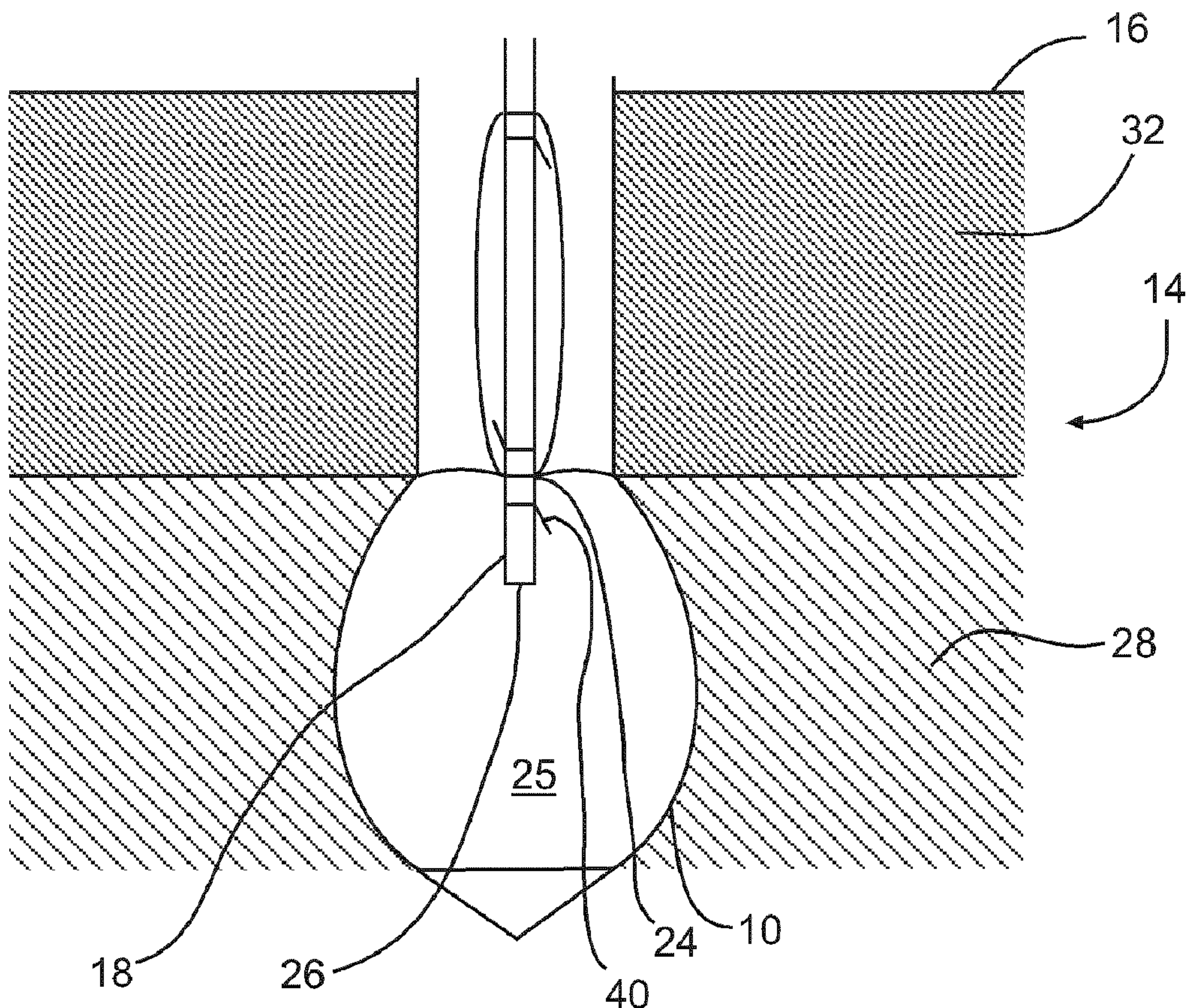




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(54) **Titre : SYSTEME COMMANDE POUR LA DENSIFICATION DE SOLS FAIBLES**
(54) **Title: CONTROLLED SYSTEM FOR THE DENSIFICATION OF WEAK SOILS**



(57) **Abrégé/Abstract:**

A method of imparting strength to earth in support of a ground surface is disclosed. A bag is placed in the earth under the ground surface, the bag having a first end oriented towards the ground surface, a second end opposite the first end, and a cross sectional

(57) Abrégé(suite)/Abstract(continued):

contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth located above and below the wedge portion when the bag is filled. A expandable polymeric resin is injected into the bag to at least partially fill the bag to compress earth around the bag. The expandable polymeric resin may be expandable polymeric resin. A bag is also disclosed for use in imparting strength to earth in support of a ground surface. The bag comprises at least an opening, a first end and a second end opposed the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth above and below the wedge portion when the bag is filled and in earth under the ground surface

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(57) Abstract: A method of imparting strength to earth in support of a ground surface is disclosed. A bag is placed in the earth under the ground surface, the bag having a first end oriented towards the ground surface, a second end opposite the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth located above and below the wedge portion when the bag is filled. A expandable polymeric resin is injected into the bag to at least partially fill the bag to compress earth around the bag. The expandable polymeric resin may be expandable polymeric resin. A bag is also disclosed for use in imparting strength to earth in support of a ground surface. The bag comprises at least an opening, a first end and a second end opposed the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth above and below the wedge portion when the bag is filled and in earth under the ground surface

CONTROLLED SYSTEM FOR THE DENSIFICATION OF WEAK SOILS

TECHNICAL FIELD

[0001] This document relates to controlled systems for the densification of weak soils, and more specifically to a bag system for densifying weak soils in a controlled fashion.

BACKGROUND

[0002] A traditional method of densifying base soils, called pressure grouting or permeation grouting, involves forcing a high density cementitious material under high pressure into the base soils with a view to increase the bearing capacity of the soils. However, in the case of weak soils there is no controlling of the amount of grout that is required and as such, extreme amounts of grout can be pressure pumped into the soils with limited or no positive results. This is especially true in the case of highly saturated soils.

[0003] An alternative method of densifying soils is the injection of expanding polymer resins directly into the base soils, as for example described in EP 0 851 064 A1. This typically works when the soils are relatively strong but in the case of weak to very weak soils that are saturated, enormous amounts of expanding polymer resin are required which once again makes it uneconomical due to the lack of control as to where the resins are expanding to.

[0004] Another alternative method of densifying weak soils involves driving a pre-formed member made of wood, or any other strong material, into the soils, densifying the soil through the displacement of the soil by the driven member. Although this system has merit, it is very intrusive and especially damaging to the surface soils as the driven members have to be of significant diameter and must be driven from the surface.

SUMMARY

[0005] A method of imparting strength to earth in support of a ground surface is disclosed. A bag is placed in the earth under the ground surface, the bag having a first end oriented towards the ground surface, a second end opposite the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge

portion extendable laterally into surrounding earth located above and below the wedge portion when the bag is filled. Expandable polymeric resin is injected into the bag to at least partially fill the bag to compress earth around the bag.

[0006] A bag is also disclosed for use in imparting strength to earth in support of a ground surface. The bag comprises at least an opening, a first end and a second end opposed the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth above and below the wedge portion when the bag is filled and in earth under the ground surface.

[0007] A method of imparting strength to earth in support of a ground surface is also disclosed. A first bag and a second bag are placed in the earth under the ground spaced along an injector inserted through the second bag and into the first bag. Expandable polymeric resin is injected into the first bag from an injection end of the injector, such as an injection tube, to compress the earth around the first bag. The injection end is removed from the first bag and expandable polymeric resin injected into the second bag from the injection end to compress the earth around the second bag. The injector is removed from the second bag. In some embodiments, the method further comprises drilling a hole in the earth with a hollow drill stem connected to a sacrificial drill bit, and in which placing further comprises placing the first bag, second bag, and injector in the hollow drill stem under the ground surface. The hollow drill stem is then removed from over the first bag prior to injection of the first bag.

[0008] A method of imparting strength to earth in support of a ground surface is also disclosed. A first bag is placed in a first layer of earth below the ground surface. A second bag is placed in a second layer of earth below the ground surface. Expandable polymeric resin is injected into each of the first bag and second bag to at least partially fill the first bag and second bag to compress the earth around the first bag and second bag, respectively, and to form a support stack of bags. The first layer is weaker than the second layer, and a maximum lateral cross sectional area of the first bag is larger than a maximum lateral cross sectional area of the second bag.

