(12) **APPLICATION**

(11) **20200605** (13) **A1**

(19) NO

NORWAY

(51) Int Cl.

E02F 5/02 (2006.01)
E02D 15/10 (2006.01)
E02D 17/16 (2006.01)
E02B 3/02 (2006.01)
F16L 1/12 (2006.01)

Norwegian Industrial Property Office

(21)	Application nr	20200605	(86)	Int. application day and application nr
(22)	Application day	2020.05.20	(85)	Entry into national phase
(24)	Date from which the industrial right has effect	2020.05.20	(30)	Priority
(41)	Available to the public	2021.11.22		

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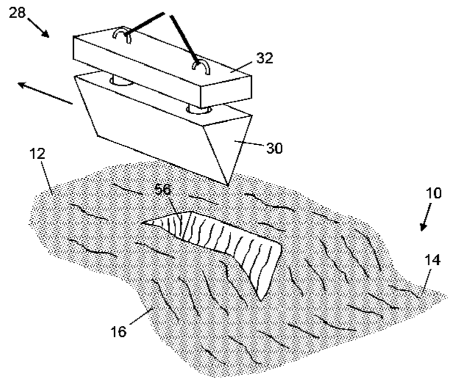
(54) Title **Modifying seabed contours**

(57) Abstract

In preparation for installing subsea infrastructure such as a pipeline, an adverse seabed contour is modified by dropping an elongate weight onto a seabed slope to penetrate the seabed. The weight is then lifted away from the slope, for example after being re-engaged with a supporting frame from which the weight was dropped. This leaves an elongate indentation at the drop location with a base less inclined than the previous inclination of the slope at that location. The indentation can be extended into a groove by repeatedly dropping the weight onto the seabed in longitudinal alignment to form a series of conjoined or overlapping indentations. The weight may be dropped at a sloped transition or shoulder between a depression in the seabed, such as an iceberg plough mark, and the general level of the seabed surrounding the depression.



Modifying seabed contours

This invention relates to modifying or rectifying the contours or morphology that define seabed topography, as may be required in preparation for installing subsea infrastructure such as pipelines for use in the subsea oil and gas industry. The invention relates particularly to smoothing abrupt transitions in seabed contours on a path along which a subsea pipeline is to be laid.

It is necessary to survey the seabed to determine its topography before installing subsea infrastructure at a given location, such as before laying a pipeline along a desired path. For example, it may be appropriate to modify the path of the pipeline to avoid rough, irregular areas in which the seabed contours are unfavourable. However, where it is impractical or too costly to re-route the pipeline around them, unfavourable contours may instead be rectified by re-shaping the seabed to remove excessively acute angles in the profile of the seabed, also known as the bathymetric profile, along the planned path of the pipeline.

It is especially desirable to avoid free-span situations in which an excessive length of the pipeline could hang unsupported, and hence potentially be overstressed, when traversing a depression in the seabed such as a subsea crevasse or trench. It is also desirable to avoid situations in which the pipeline may be bent sharply, and so could also be overstressed, by crossing an abrupt transition such as a subsea cliff or ridge, or the steep gradient of a subsea escarpment.

In these cases, the unfavourable contours of the seabed require preparatory operations before laying the pipeline, such as flattening ridges and filling depressions that lie along the chosen pipelay path. Another known technique for rectifying an adverse seabed profile involves placing a support in a depression between two successive ridges to shorten, or to eliminate, free-span portions of the pipeline.

A particular challenge shown in Figure 1 of the drawings, which will be used throughout this specification to illustrate the invention, is when encountering an iceberg plough mark 10 as shown in the seabed 12. Plough marks like this are common in higher latitudes such as Arctic waters. They comprise depressions in the form of long, steep-sided trenches or grooves that were gouged in the seabed soil by the scraping or scouring action of an ice keel under an iceberg or a mobile ice sheet.

Unhelpfully for pipelaying, as Figure 1 shows, a plough mark 10 often combines a central depression 14 with peripheral raised features, in particular parallel ridges, berms or shoulders 16 of displaced seabed soil piled up on each side of the depression 14. The result is to create severe discontinuities in the profile of the seabed 12 intersecting the plough mark 10, characterised by steep gradients and sudden changes and reversals in the slope of the seabed 12. It will also be noted that the shoulders 16 increase the apparent depth of the depression 14 and that there is a particularly sharp transition at the edges between the shoulders 16 and the steep side walls of the depression 14.

It will be apparent that if a subsea pipeline were simply laid across the plough mark 10 shown in Figure 1, its central span would be unsupported by the depression 14; conversely, the shoulders 16 that would support the ends of the central span would also apply point loadings to the pipeline. These factors would be likely to over-stress the pipeline and so must be corrected before pipelaying across the plough mark 10 can take place.

If a similar situation were encountered on shore, one option would be to drill shallowly-inclined tunnels for the pipeline from the surrounding seabed 12 under the shoulders 16 and into opposite sides of the depression 14. However, a tunnelling solution is not practical underwater. Instead, Figures 2a and 2b and Figures 3a to 3c show conventional techniques for correcting unfavourable seabed contours, in each case exemplified by the plough mark 10 of Figure 1.

In Figure 2a, a grab 18 is shown dumping rocks 20 into the depression 14 to fill the plough mark 10 up to the level of the surrounding shoulders 16. This creates an approximately level surface onto which the pipeline 22 shown in Figure 2b may then be laid without leaving a significant free span of the pipeline 22 unsupported. Rocks could be substituted by other infill elements or materials such as cement, mats, blocks, sand or rubble.

Figure 3a shows an alternative approach of using a remote-controlled subsea excavator 24 to excavate the soil of the seabed 12 away from the sides of the depression 14. For example, US 9353501 describes various techniques for underwater excavation. Dredging may also be possible if the water is sufficiently shallow. The objective, as shown in Figure 3b, is to remove mutually-opposed portions of the shoulders 16 to leave mutually-aligned shallow ramps 26 that extend from the base of the depression 14 up to the level of the surrounding seabed 12.

By, in effect, locally widening and smoothing the profile of the plough mark 10, the excavation shown in Figures 3a and 3b imparts a gently undulating profile to the path along which the pipeline 22 can then be laid as shown in Figure 3c. Notably, there are moderate and gradual angular transitions between the central portion of the pipeline 22 that dips beneath the level of the surrounding seabed 12 and the surrounding portions of the pipeline 22 that lie on the surrounding seabed 12.

Whilst a plough mark 10 is usually dealt with by dredging or excavation of the shoulder 16, it can be less costly in some situations just to dump more rocks to fill the depression 14. However, in other situations, rock dumping can be combined with dredging or excavation. Specifically, rocks could be used to part-fill the depression 14 so that less material needs to be removed from the sides of the plough mark 10.

Rock dumping and excavation are challenging and time-consuming operations when performed underwater, especially in deep water, and especially in combination. In this respect, time is a precious commodity in the field of offshore engineering. The necessary supporting vessels are valuable capital assets that have high operating costs. Also, the time available to complete a rock dumping or excavation operation may be limited to a narrow window of calm weather. If that window is missed, the larger project that depends upon installation of the pipeline could be delayed significantly and at enormous cost.

