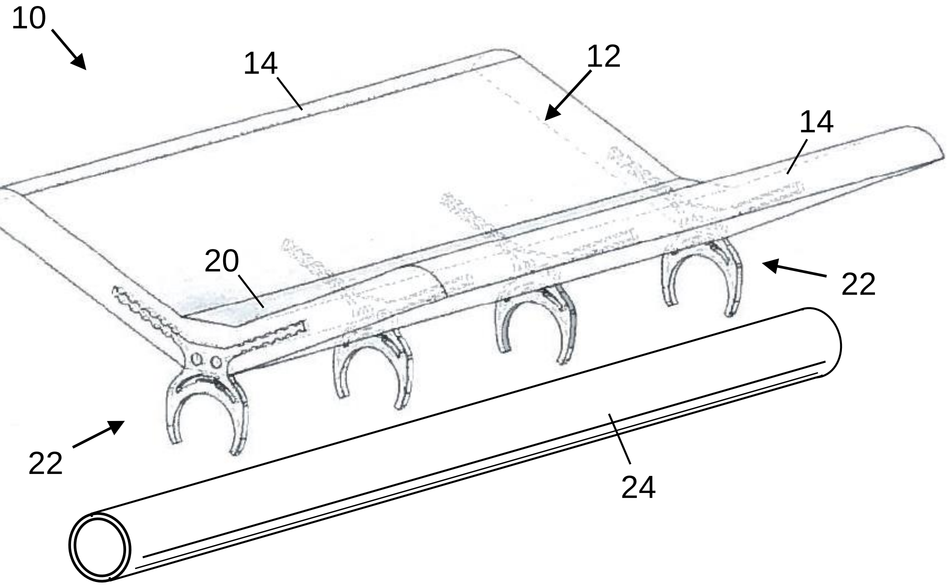


Figure 2

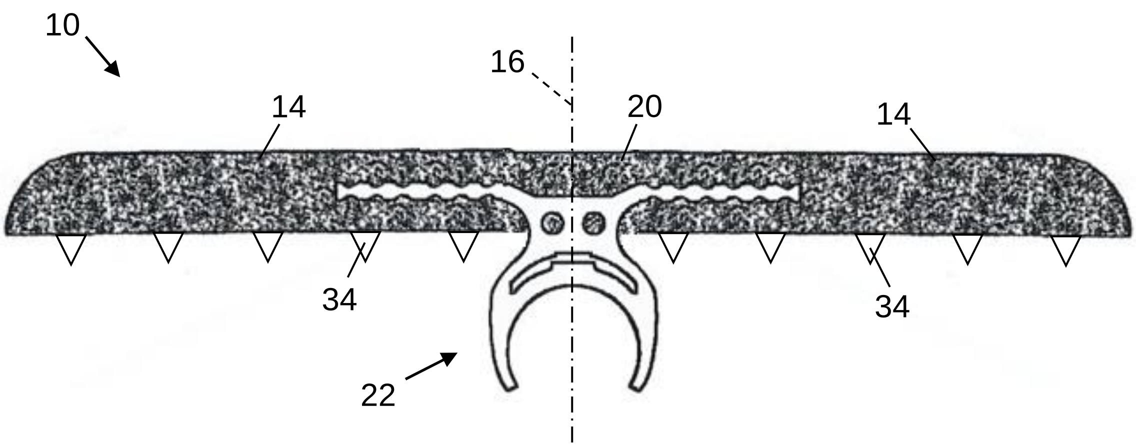


Figure 3