[0009] A method of densifying weak earth at least partially saturated with water and in support of a ground surface is also disclosed. A first bag is placed in the weak earth below a first location of the ground surface and expandable polymeric resin injected to at least

partially fill the first bag and to compress weak earth around the first bag. A second bag is placed in the weak earth below a second location of the ground surface and expandable polymeric resin injected to at least partially fill the second bag and to compress weak earth around the second bag. After a pre-determined amount of time to allow the first bag and the second bag to at least partially drive out water from the weak earth between the first bag and the second bag, a third bag is placed in the weak earth below a third location of the ground surface in between the first location and the second location and expandable polymeric resin is injected to at least partially fill the third bag and to compress weak earth around the third bag.

[0010] A further method involves inserting a bag or an array of bags of predetermined shape and size into a pre-drilled hole to a predetermined depth, air filling the bag or bags to allow for free flow of an expanding polymeric resin thereby allowing the expanding resin to be confined yet allowing the expanding confinement bag to compact, compress and densify the soils in proximity to the confinement bag(s) to increase bearing capacity of soils beneath foundation support systems.

[0011] In a further method, a geotechnical survey is carried out on weak soils to determine a profile of soil weakness. A bag or stack of bags is then placed in the weak soils and injected with an expanding polymeric resin to compress the weak soils around the bag or stack of bags. The bag or stack of bags is selected to have a shape that conforms to the soil weakness profile such that a portion of the bag or stack of bags placed in a weaker layer of the weak soils has a greater diameter than another portion of the bag or stack of bags placed in a stronger layer of the weak soils. The portions of the bags or bags having the greater diameter may provide a bridge between stronger layers of soil. The portions with greater diameter thus form wedges that provide the bridging function.

[0012] A bag for use in imparting strength to earth in support of a ground surface is disclosed, comprising: at least an opening; a first end and a base end opposed the first end; and a cross sectional contour from the base end to the first end, at least a portion of the cross sectional contour being configured to taper conically outwards from the base end when the bag is filled.

[0013] A method of imparting strength to earth in support of a ground surface is also disclosed, the method comprising: placing a bag in the earth under the ground surface, the bag having a base end, a first end opposite the base end, and a cross sectional contour from the base end to the first end, at least a portion of the cross sectional contour being configured to taper conically outwards from the base end when the bag is filled; and injecting expandable polymeric resin into the bag to at least partially fill the bag to compress earth around the bag.

[0014] Various applications of these methods include the densification of weak soils beneath foundation footings, concrete floor slabs, perimeter thickened or non-thickened concrete slab-on-grade slabs, asphalt and concrete pavements, walks, and railroad track for example. Methods as disclosed herein may be used as methods of replacing the pre-loading of weak soils at construction sites. In use, the wedge portions extend between layers of soil and form a supportive bridge between the layers.

[0015] These and other aspects of the device and method are set out in the claims, which are incorporated here by reference.

BRIEF DESCRIPTION OF THE FIGURES

[0016] Embodiments will now be described with reference to the figures, in which like reference characters denote like elements, by way of example, and in which:

[0017] Figs. 1-5 are side elevation views, in section and not to scale, of earth under a ground surface and illustrating a process forming a support stack of plural bags in earth under a ground surface.

[0018] Fig. 6 is a perspective view, partially in section and not to scale, that illustrates an opening in a bag housing a back-flow prevention valve.

[0019] Fig. 7 is a side elevation view, in section and not to scale, of earth under a ground surface containing a support stack of four bags.

[0020] Figs. 8-9 are perspective views, in section and not to scale, of earth under a ground surface and illustrating a method of placing support stacks of at least one bag.

[0021] Figs. 10-11 are side elevation views, in section and not to scale, that illustrate a further method of placing support stacks of at least one bag.

[0022] Fig. 12 is a side elevation view, in section and not to scale, that illustrates an embodiment of a support stack with two bags, in which one bag has an hourglass cross section, and the other bag has a bulged midsection, as well as a soil weakness profile of the soil of illustrated.

[0023] Figs. 13-15 are flow diagrams that illustrate various methods of imparting strength to earth under a ground surface.

[0024] Fig. 16 is a flow diagram that illustrates a method of densifying weak earth at least partially saturated with water and in support of a ground surface.

[0025] Figs. 17A and 17B are side elevation views, in section and not to scale, that illustrate the placement and filling, respectively, of a bag in the earth.

[0026] Figs. 18-19 are side elevation views, in section and not to scale, that illustrate the formation of a support stack of bags.

[0027] Fig. 20 is a side elevation view, in section and not to scale, that illustrates the first and second bags from Fig. 18 fully filled out of the ground.

[0028] Fig. 21 is a perspective view, in section and not to scale, that illustrates a bag with an annular wedge portion.

[0029] Fig. 22 is a perspective view, in section and not to scale, that illustrates a bag with an arm.

[0030] Fig. 23 is a flow diagram that illustrates a method of imparting strength to weak soils in support of a ground surface.

[0031] Fig. 24A is a side elevation, in section, of a bag with a conically outwards taper.

[0032] Fig. 24B is a side elevation view, in section, of a bag with an inwardly tapered base.

[0033] Fig. 25 is a flow diagram that illustrates a method of imparting strength to earth in support of a ground surface.

DETAILED DESCRIPTION

[0034] Immaterial modifications may be made to the embodiments described here without departing from what is covered by the claims.

[0035] This document relates to the construction of in-situ expandable vertical/horizontal support member(s) in weak base soils as a means of densifying the weak base soils for supporting and under-pinning structures on these soils. For example, these methods and apparatuses may carry out the densification of foundation soils support systems for buildings, walks, bridge approaches, concrete or asphalt paved roads, rail beds, and any other structure requiring a base support system or requiring enhancement or strengthening of the existing soil-based support system.

[0036] The present disclosure is directed to providing a controlled method of densifying soils at depth to increase bearing capacity of the weak soils as an alternative to pressure grouting and to direct injection of expanding polymer resins into weak base soils. Weak alluvial soils and silts replete with peat, hog fuel, and other weak sediments that may be highly saturated and demonstrative of Standard Penetration Test N-values of 5 or lower are examples of soils that this disclosure relates to.

[0037] In many types of weak soils, such as weak alluvial soils, silts, clay, peat, hog fuel, wood chips, and water saturated soils for example, the inherent strength of the earth below the ground surface is limited. Soils of these types are known to have caused hazardous situations such as standing derailments of trains, and the cracking of foundations of various structures. In order to stabilize these types of soils, and prevent such incidents from occurring, the earth below the ground surface must be strengthened.

[0038] Referring to Fig. 17A, a bag 10 is illustrated for use in imparting strength to earth 14 in support of a ground surface 16. Bag 10 may be made of non-expandible material, for example thick polymer material. Referring to Fig. 17B, the material may resist the expansion of the bag itself, thus compressing the inside and outside of the bag while maintaining structural integrity. In some embodiments, the bag is made of resilient material. Bag 10 may be filled underground with an expandable polymeric resin that fills bag 10 to compress and densify the adjacent earth. The expandable polymeric resin reacts to expand and fill bag 10, compressing and densifying as it does so. By densifying and strengthening the weak adjacent soils, the weight bearing capacity of the ground surface 16 is increased, and overlying structures may be more easily stabilized and built on top. Referring to Figs. 17A and 17B, bag 10 has at least an opening 24 through which an injector, such as an

injection tube 18 (shown in Fig. 2), is inserted to dispense the expandable polymeric resin. It should be understood that the injector need not be a tube.

[0039] Referring to Fig. 13, a method of imparting strength to earth in support of a ground surface is illustrated. Referring to Fig. 2, in a stage 100 (shown in Fig. 13), a first bag 10 and a second bag 12 are placed in the earth 14 under the ground 16 spaced along an injector, such as injection tube 18, inserted through the second bag 12 and into the first bag 10. The injection tube 18 may be inserted through the second bag 12 through openings 20, 22, and into first bag 10 through opening 24. The bags 10, 12 may form an array of non-identical containment bags vertically placed one on top of each other to the appropriate depth. Non-identical refers to the fact that the bags may have different potential shapes and volumes. Bags 10, 12, and injection tube 18 may be placed in the earth 14 through a hole 34. Referring to Fig. 1, an embodiment is illustrated where hole 34 is drilled. Hole 34 may be drilled by a conventional means, in which the drilling device (not shown) is removed upon completion of the hole and prior to placement of bags 10, 12, and tube 18. In other embodiments, hole 34 may be drilled in the earth using a hollow drill stem 36 connected to a sacrificial drill bit 38. This embodiment is described in greater detail below.