It is also known to tow a plough to pull it through seabed soil for preparing a pipelay path or cutting a trench for a pipeline. For example, WO 2015/026443 describes the use of a wedge-shaped indenter that is towed to gouge a path for burying a pipeline into the seabed. In that case, the pipeline is buried along most of its length for the purpose of avoiding subsequent damage from moving ice, for example where the pipeline is installed in Arctic regions. However, a ploughing solution is not appropriate to remedy discrete unfavourable seabed contours like those defined by plough marks.

EP 3325866, also published as WO 2017/013541, teaches mitigating unfavourable contours beneath a pipeline by using a mechanical member attached to the pipeline.

Conversely, in US 10508414, a pipeline is shaped to follow the profile of the seabed. Both of these approaches give rise to significant complexities in pipeline design and installation.

In KR 101918172, buoys support a pipeline above an irregular seabed but this is only a temporary solution. Also, limits on its deformation mean that the pipeline will not perfectly follow the seabed profile once installed.

Against this background, the invention resides in a method of modifying a seabed slope, the method comprising: dropping a weight onto the slope, for example from a supporting frame suspended underwater above the seabed, to penetrate the seabed at a drop location; and then lifting the weight away from the slope. This leaves an indentation at the drop location that has a base less inclined than a previous inclination of the slope at the drop location. A subsea pipeline or other subsea infrastructure may then be laid or placed in the indentation.

The indentation may, for example, have a substantially horizontal base. For that purpose, the weight suitably has a substantially horizontal bottom profile. The seabed may be penetrated with a downwardly-tapering formation of the weight, preferably with a blade edge of the weight, which leaves a corresponding downwardly-narrowing indentation. For simplicity, the weight may drop only under gravitational force.

The indentation may be extended by dropping the weight onto the seabed again, for example by dropping the weight at a further drop location that adjoins a preceding drop location. In that case, the weight may be dropped from different heights relative to the seabed at the different drop locations, hence varying the depth of the respective indentations.

The weight is preferably elongate to leave a correspondingly elongate indentation. In that case, the weight may be dropped again to form a further elongate indentation in longitudinal alignment with a preceding elongate indentation. The elongate indentation suitably intersects the slope such that an end of the indentation is open. The weight and hence the direction of elongation suitably extends down the slope.

For example, the weight may be dropped at a sloped transition between a depression in the seabed, such as an iceberg plough mark, and the surrounding seabed. In that case, advantageously, the weight may intersect a side wall of the depression to leave an indentation that opens onto the depression. At least one corresponding indentation may be formed at a mutually-opposed transition across the depression. Where the transition is raised above the surrounding seabed, the indentation may extend to a depth beneath the surrounding seabed.

The inventive concept also embraces apparatus for modifying a seabed slope to implement the method of the invention. The apparatus comprises: a supporting frame; a wedge-shaped, horizontally-elongate penetrator weight that is suspended from the frame and that tapers away from the frame; and a quick-release mechanism that releasably couples the penetrator weight to the frame and that is operable to drop the weight away from the frame. For example, the penetrator weight may have downwardly-converging sides that define an acute angle of up to 60° between them.

The frame is apt to be suspended from a lifting wire that extends to a surface vessel but could instead be supported by, or integral with, a subsea vehicle. The apparatus may further comprise a subsea-operable actuator coupling for operating the quick-release mechanism.

The penetrator weight suitably weighs at least two metric tons per linear metre along its length. For this purpose, the penetrator weight may comprise a monolithic block or a hollow body that contains a different dense material, which may be solid or granular.

Thus, the invention contemplates a simple method to mitigate the problems of the prior art by cutting a straight transverse indentation such as a notch, groove or trench through a subsea ridge or slope, such as that defined by the shoulders of an iceberg plough mark. This is done by dropping a wedge-shaped clump weight at the shoulders of the plough mark to make a groove in the seabed so that the height and length of a free span of pipeline in the depression of the plough mark is reduced.

It is of course known to penetrate the seabed with heavy items dropped under the influence of gravity. For example, torpedo piles for use as foundation members are described in EP 1827956, also published as WO 2006/067410. However, the purpose of a torpedo pile is to disturb the soil no more than is necessary to receive the dropped pile. The pile is then held embedded in the seabed by frictional and/or cohesive engagement with the soil.

Once dropped into position in the seabed, a torpedo pile is designed to remain *in situ* and therefore would obstruct, rather than facilitate, subsequent pipelay operations along the same path. Even if subsequently removed in contradiction of its intended purpose, a torpedo pile will not form an indentation whose shape is apt to receive a subsequently-laid pipeline.

The weight of the invention is dropped from a supporting frame at or slightly above the seabed level. The frame has a quick-release mechanism that is operable remotely or subsea, for example by an attendant ROV. Provision may also be made for the weight to be reattached to the frame to be lifted and potentially repositioned for a subsequent release.

The wedge may, for example, have a downwardly-converging angle of about 30° at its bottom. With a wedge of that profile, it is estimated that a weight of about three metric tons per linear metre will suffice to penetrate to a depth of about one metre in typical seabed soil. Such a weight can be achieved with a solid metallic block, for example of steel or iron, or possibly with a hollow fabricated body of, for example, steel that contains a dense material such as concrete or lead.

The invention aims to be more cost-effective than excavating or dredging soil to form a groove that intersects a trench or depression in the seabed. This reduces or eliminates the need to dump rock or other infill materials into the depression. The wedge-shaped weight contemplated by the invention can be operated from a small construction vessel or survey vessel that is more readily available and less expensive than larger construction vessels.

Embodiments of the invention implement a method to smooth a slope gradient of the seabed locally, for example at a shoulder of an iceberg plough mark. The method comprises: lifting a weight above the seabed; dropping the weight from a height above the seabed at the location where the slope has to be corrected; and recovering the weight. The method may be repeated at the same location until a desired slope profile is achieved.

The weight may have a wedge shape, with the acute angle of the wedge being directed downwards. The weight may be hoisted via a quick-release system.

In summary, in preparation for installing subsea infrastructure such as a pipeline, an adverse seabed contour may be modified in accordance with the invention by dropping an elongate weight onto a seabed slope to penetrate the seabed. The weight is then lifted away from the slope, for example after being re-engaged with a supporting frame from which the weight was dropped. This leaves an elongate indentation at the drop location. The base of the indentation is less inclined than the initial inclination of the slope at that location and may, indeed, be substantially horizontal.

The indentation can be extended into a groove by repeatedly dropping the weight onto the seabed in longitudinal alignment to form a series of conjoined or overlapping indentations.

The weight may, for example, be dropped at a sloped transition or shoulder between a depression in the seabed, such as an iceberg plough mark, and the general level of the seabed that surrounds the depression.