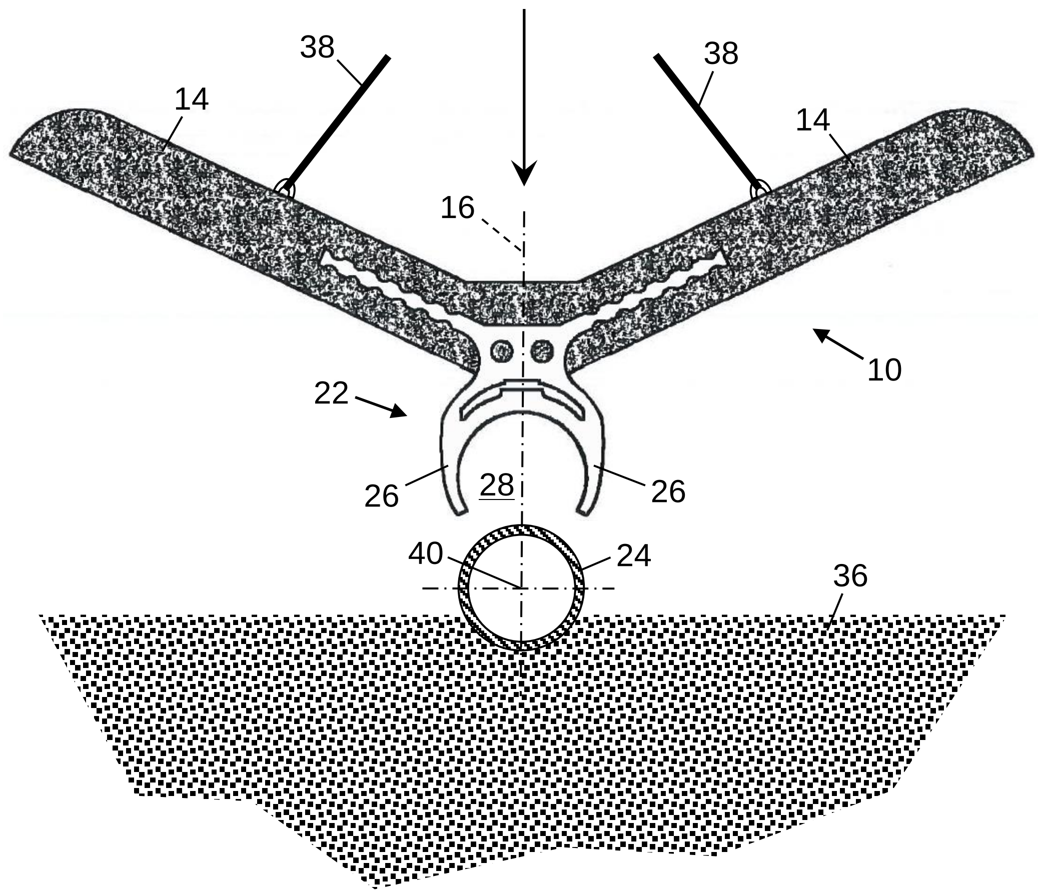


Figure 4

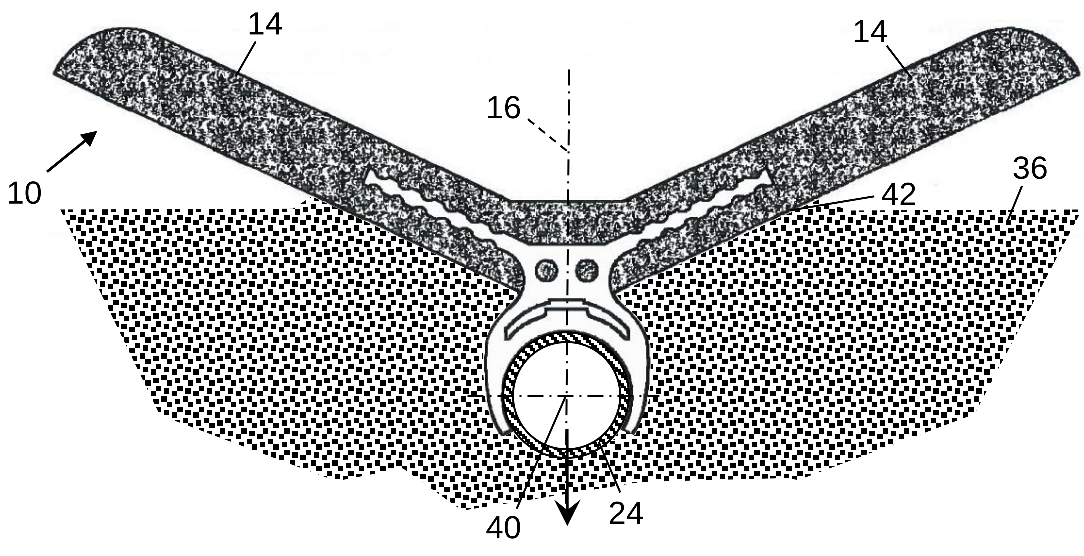


Figure 5