[0040] Referring to Fig. 4, in stage 102 (shown in Fig. 13) expandable polymeric resin 25 is then injected into the first bag 10 from an injection end 26 of the injection tube 18 to compress the earth 28 around the first bag 10. Referring to Fig. 3, prior to injecting expandable polymeric resin 25 into the first bag 10, gas, for example compressed air, may be injected to at least partially fill the first bag 10. Each containment bag may be expanded in-situ using compressed air to facilitate filling of each bag with a predetermined amount of expandable polymeric resin. In some embodiments, the expandable polymeric resin is added as a liquid and fills the containment bag(s) through the expansion of the polymeric resin, the balloon effect on the containment bags compacting and compressing the base soils surrounding the containment bag(s). By filling the first bag 10 with air prior to injection, the expandable polymeric resin is allowed to free flow into bag 10 and properly fill, yet be confined by, the dimensions of bag 10 upon expansion. Each bag 10, 12 may be expanded in-situ as much as possible using compressed air to allow as easy as possible filling of each bag with a predetermined amount of expandable polymeric resin. The predetermined amount

of liquid resin injected may be an amount much smaller than the fully expanded volume of the bag, depending on the expansion ratio of the resin used. Referring to Figs. 3 and 4, injection of the expandable polymeric resin may proceed first with injection end 26 of tube 18 near the base of first bag 10 (shown in Fig. 3). Once bag 10 has begun to fill up, injection end 26 is gradually drawn up towards opening 24. The predetermined amount of resin may be hydro-insensitive polyurethane for example.

[0041] Referring to Fig. 5, in stage 104 (shown in Fig. 13), the injection end 26 is removed from the first bag 10 and expandable polymeric resin 30 injected into the second bag 12 from the injection end 26 to compress and compact the surrounding solids, for example earth 32, around the second bag 12, thereby increasing the bearing capacity of the soils being treated. A pre-determined amount of expandable polymeric resin 25 may be injected into bag 10. Referring to Fig. 4, opening 24 of first bag 10 may comprise a backflow prevention valve 40. Valve 40 may be provided to prevent material contained within the bag 10 from flowing out of the bag 10 when the opening 24 is unobstructed. Valve 40 allows the injection tube to be threaded through, but once the injection tube 18 has been removed the valve will close and not allow expandable polymeric resin to escape from the containment bag. Valve 40 is sized to accept the passage of injection tube 18. Normally, valve 40 may be biased to close opening 24, unless tube 18 is extending through opening 24. Valve 40 is illustrated in Fig. 6, and described in detail below. Referring to Fig. 5, once tube 18 is removed from bag 10, valve 40 closes and prevents any expandable polymeric resin pressure from expandable polymeric resin 25 from passing out of bag 10 through opening 24, for example into second bag 12. This is especially useful when the expandable polymeric resin used is expanding polymeric resin. The valves and openings used may be of sufficient diameter to allow the injection probe to freely move through.

[0042] Referring to Fig. 13, in stage 106, the injection tube 18 is removed from the second bag 12. Bag 12 may be filled in much the same fashion as bag 10. Similarly, openings 20, 22 of bag 12 may have valves 42, 44, respectively, which may function the same as valve 40. In some embodiments, at least one of valves 40, 42, and 44 are at least partially threaded on to tube 18. In such embodiments, tube 18 must be unscrewed out of the respective valve.

[0043] Referring to Fig. 12, in some embodiments first bag 10 and second bag 12 are connected. Bags 10 and 12 may be connected, for example via a sleeve 46, for further example a polymer connector. Injection probe 18 (not shown) may be passed through bags 10, 12 through sleeve 46. In such embodiments, it may only be necessary to provide one backflow prevention valve on sleeve 46. Referring to Fig. 6, sleeve 46 may be initially affixed to at least one of bags 10, 12, in this case the bag 10. Referring to Fig. 24A, sleeve 46 may extend into at least one, and preferably both, of bags 10, 12 a predetermined distance when in position. By passing the sleeve 46 partially through at least one of the bags, the firming action of the polymer acts to cement the sleeve 46 in place, effectively affixing the sleeve to the two bags and anchoring the two bags together. Sleeve 46 thus acts as a reinforcement member that helps prevent the array from buckling.

[0044] Referring to Fig. 14, a further method of imparting strength to earth 14 in support of a ground surface 16 is disclosed. Referring to Figs. 18-19, this method is illustrated. Referring to Fig. 18, in stage 108 (shown in Fig. 14), first bag 10 is placed in a first layer 48 of earth 14 below the ground surface 16. A second bag 12 is placed in a second layer 50 of earth 14 below the ground surface 16. Referring to Fig. 12, this is also illustrated as first bag 10 is placed predominantly in first layer 48, and second bag 12 is placed predominantly in second layer 50. Referring to Fig. 19, in stage 110 (shown in Fig. 14) expandable polymeric resin 25, 30 is injected into the first bag 10 and second bag 12, respectively, to at least partially fill the first bag 10 and second bag 12 to compress the earth 14 around the first bag 10 and second bag 12, respectively, and to form a support stack 52 of bags. In this embodiment, the first layer 48 is weaker than the second layer 50, and referring to Fig. 20, a maximum lateral cross sectional area 54 of the first bag 10 is larger than a maximum lateral cross sectional area 56 of the second bag 12. Referring to Fig. 20, in some embodiments, first bag 10 has a larger maximum width than second bag 12. This method takes advantage of the lower density of weaker soil layers, as larger volume bags may be spaced to align within weaker soils. This allows further densification of the weak soils to take place than would be the case if the same size bag was used for the entire support stack 52.

[0045] Referring to Fig. 15, a further embodiment of methods of imparting strength to earth in support of a ground surface is illustrated. This method may be illustrated with reference to Fig. 12, despite the fact that Fig. 12 illustrates bag 12 in a filled state. Referring to Fig. 12, in stage 116 (shown in Fig. 15), bag 12 is placed in the earth 14 under the ground surface 16. Bag 12 has a first end 58 oriented towards the ground surface 16, and a second end 60 opposite the first end 58. Bag 12 also has a cross sectional contour 62 from the first end 58 to the second end 60 that includes at least one wedge portion 64 extendable laterally into surrounding earth 14 located above and below the wedge portion 64 when the bag 12 is filled. Wedge portion may be between the first end 58 and the second end 60 of the bag. This method may also be illustrated with reference to bag 10 in Fig. 12, as bag 10 includes a wedge portion 64. Wedge portion 64 may extend laterally into soil, for example layer 48 to bridge the soil above and below the wedge portion 64. In the example shown, wedge portion 64 on bag 10 extends into weak layer 48 and bridges between soil layers above and below layer 48. In stage 118, expandable polymeric resin 25 is injected into the bag 12, for example through an opening (not shown) to at least partially fill the bag 12 to compress earth around the bag 12. Wedge portion 64 is used to extend into and wedge between earth 14 adjacent the bag, increasing the structural effectiveness of the bag and densifying the soil. This is contrasted with a traditional bag shape, which merely compresses the adjacent soil. Wedge portion 64 is understood to be defined by a portion only of the cross-sectional contour between ends 58 and 60, and not the entire vertical contour itself. This way, wedge portion 64 effectively fingers laterally into the surrounding earth, compressing adjacent soil vertically as well as horizontally and bridging between soil above and below wedge portion 64. This type of friction pile is also more effective at forming a support stack than a stack of conventional bags, because it is harder to vertically displace due to the lateral interaction with the adjacent soil by the wedge portion(s).

[0046] The method illustrated in Fig. 15 is particularly useful for densifying particularly narrow strata of weak soil, such as layer 48 in Fig. 12. Because a weak layer may be short enough vertically that a bag positioned within such a layer will extend beyond the layer as illustrated, this method allows a portion of the bag to be modified to target the small weak layer and provide more compression to it. In some embodiments, the wedge

portion 64 is oriented in a first strata 48 of earth 14 over a second strata 68, the first strata 48 of earth being weaker than the second strata 68. This method allows a bag 10 to ledge over and be shouldered by an underlying layer of earth. For example, in Fig. 12, wedge portion 64 effectively sits over earth layer 68, which is stronger and denser than layer 48. Referring to Fig. 12, this may also be illustrated as bag 12 may have an hourglass cross sectional contour 66 from the first end 58 to the second end 60. Referring to Fig. 12, in some embodiments, wedge portion 64 comprises a sloped ledge 71. The bag may also have at least two wedge portions, for example wedge portion 64 and 70 illustrated for bag 12. Referring to Fig. 21, wedge portion 64 may be defined annularly around an axis of the bag. In this way, wedge portion 64 may form an annular portion. As illustrated, the wedge portion 64 may comprise a bulged cross sectional contour when the bag is filled. This is also illustrated in Fig. 12 with bag 10. Referring to Fig. 22, wedge portion 64 may comprise an arm 72. Arm 72 may be useful for targeting an inconsistent layer of weak soil.