To put the invention into its context, reference has already been made to Figures 1 to 3c of the accompanying drawings, in which:

Figure 1 is a schematic side view of a subsea depression in the form of a plough mark that has been gouged in the seabed by moving ice;

Figures 2a and 2b are schematic side views of a known preparation technique in which the plough mark is filled with rock before a subsea pipeline is laid across it; and

Figures 3a to 3c are schematic side views of another known preparation technique in which side slopes of the plough mark are excavated along a pipelay path before a subsea pipeline is laid across the plough mark along the excavated path.

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

Figure 4 is a schematic side view of a penetrator apparatus of the invention;

Figure 5 is a schematic end view of the penetrator apparatus shown in Figure 4;

Figure 6 corresponds to Figure 5 but shows a penetrator weight released from a frame of the apparatus;

Figures 7a and 7b are schematic perspective views of the penetrator apparatus of Figures 4 and 5 being used to prepare a plough mark for laying a subsea pipeline, by forming a transverse pipelay trench or groove that intersects the plough mark and that cuts through side slopes of the plough mark;

Figures 8a to 8f are schematic side views showing another way of using the penetrator apparatus of Figures 4 and 5 to prepare a subsea trench or groove for laying a subsea pipeline across the plough mark; and

Figure 9 is a schematic side view of a plough mark prepared as shown in Figure 8e and then further prepared by depositing a rock foundation before laying the pipeline.

Referring next, then, to Figures 4 and 5 of the drawings, these show a penetrator apparatus 28 of the invention that comprises a penetrator weight 30 suspended beneath a supporting frame 32. The frame 32 is suspended, in turn, from a lifting wire 34 that terminates at its upper end at a winch or crane of a surface vessel, not shown, that supports and guides the apparatus 28.

By manoeuvring and by winding in or paying out the lifting wire 34, the surface vessel determines the position and depth of the apparatus 28 and hence the height of the apparatus 28 above the seabed. The position, orientation and height of the apparatus 28 relative to the seabed may conveniently be monitored and controlled by an ROV.

In this example, the penetrator weight 30 is wedge-shaped and elongate in the form of a right triangular prism, comprising parallel triangular ends 36 and downwardly-converging side faces 38 that meet at an elongate bottom edge 40. The bottom edge 40 is substantially horizontal when the apparatus 28 is oriented for use.

There is an acute angle between the faces 38, preferably of less than 60°, potentially of about 30° and in this example of about 45°. The penetrator weight 30 is substantially symmetrical about a vertical central longitudinal plane 42 on which the bottom edge 40 lies.

With further reference to Figure 6, the apparatus 28 also comprises a quick-release mechanism 44 that is operable to release the penetrator weight 30 from the frame 32. If present, an ROV may operate the quick-release mechanism 44 by manipulating or driving an actuator coupling 46 on the frame 32.

In the example shown in Figure 6, the penetrator weight 30 is connected to the frame 32 by legs 48 that depend from the frame 32 and are received in sockets 50 that open to the top of the penetrator weight 30. Here, the quick-release mechanism 44 comprises downwardly-tapering lugs 52 on the legs 48 that engage with complementary latch formations 54 within the sockets 50. The lugs 52 are retractable radially inwardly toward the legs 48, as shown, to disengage from the latch formations 54. This allows the penetrator weight 30 to drop from the frame 32 toward the seabed under gravity.

Figure 7a shows the dropped penetrator weight 30 now embedded in the seabed 12 at a drop location beneath the frame 32. The penetrator weight 30 embeds under its self-weight and momentum, aided by the point or line loading of its blade-like, downwardly-tapering shape.

It will be noted from Figure 7a that the frame 32 is suspended above the shoulder 16 of a plough mark 10 where the surrounding seabed 12 steps down sharply into a depression 14. The frame 32 is oriented such that the penetrator weight 30 intersects the plough mark 10, for example substantially orthogonally as shown, with an inner end of the penetrator weight 30 overhanging the depression 14. Thus, the penetrator weight 30 is oriented to extend down or up the slope of the shoulder 16 or of the side wall of the depression 14.

On being dropped from the frame 32, the penetrator weight 30 cuts through the shoulder 16 to a level beneath that of the surrounding seabed 12. The penetrator weight 30 therefore also cuts down through at least part of the depth of the plough mark 10 and, potentially, substantially to the base of the depression 14.

Next, the frame 32 is lowered onto and re-engaged with the penetrator weight 30, in this example by engaging the legs 48 of the frame 32 within the sockets 50 of the penetrator weight 30. When so engaged with the frame 32, the penetrator weight 30 can be lifted from the seabed 12 as shown in Figure 7b. This leaves behind an elongate indentation 56 that corresponds to the shape of the penetrator weight 30 and is aligned with the proposed pipelay path. That indentation 56 may be described as a notch, groove or trench that cuts through the shoulder 16 and intersects, and hence opens onto and communicates with, the depression 14 of the plough mark 10.

The frame 32 carrying the penetrator weight 30 may then be moved across the plough mark 10 to form a similar indentation 56 in mutual alignment on the opposite side of the plough mark 10. A pipeline is laid subsequently along the aligned indentations 56, thereby dipping beneath the level of the surrounding seabed 12 toward the level of the base of the depression 14. In this way, the pipeline is able to cross the plough mark 10 with gently undulating curvature supported by the indentations 56 and the base of the depression 14.

Single indentations 56 like those shown in Figure 7b may be long enough, and deep enough, for the pipeline to traverse the plough mark 10 without lengthy free spans or other causes of excessive stress. However, if needs be, the indentations 56 can be lengthened, widened or deepened by repeatedly dropping the penetrator weight 30 into the seabed 12 at appropriate drop locations. For example, a longitudinally-aligned series of drops of the penetrator weight 30 in the direction of elongation of the indentation 56 could be used to form an elongate trench or groove that intersects the plough mark 10. In this respect, Figure 7b shows the penetrator apparatus 28 being moved to drop the penetrator weight 30 again in alignment with the indentation 56.

Figures 8a to 8f further illustrate this principle and show an optional variant in which the depth of the successive indentations may be varied. Figure 8a shows the penetrator apparatus 28 suspended above a shoulder 16 of the plough mark 10. Figure 8b shows the penetrator weight 30 dropped from the frame 32 to embed into the seabed 12, cutting through the shoulder 16 to a level close to the base of the depression 14. This corresponds to the situation shown in Figure 7b.

Figure 8c shows the frame 32 lowered onto and reunited with the penetrator weight 30, ready to lift the penetrator weight 30 clear of the seabed 12 to leave behind a first indentation 56 as shown in Figure 8d. Figure 8d also shows the penetrator weight 30 dropped again in longitudinal alignment with the first indentation 56, forming a second, outer indentation 58 that communicates with the first, inner indentation 56 to form an elongate trench or groove.

Optionally, as also shown in Figure 8d, the second drop of the penetrator weight 30 takes place with the frame 32 at a lesser height above the seabed 12 than for the first drop. This reduces the speed and momentum of the penetrator weight 30 and therefore reduces the depth of the second indentation 58 relative to that of the first indentation 56. As a result, the trench or groove formed by the first and second indentations 56, 58 defines a ramp that steps down from the level of the surrounding seabed 12 toward the level of the base of the depression 14.