[0047] Referring to Fig. 12, placing the bag in the earth under the ground surface may further comprise placing the bag 12 in the earth 14 with an injector, such as an injection tube (not shown), inserted through an opening (not shown) of the bag 12, and in injecting may further comprise injecting expandable polymeric resin into the bag from an injection end of the injection tube. This is illustrated in the embodiments shown in Fig. 4 for example. Similarly, the injection end may be removed from the bag. Referring to Fig. 6, the bag 10 may further comprises a backflow prevention valve 40 to prevent material contained within the bag 10 from passing out of the bag 10 when the opening 24 is unobstructed. Valved opening 24 may comprise a rigid flange 41.

[0048] Referring to Fig. 12, also disclosed is a structural support 74 for a ground surface 16 comprising the confinement bag 12 located in earth 14 under the ground surface 16 and at least partially filled with the expandable polymeric resin 25 to compress the earth 14 around the bag 10.

[0049] Referring to Figs. 7, 12, and 24A-B, embodiments of a bag 12 are illustrated, having an opening 24, a first end 58 and a base end 59 (for example second end 60) opposed the first end 58, and a cross sectional contour 62 from the base end 59 to the first end 58, at least a portion of the cross sectional contour 62 being configured to taper when the bag 12 is

filled. In some embodiments, the taper may be frusto-conical. Referring to Fig. 7, in some embodiments a portion of the cross sectional contour 62 (illustrated for bag 10B) is configured to taper conically outwards with increasing distance from the base, for example from base end 59. Fig. 17B illustrates a conical bag 10 similar to bag 10B, but with the entire cross sectional contour 62 tapered conically outwards from the base. Referring to Fig. 24A, a further embodiment of this is illustrated, with the conically-tapered portion 87 spaced from the base end 59. The conically outwards taper may be linear. In these embodiments, the base of the bag is smaller than the balance of the bag. As liquid material is pumped into the bottom of the bag, gravity pulls the liquid polymer downward and as such it starts to foam at the base first. Since the first-injected polymer expands first, the first-injected polymer pushes the non-expanded polymer upward. This is because it is easier to push upward rather than laterally, as the expanding resin will follow the path of least resistance. As more polymer is injected and raised, there is a larger amount of polymer that can begin pressing laterally against the bag to compress the soil. Hence, a conically outward tapered cross section contour 62 at or near base end 59 gives an effective shape for the bag. It should be understood that contour 62 may refer to a single contour, plural contours, or an infinite number of contours, defined at least partially around an axis of the bag between the first and second ends. Referring to Fig. 12, an example where contour 62 refers to an infinite number of contours is when wedge portion 64 is defined annularly around an axis 150 of the bag 10. This can be understood by meaning that if bag 10 was rotated 360 degrees about axis 150 over an infinite number of incremental steps, wedge portion 64 would have the same shape at each incremental stage. Referring to Fig. 25, a method is illustrated. Steps 132 and 134 are carried out in a fashion similar to steps 116 and 118, respectively, of the method of Fig. 15.

[0050] Referring to Fig. 24B, the base of cross section contour 62 may be tapered inwards at lower end 60. Another example of this is illustrated in bag 12 of Fig. 12. In some embodiments, the entire cross sectional contour 62 may be tapered inwards (not shown). Referring to Fig. 24B, the tapering may be at least one of non-linear, for example curved as shown, and linear (not shown).

[0051] Referring to Fig. 1, in some embodiments of the methods disclosed herein, a hole 34 may be initially drilled in earth 14 with a hollow drill stem 36 connected to a

sacrificial drill bit 38. Referring to Fig. 2, in these methods, the injection tube 18, along with at least one of the first bag 10, and second bag 12 are placed in the hollow drill stem 36 under the ground surface 16. In some weak soils, the hollow drill stem may be required to prevent the drilled hole from collapsing prior to placement of the bags. Referring to Fig. 3, the hollow drill stem 36 (shown in Fig. 2) is at least removed from over the first bag 10 prior to injection of the first bag 10. In the embodiment illustrated in Fig. 3, the hollow drill stem 36 is completely removed at this stage. In other embodiments, the hollow drill stem 36 may be removed enough to clear each bag one at a time as the cleared bag has expandable polymeric resin injected into it.

[0052] Referring to Fig. 16, a method of densifying weak earth at least partially saturated with water and in support of a ground surface is detailed. Referring to Figs. 10-11, this is illustrated. Referring to Fig. 10, in stage 120 (shown in Fig. 16), a first bag 74 is placed in the weak earth below a first location 76 of the ground surface 16 and expandable polymeric resin 25 is injected to at least partially fill the first bag 74 and to compress weak earth around the first bag 74. In stage 122, a second bag 78 is placed in the weak earth below a second location 80 of the ground surface 16 and expandable polymeric resin 25 is injected to at least partially fill the second bag 78 and to compress weak earth around the second bag 78. A pre-determined amount of time is then elapsed to allow the compression from first bag 74 and the second bag 78 to at least partially drive out water 82 from weak earth between the first bag 74 and the second bag 78. Referring to Fig. 11, in stage 124 (shown in Fig. 16), after the pre-determined amount of time a third bag 84 is placed in the weak earth below a third location 86 of the ground surface 16 in between the first location 76 and the second location 80 and expandable polymeric resin 25 is injected to at least partially fill the third bag 84 and to compress weak earth around the third bag 84. Referring to Fig. 10, the placement of bags 74 and 78 is close enough such that water 82 is driven out along lines 88 for example. In some embodiments, the first location 76 and the second location 80 are any suitable distance apart, for example less than 10, 20 feet apart. As illustrated in Fig. 11, the third location 86 may be centrally located between the first location 76 and the second location 80.

[0053] Referring to Fig. 8, in one embodiment of the method, prior to placement of the third bag 84, a fourth bag 90 is placed in the weak earth below a fourth location 92 of the ground surface 16 and expandable polymeric resin 25 is injected to at least partially fill the fourth bag 90 and to compress weak earth around the fourth bag 90. The fourth bag 90 acts to at least partially drive out water 82 from weak earth between the first bag 74, the second bag 78, and the fourth bag 90 during the pre-determined amount of time. Referring to Fig. 9, the third position 86 is in between the first position 76, second position 80, and fourth position 92. In this way, a triangle of bags may be employed, and the third bag 84 placed in between the triangle.

[0054] Referring to Fig. 8, in a further embodiment of the method, prior to placement of the third bag 84, a fifth bag 94 is placed in the weak earth below a fifth location 96 of the ground surface 16 and expandable polymeric resin 25 is injected to at least partially fill the fifth bag 94 and to compress weak earth around the fifth bag 94. The fifth bag 94 acts to at least partially drive out water 82 from weak earth between the first bag 74, the second bag 78, the fourth bag 90, and the fifth bag 94 during the pre-determined amount of time. Referring to Fig. 9, the third position 86 is in between the first position 76, second position 80, fourth position 92 and fifth position 96. In this way, a grid of bags may be placed to drive out water from in between prior to placement of the final bag. Once the final bag is placed, the final bag acts to further drive out water from in between the final bag and the prior placed bags, thus drying the soil at least in part and imparting strength to the soil. The separation of the bags may be the same as the separation between the first and second bags 74, 78 for example. An appropriate grid system of these containment bags may be placed under whatever structure requires under-pinning and support. Further bag supports may be placed in between the already placed bags after a further pre-determined amount of time.

[0055] In some embodiments, the pre-determined amount of time is any suitable amount of time, for example more than 4 or 8 hours. As illustrated in Figs. 10-11, the steps of placing the bags may actually involve placing stacks of bags by, for example using the methods disclosed in this document. This method may further comprise removing water from between the first bag and the second bag through at least one relief hole 23. Relief hole 23 may be drilled near enough to at least one of bags 74, 78 to relieve the water pressure that

has been increased due to the placement and expansion of the bags. A pump (not shown) may be used to further aid in the removal of water from between the bags.