When corresponding indentations 56, 58 are formed in mutual alignment on the opposite side of the plough mark 10 as shown in Figure 8e, a pipeline 22 that crosses the plough mark 10 can be laid along the aligned indentations 56, 58 as shown in Figure 8f. The pipeline 22 has gently undulating curvature that is supported by the indentations 56, 58 and the base of the depression 14.

Finally, Figure 9 shows that some infill material such as rock 20 can be placed in the base of the depression 14 and/or in the indentations 56, 58 before laying the pipeline 22. This further reduces free spans of the pipeline 22 and reduces stress concentrations in the pipeline 22.

Many variations are possible within the inventive concept. For example, the quick-release mechanism could be powered and operated from the surface via a power and command link extending parallel to or integral with the lifting wire. Also, the quick-release mechanism could be disposed in the penetrator weight rather than in the frame.

In another variant, the penetrator apparatus could be incorporated into a subsea vehicle that positions and releases the weight from an appropriate height above the seabed. Such a vehicle could be supported by the seabed.

The ends of the penetrator weight need not be parallel but could instead converge downwardly. Thus, the penetrator weight could take the form of an oblique prism. Also, the side faces and the ends of the penetrator weight need not be flat; for example, they could be concave or convex.

Claims

1. A method of modifying a seabed slope, the method comprising:

dropping a weight onto the slope to penetrate the seabed at a drop location; and then

lifting the weight away from the slope, leaving an indentation at the drop location that has a base less inclined than a previous inclination of the slope at the drop location.

2. The method of Claim 1, wherein the indentation has a substantially horizontal base.

3. The method of Claim 2, wherein the weight has a substantially horizontal bottom profile.

4. The method of any preceding claim, further comprising extending the indentation by dropping the weight onto the slope again.

5. The method of Claim 4, comprising extending the indentation by dropping the weight at a further drop location adjoining a preceding drop location.

6. The method of Claim 5, comprising dropping the weight from a different height relative to the seabed at the further drop location than at the preceding drop location.

7. The method of any preceding claim, comprising penetrating the seabed with a downwardly-tapering formation of the weight.

8. The method of Claim 7, comprising penetrating the seabed with a blade edge of the weight.

9. The method of any preceding claim, comprising dropping the weight from a supporting frame suspended underwater above the seabed.

10. The method of any preceding claim, wherein the weight is elongate and leaves a correspondingly elongate indentation.

11. The method of Claim 10, comprising dropping the weight again to form a further elongate indentation in longitudinal alignment with a preceding elongate indentation.

12. The method of Claim 10 or Claim 11, wherein the indentation intersects the slope such that an end of the indentation is open.

13. The method of any of Claims 10 to 12, wherein the weight extends down the slope.

14. The method of any preceding claim, wherein the weight is dropped at a sloped transition between a depression in the seabed and the seabed surrounding the depression.

15. The method of Claim 14, wherein the weight intersects a side wall of the depression to leave an indentation that opens onto the depression.

16. The method of Claim 14 or Claim 15, comprising leaving at least one corresponding indentation at a mutually-opposed transition across the depression.

17. The method of any of Claims 14 to 16, wherein the transition is raised above the surrounding seabed and the indentation extends to a depth beneath the surrounding seabed.

18. The method of any of Claims 14 to 17, wherein the depression is an iceberg plough mark.

19. The method of any preceding claim, further comprising laying a subsea pipeline or other subsea infrastructure in the indentation.

20. The method of any preceding claim, wherein the weight drops only under gravitational force.

21. Apparatus for modifying a seabed slope, the apparatus comprising:

a supporting frame;

a wedge-shaped, horizontally-elongate penetrator weight that is suspended from the frame and that tapers away from the frame; and

a quick-release mechanism that releasably couples the penetrator weight to the frame and that is operable to drop the weight away from the frame.

22. The apparatus of Claim 21, further comprising a subsea-operable actuator coupling for operating the quick-release mechanism.

23. The apparatus of Claim 21 or Claim 22, wherein the frame is suspended from a lifting wire extending to a surface vessel.

24. The apparatus of Claim 21 or Claim 22, wherein the frame is supported by or integral with a subsea vehicle.

25. The apparatus of any of Claims 21 to 24, wherein the penetrator weight has downwardly-converging sides with an acute angle of up to 60° between them.

26. The apparatus of any of Claims 21 to 25, wherein the penetrator weight comprises a monolithic block.

27. The apparatus of any of Claims 21 to 25, wherein the penetrator weight comprises a hollow body containing a different solid or granular material.

28. The apparatus of any of Claims 21 to 27, wherein the penetrator weight weighs more than two metric tons per linear metre along its length.

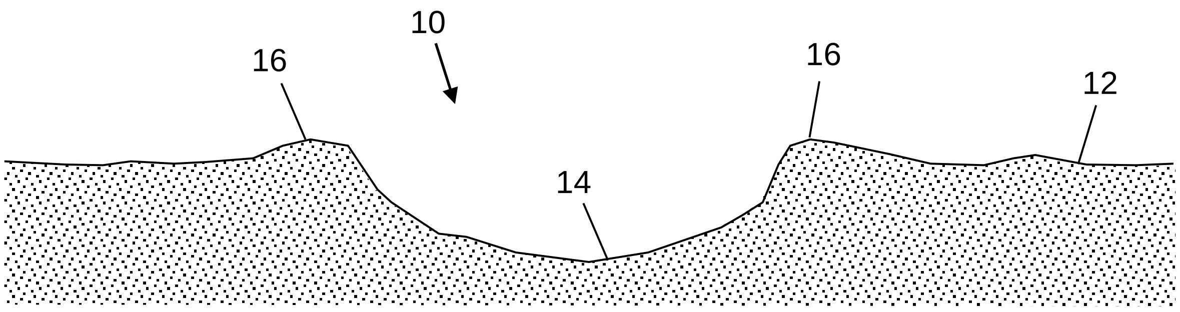


Figure 1

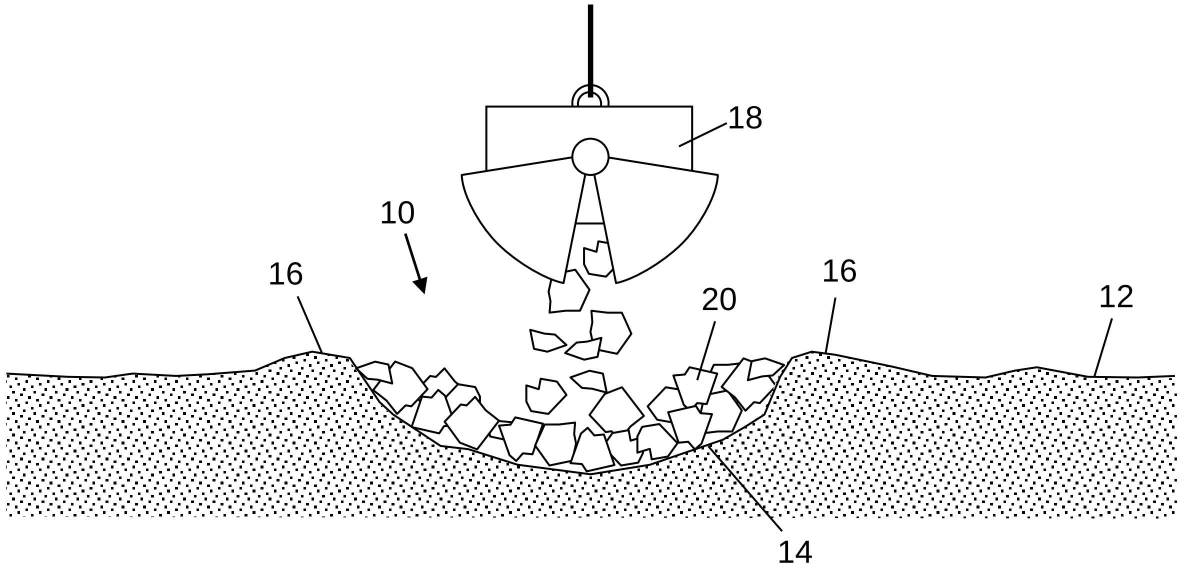


Figure 2a

PRIOR ART

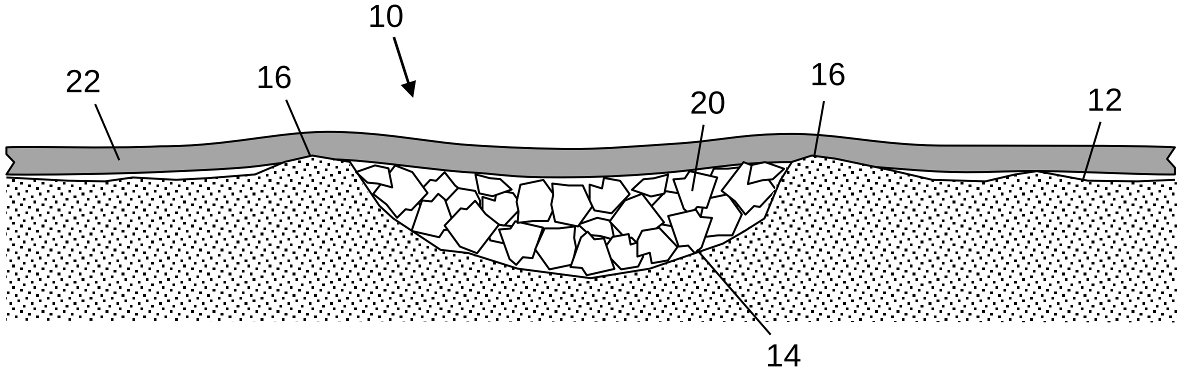


Figure 2b

PRIOR ART

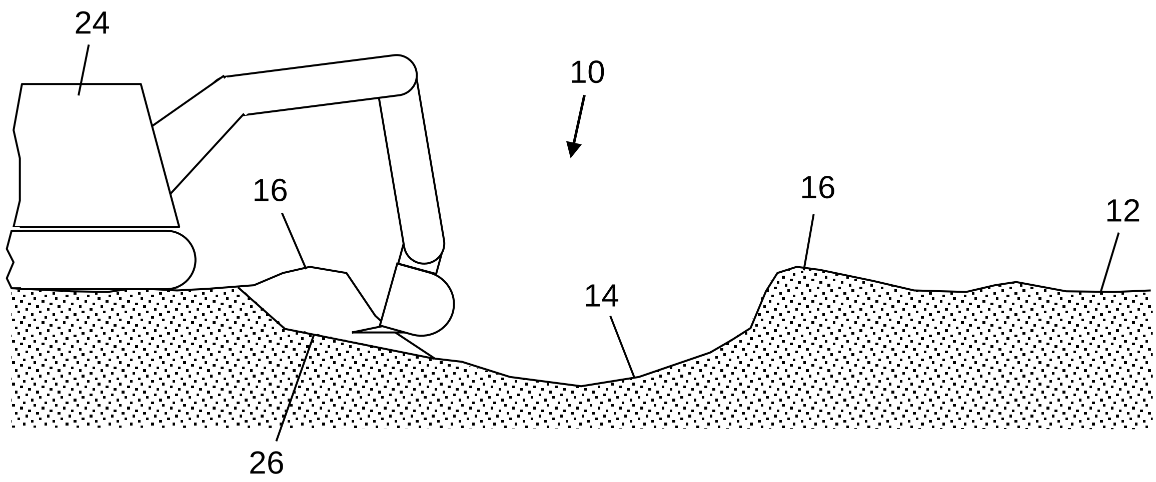


Figure 3a

PRIOR ART