[0056] In some of the embodiments of methods disclosed herein, the earth comprises at least one of weak alluvial soils, silts, clay, peat, hog fuel, wood chips, and water saturated soils. It should be understood that each method disclosed herein can incorporate all the characteristics of the other methods. Weak soils may have Standard Penetration Test blow counts (N-values) of between 0 to 10, for further example 0-8.

[0057] In the embodiments of the methods disclosed herein, the expandable polymeric resin may be expanding polymeric resin that comprises a high density, closed cell expanding two component polyurethane foam system. The resin may be hydro-insensitive. In some embodiments, the polymeric resin is a high density, two-part, closed cell expanding polymeric resin system, such as a polyurethane system which is injected into the confinement bag or array of confinement bags. The particular foam system used may be tailored to meet specific design applications relating to tensile strength, compressive strength, shear strength, flexural strength and other structural characteristics to meet the specific design applications of the controlled foam densification system. It is also possible to use other expandable substances having similar properties.

[0058] The expansion rate of the freely blown polymeric resin system is known as is the approximate relationship of the expanding polymeric resin system under confinement in a weak soils condition and hence the amount of resin can be pre-estimated to minimize resin usage and maximize soils densification around the confinement bag or array of confinement bags.

[0059] The shape and size of containment bags, constructed of natural or synthetic fibers for example, will be determined depending upon the soils conditions. The weaker the soil's condition, the larger the containment bag may be in both width and depth. The containment bags will typically not be symmetrical in shape to enhance the stability of the filled bag in the weak soils as well as enhance any "friction" effect the containment bag may have. The containment bags may be designed to meet specific soils needs, for example using a containment bag in a specifically weak soil strata that has been designed to more so compact the weak soil as compared to the soils above and below the weak strata.

[0060] In some embodiments of the methods disclosed therein, various placements of bags as support stacks may be employed. The grid for placement of the expanding stabilization members for densifying soils under any structure will depend upon the structure and the weakness of the soils, and to what depth the weak soils exist at. For example, for densifying soils beneath a railroad track a typical grid may be a staggered grid pattern under each track at four foot intervals to a depth of twelve feet comprising an array of three hour-glass shaped containment bags one on top of the other. In some embodiments, testing is carried out on the soil layers below the ground surface to determine exactly where to place the bags.

[0061] Referring to Fig. 1, the diameter of the drill stem 36 and the sacrificial drill head 38 may be variable in dimension. Referring to Fig. 2, in that the drill head will be sacrificed (left at the bottom of the hole), the bag or array of bags complete with injection tube can be inserted into the vacant drill stem and then the drill stem removed leaving the bag or array of bags in the weak soils.

[0062] As described above, in some embodiments the expandable polymeric resin used may be an expandable polymeric resin. A positive benefit of this is that expanding polymeric resin systems set up extremely quickly and allow for immediate use of the structure shortly after completion of the soils densification. Although it is recognized that because of the expansive nature of these resin systems the containment bags may rupture, this should not materially effect the densification of the soils around the containment bag because of the rapidity with which the resins set up. Referring to Fig. 5, the pre-determined amount of expandable polymeric resin 25 may be selected to rupture the bag 10. Rupturing forms one or more resin pockets 27 that extend from bag 10 and help to stabilize the array in soil.

[0063] A further positive benefit of the foam bag containment system used to densify weak base soils is that the expanding polymer resin is light weight, for example in the range of 300 lbs per cubic meter. Thus, the use of expandable polymeric resin does not contribute a severe weight or over-burden effect on the weak soils being densified. Further, in embodiments where the polymer resin is a closed cell material, water permeation is not a consideration. This is a significant factor in the event the containment bag splits and the

weak soils being treated are saturated, since such ruptured supports will not lose their function, namely to compress and compact the adjacent soils.

[0064] In some embodiments of these methods, the first bag and second bag are injected with expandable polymeric resin until full. Referring to Fig. 7, any number of bags may be used with the methods disclosed herein, for example four bags 10A-D as illustrated. Referring to Fig. 12, the methods disclosed herein may be used to strengthen earth 14 in support of a railroad track 97 on ground surface 16. As illustrated, the bags may be placed adjacent the railroad track 97, in order to not disturb the track itself. In other embodiments, a hole may be drilled directly underneath the tracks 97, and the bag or bags inserted through the hole and injected. Thus, the methods disclosed herein may be carried out with minimal obstruction to surface activities.

[0065] In a further method illustrated in Fig. 23, in a stage 126 a geotechnical survey is carried out on weak soils to determine a pattern or profile of soil weakness. Referring to Fig. 12, an exemplary profile 131 is indicated of the soil weakness of the soils of Fig. 12. The profile 131 illustrates the relative weakness of the soil, which may be plotted using for example negative N-values obtained at spaced intervals below the surface 16. As an illustration, region 132 corresponds to layer 48, indicating a weak region or layer of soil relative to the surrounding regions 134 and 136. In a stage 128 (shown in Fig. 23), a bag or stack of bags (for example bags 10, 12) is placed in the weak soils. The bag or stack of bags is selected to have a shape that conforms to the soil weakness profile 131, such that a portion of the bag or stack of bags placed in a weaker layer of the weak soils has a greater diameter than another portion of the bag or stack of bags placed in a stronger layer of the weak soils. For example, bag 10 is selected to have a portion (illustrated as portion 64) that has a greater diameter than portion 67. Portion 64 is placed in the weaker region 132, while portion 67 is placed in stronger region 134. The bag or stack of bags is then injected in stage 130 (shown in Fig. 23) with an expanding polymeric resin to compress the weak soils around the bag or stack of bags. The soil weakness profile will have at least one weak region adjacent at least one stronger region, and this will mean that the bags will have at least one larger diameter portion adjacent a smaller diameter portion. In some embodiments the larger diameter portion (for example portion 64) placed in the weaker layer forms a supportive bridge

between stronger layers of soil, for example regions 134 and 136. In other embodiments, the stronger layer (for example region 140) may be clamped by two large diameter portions (for example portions 64 and 70 of bag 12) positioned in surrounding weak regions, such as regions 138 and 134, respectively. A smaller diameter portion (for example portion 69) is positioned in the strong region. The portions with greater diameter thus form wedges that provide the bridging or clamping function. Referring to Fig. 19, as illustrated, the portion placed in the weaker layer may comprise at least one bag, for example bag 10. As illustrated, the shape of the bag or bags does not have to exactly conform to the profile, but should be tailored maximize the strength of the weak soils.

[0066] Some methods disclosed herein relate to the use of pre-designed containment bags dependent upon geo-technical data received on the weak soils to be treated. The containment elements will be irregular in shape to more effectively densify the weak soils and also to provide additional vertical strength to the ground surface.

[0067] In the claims, the word “comprising” is used in its inclusive sense and does not exclude other elements being present. The indefinite article “a” before a claim feature does not exclude more than one of the feature being present. Each one of the individual features described here may be used in one or more embodiments and is not, by virtue only of being described here, to be construed as essential to all embodiments as defined by the claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of imparting strength to earth in support of a ground surface comprising:
 - placing a bag in the earth under the ground surface, the bag having a first end oriented towards the ground surface, a second end opposite the first end, and a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth located above and below the wedge portion when the bag is filled; and
 - injecting expandable polymeric resin into the bag to at least partially fill the bag to compress earth around the bag.
2. The method of claim 1 in which the wedge portion is defined annularly around an axis of the bag.
3. The method of any one of claims 1 - claim 2 in which the bag has at least two wedge portions.
4. The method of any one of claims 1 - 3 in which the bag has an hourglass cross sectional contour from the first end to the second end.
5. The method of any one of claims 1 - 4 in which the wedge portion is oriented in a first strata of earth over a second strata, the first strata of earth being weaker than the second strata.
6. The method of any one of claims 1 - 5 in which the wedge portion comprises a sloped ledge.

7. The method of any one of claims 1 - 6 in which the wedge portion comprises an arm.
8. The method of claims 1 - 7 in which the expandable polymeric resin is injected through a valved opening in the bag.
9. The method of claim 8 in which placing the bag in the earth under the ground surface further comprises placing the bag in the earth with an injector inserted through the opening of the bag, and in which expandable polymeric resin is injected into the bag from an injection end of the injector.
10. The method of claim 9 further comprising removing the injection end from the bag.
11. The method of any one of claims 1 - 10 in which expandable polymeric resin is injected into the bag in a pre-determined amount selected to rupture the bag.
12. The method of any one of claims 1 - 11 further comprising injecting gas to at least partially fill the bag prior to injecting expandable polymeric resin into the bag.
13. The method of claims 1 - 12 in which the earth comprises at least one of weak alluvial soils, silts, clay, peat, hog fuel, wood chips, and water saturated soils.
14. The method of any one of claims 1 - 13 in which the earth supports a railroad track on the ground surface.

15. A bag for use in imparting strength to earth in support of a ground surface comprising:
- at least an opening;
 - a first end and a second end opposed the first end; and
 - a cross sectional contour from the first end to the second end that includes at least one wedge portion extendable laterally into surrounding earth above and below the wedge portion when the bag is filled and in earth under the ground surface.
16. The bag of claim 15 in which the opening further comprises a backflow prevention valve to prevent material contained within the bag from passing out of the bag when the opening is unobstructed.
17. The bag of any one of claims 15 - 16 in which a portion of the cross sectional contour is tapered conically outwards from the base.
18. A structural support for a ground surface comprising the bag of any one of claims 15 - 17 located in earth under the ground surface and at least partially filled with expandable polymeric resin to compress the earth around the bag.
19. The method of any one of claims 15 - 18 in which the earth comprises at least one of weak alluvial soils, silts, clay, peat, hog fuel, wood chips, and water saturated soils.
20. The method of any one of claims 15 - 19 in which the earth supports a railroad track on the ground surface.

21. A bag for use in imparting strength to earth in support of a ground surface comprising:
- at least an opening;
 - a first end and a base end opposed the first end; and
 - a cross sectional contour from the base end to the first end, at least a portion of the cross sectional contour being configured to taper conically outwards from the base end when the bag is filled.
22. A method of imparting strength to earth in support of a ground surface comprising:
- placing a bag in the earth under the ground surface, the bag having a base end, a first end opposite the base end, and a cross sectional contour from the base end to the first end, at least a portion of the cross sectional contour being configured to taper conically outwards from the base end when the bag is filled; and
 - injecting expandable polymeric resin into the bag to at least partially fill the bag to compress earth around the bag.

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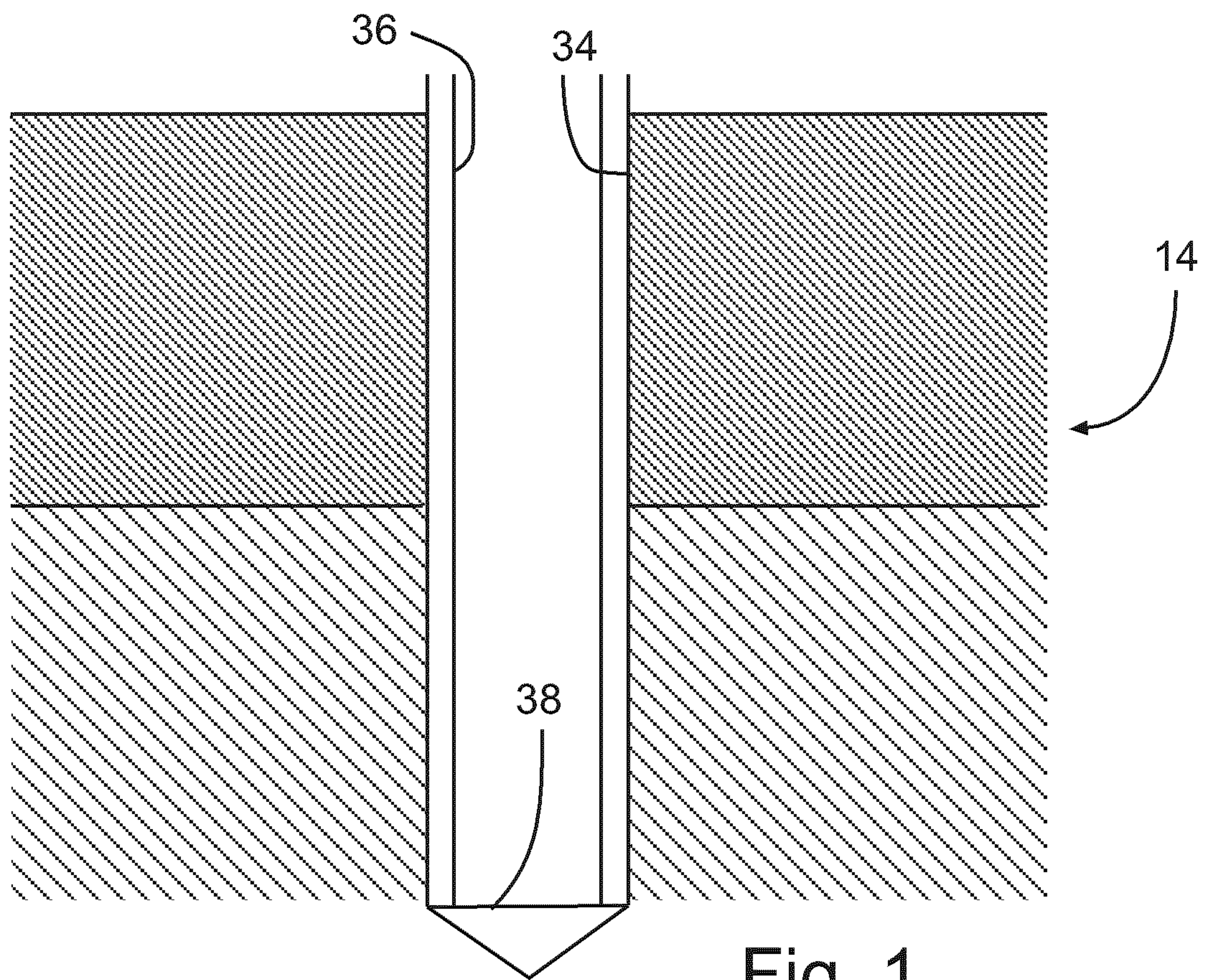