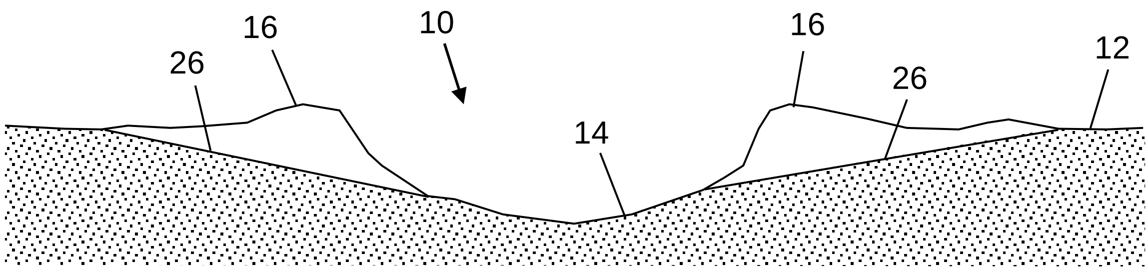


Figure 3b

PRIOR ART

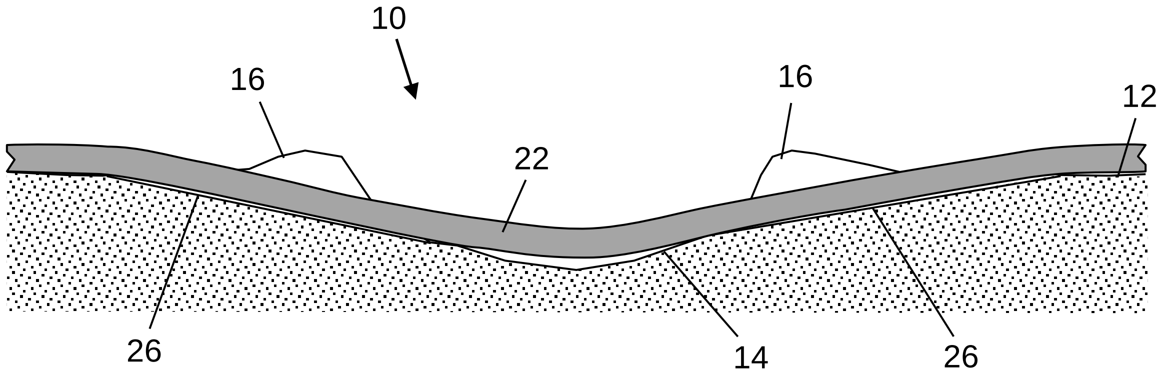


Figure 3c

PRIOR ART

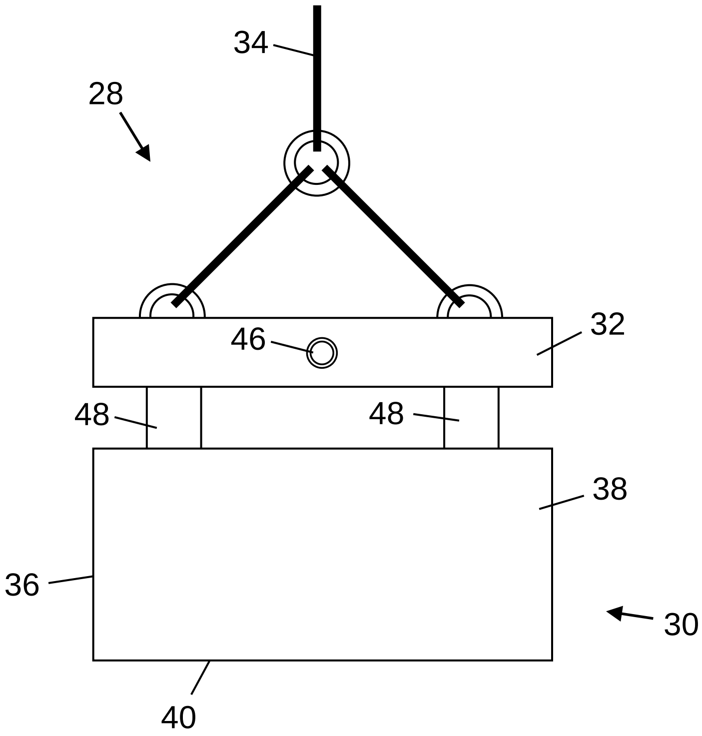


Figure 4

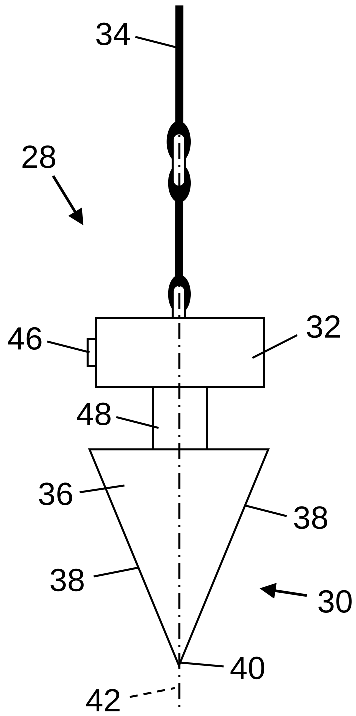


Figure 5

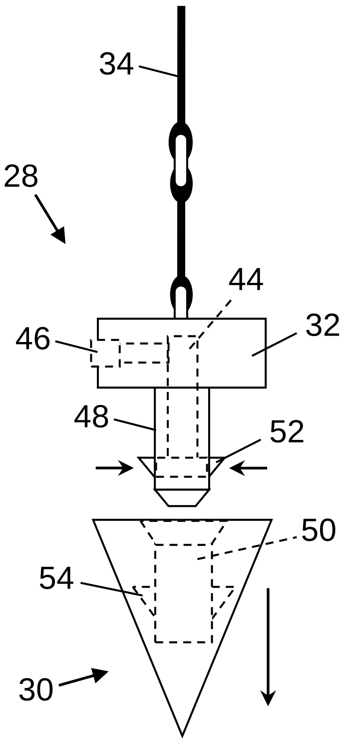