Fig. 1

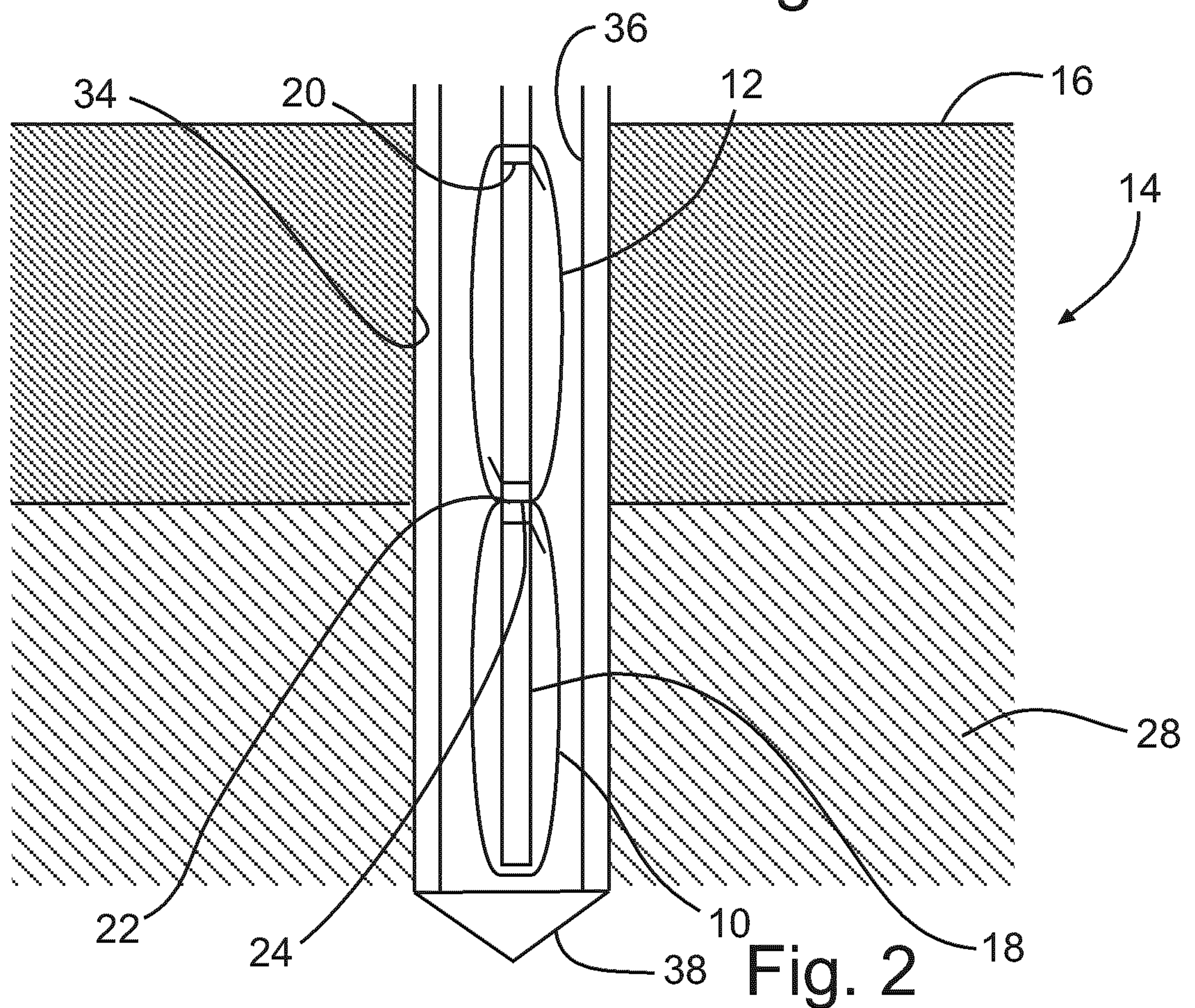
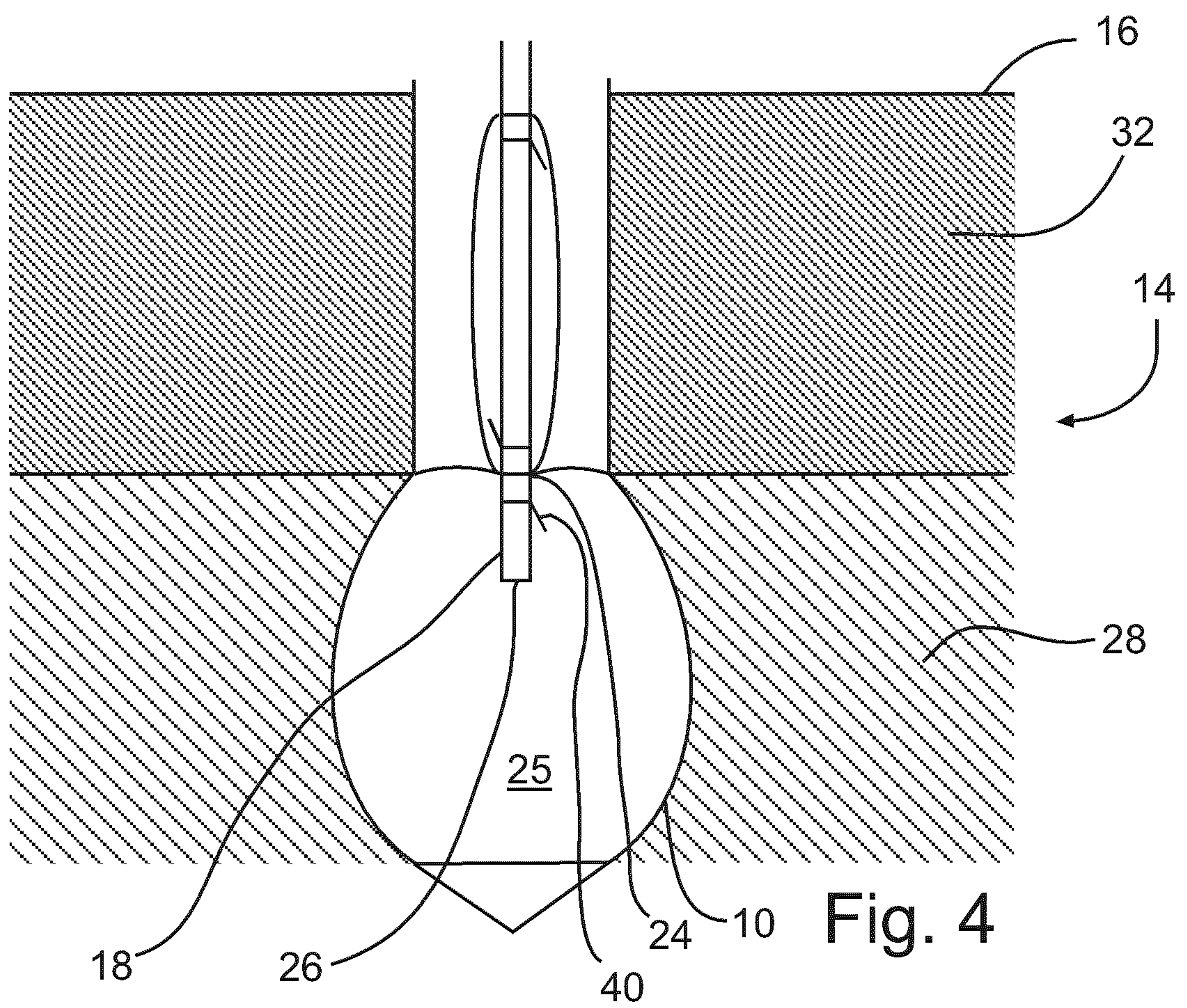