Figure 6

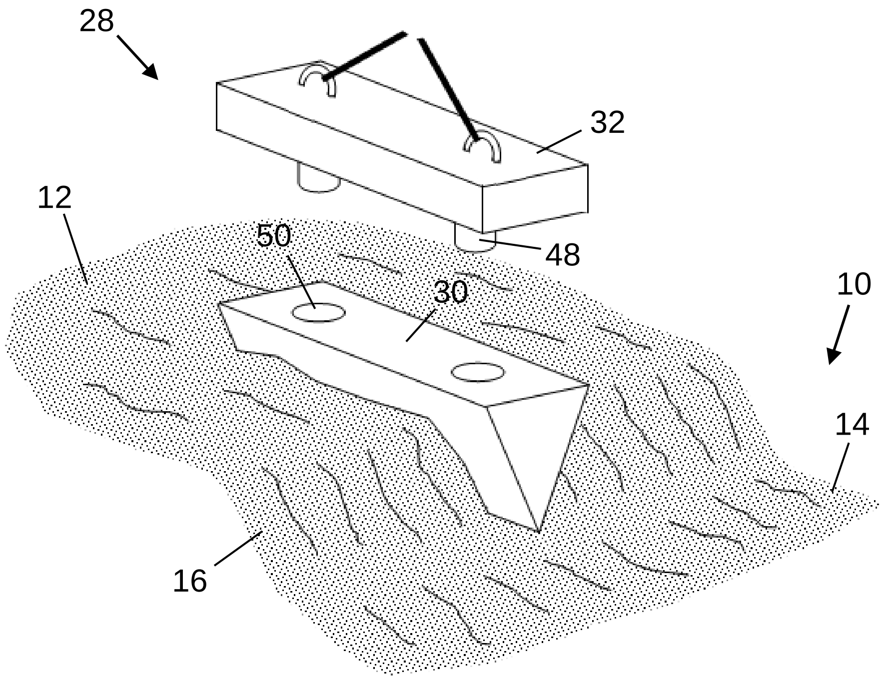


Figure 7a

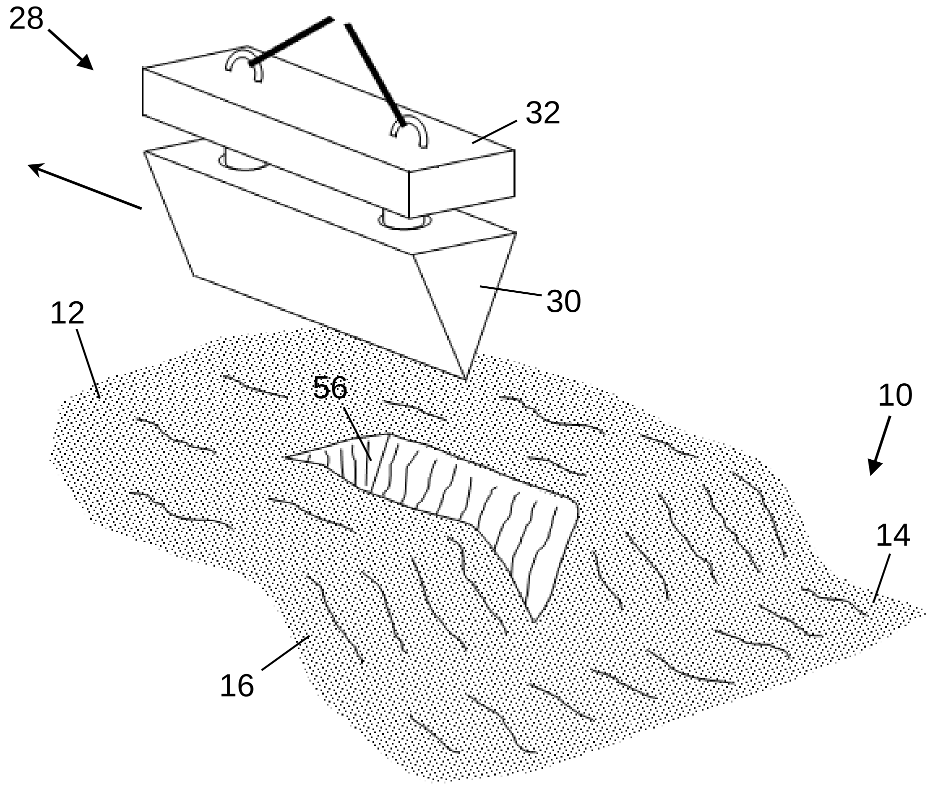


Figure 7b

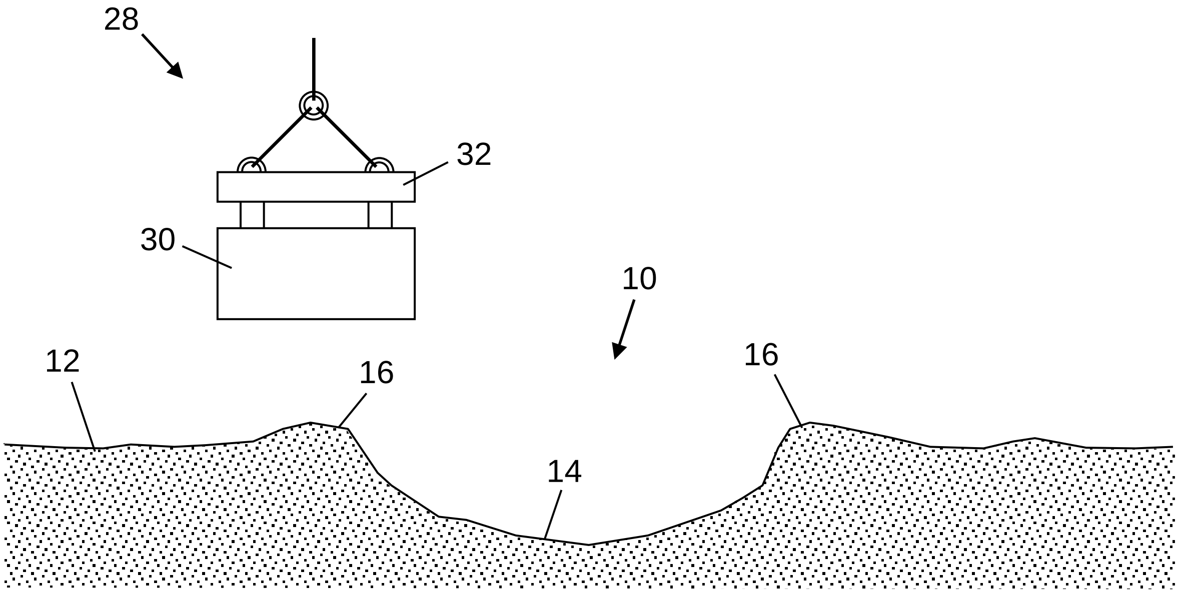


Figure 8a

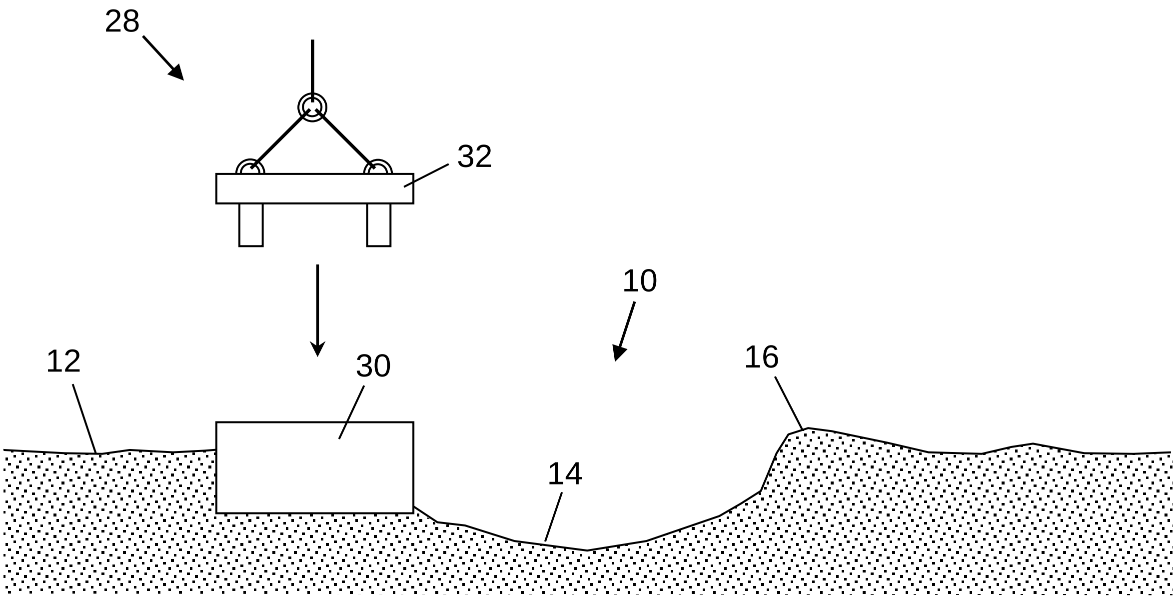


Figure 8b

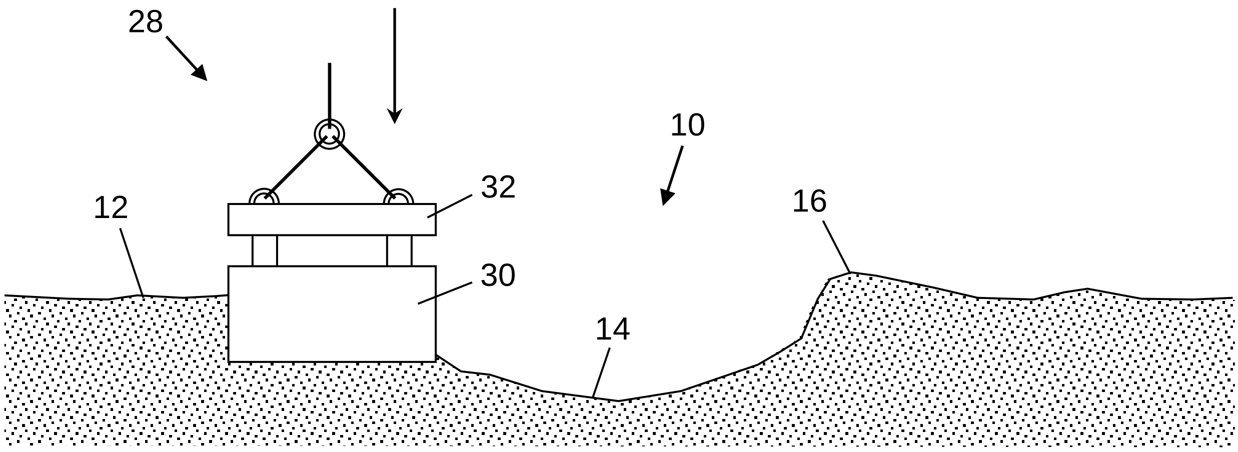


Figure 8c

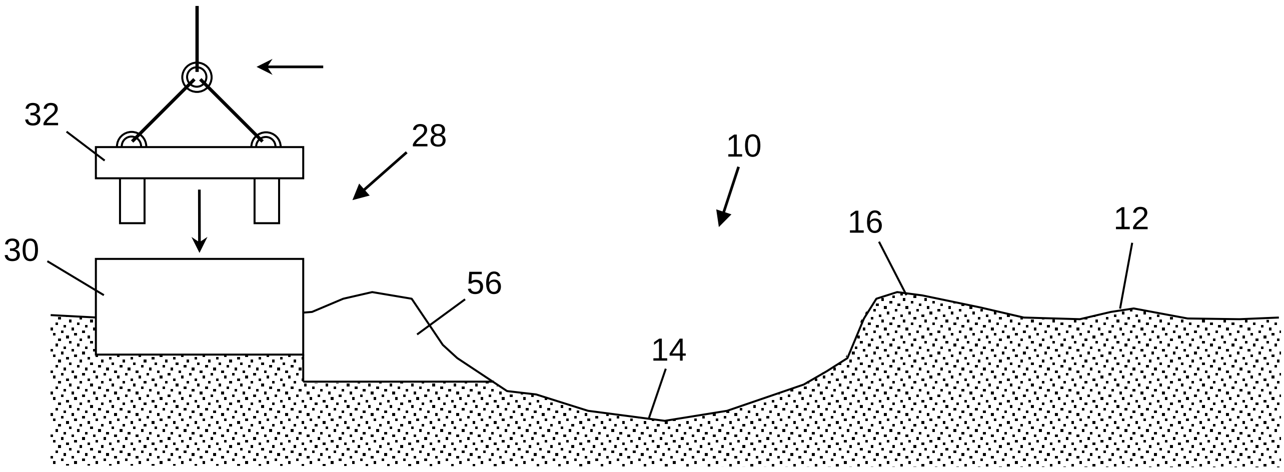


Figure 8d

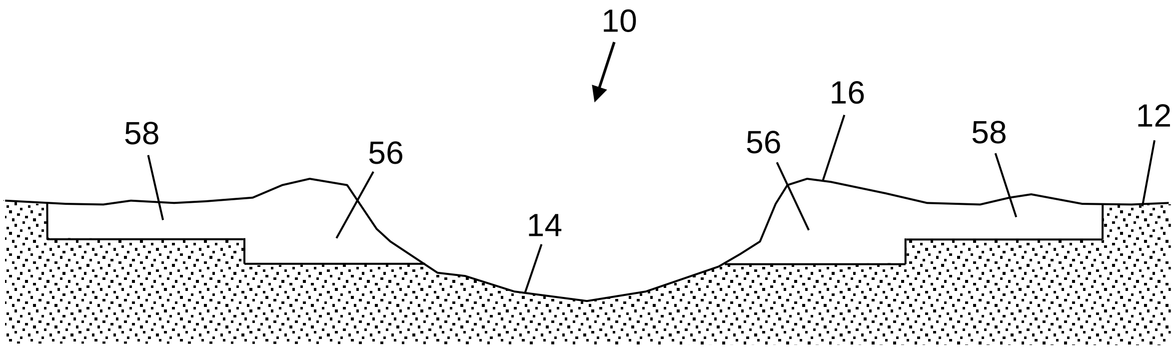


Figure 8e

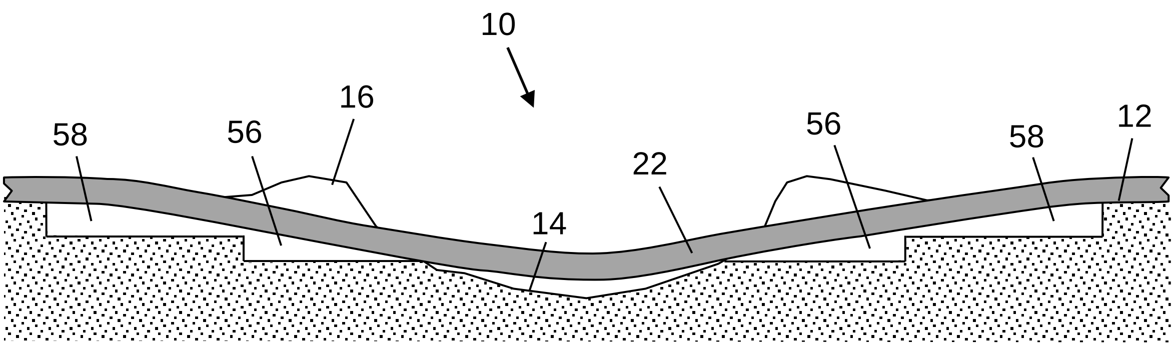


Figure 8f

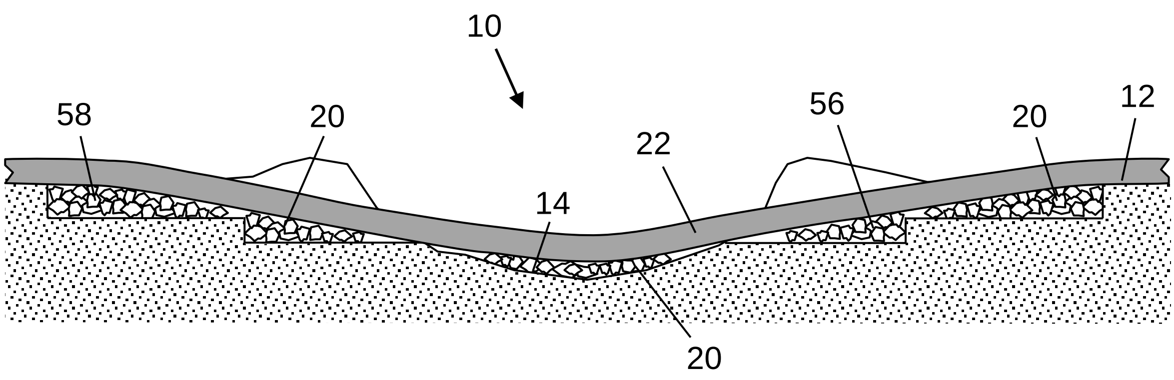


Figure 9