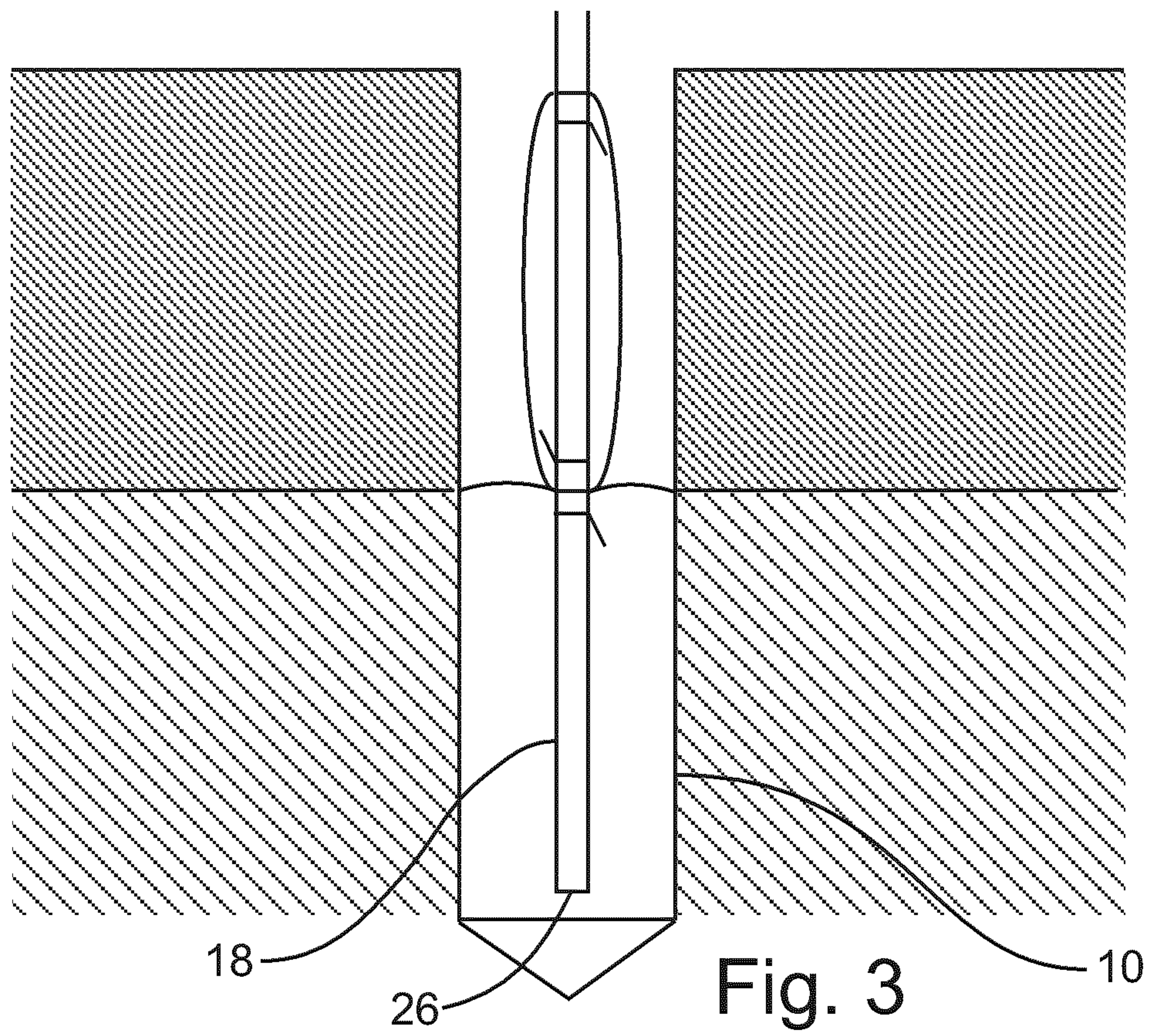
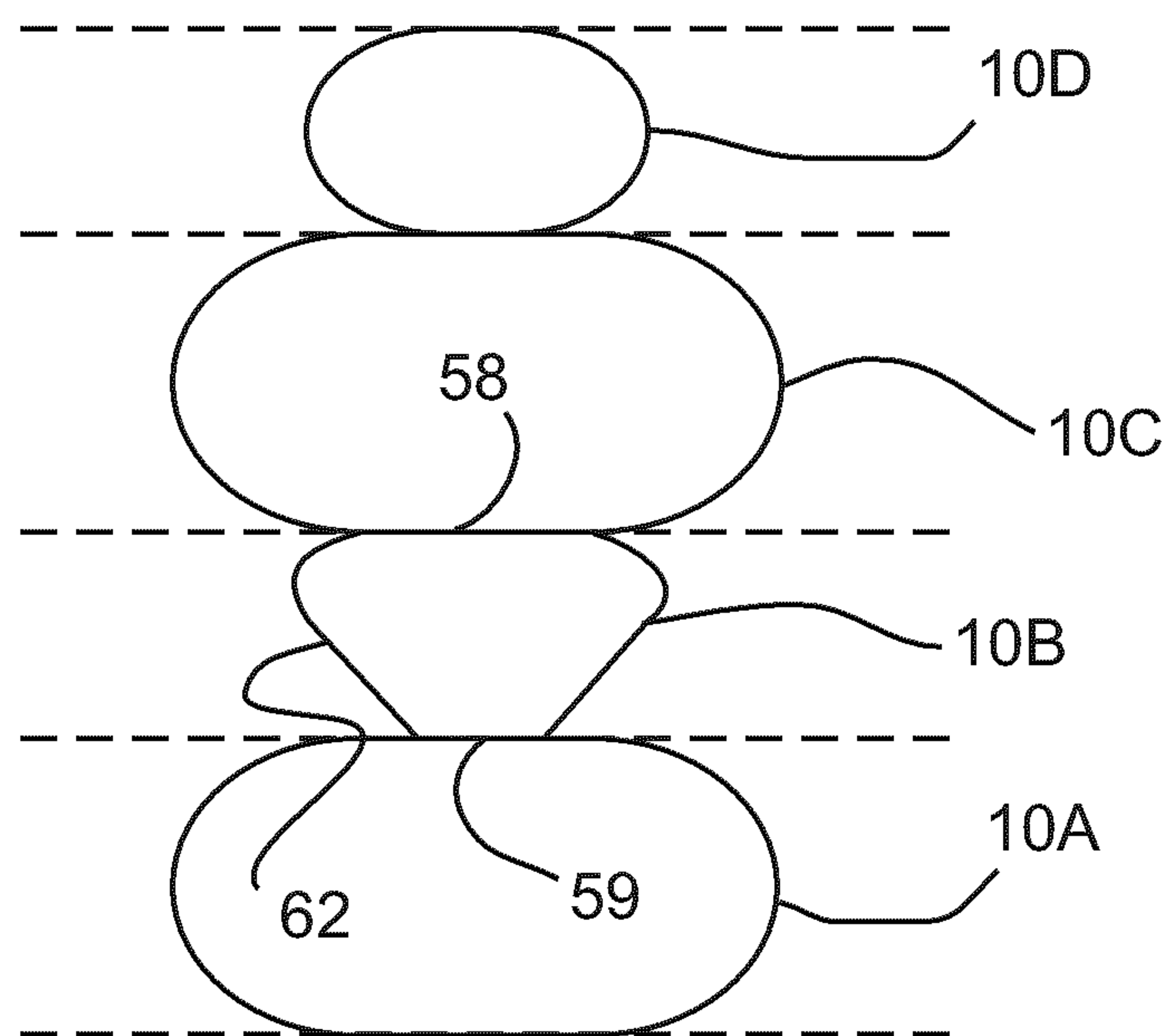
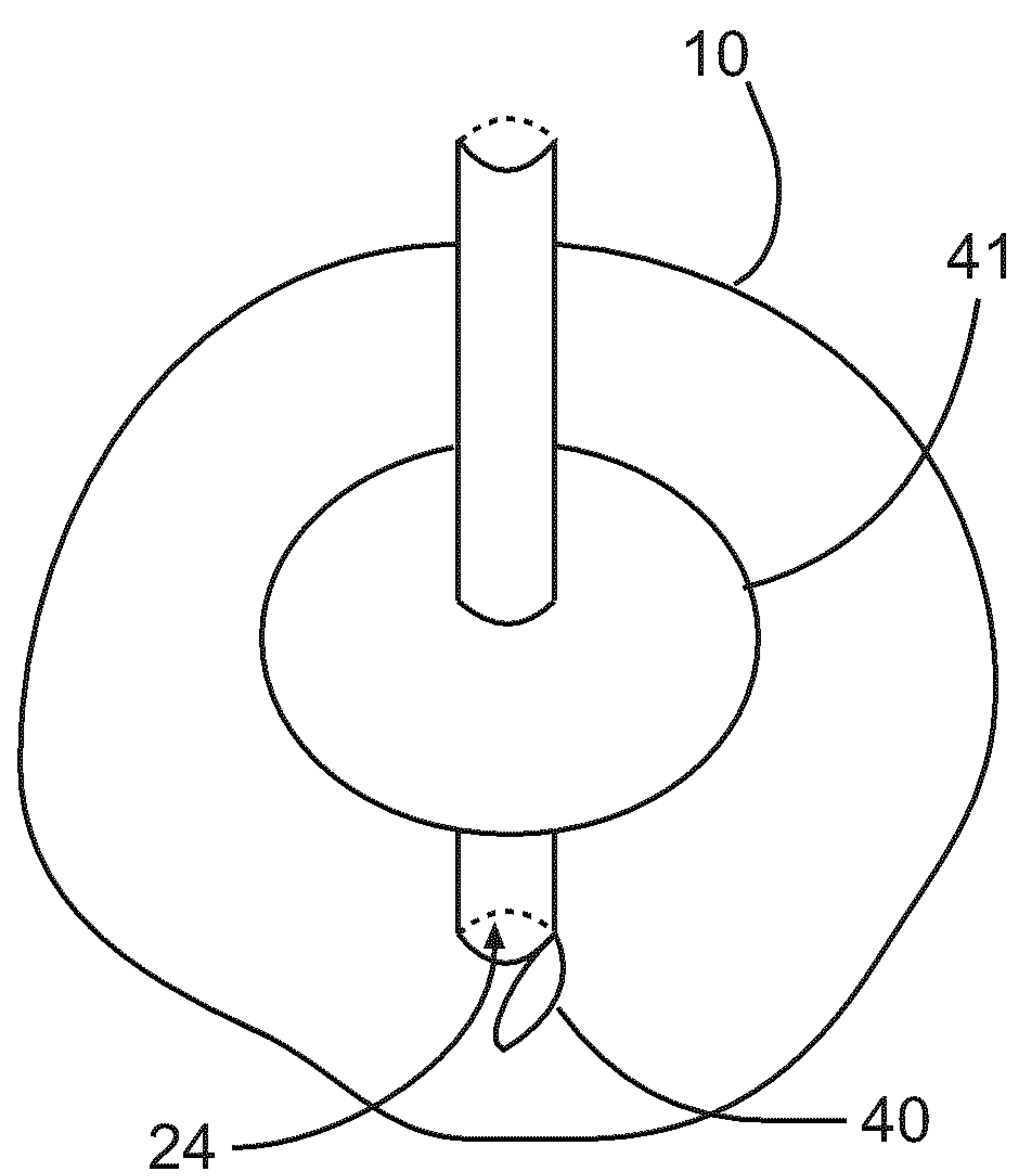
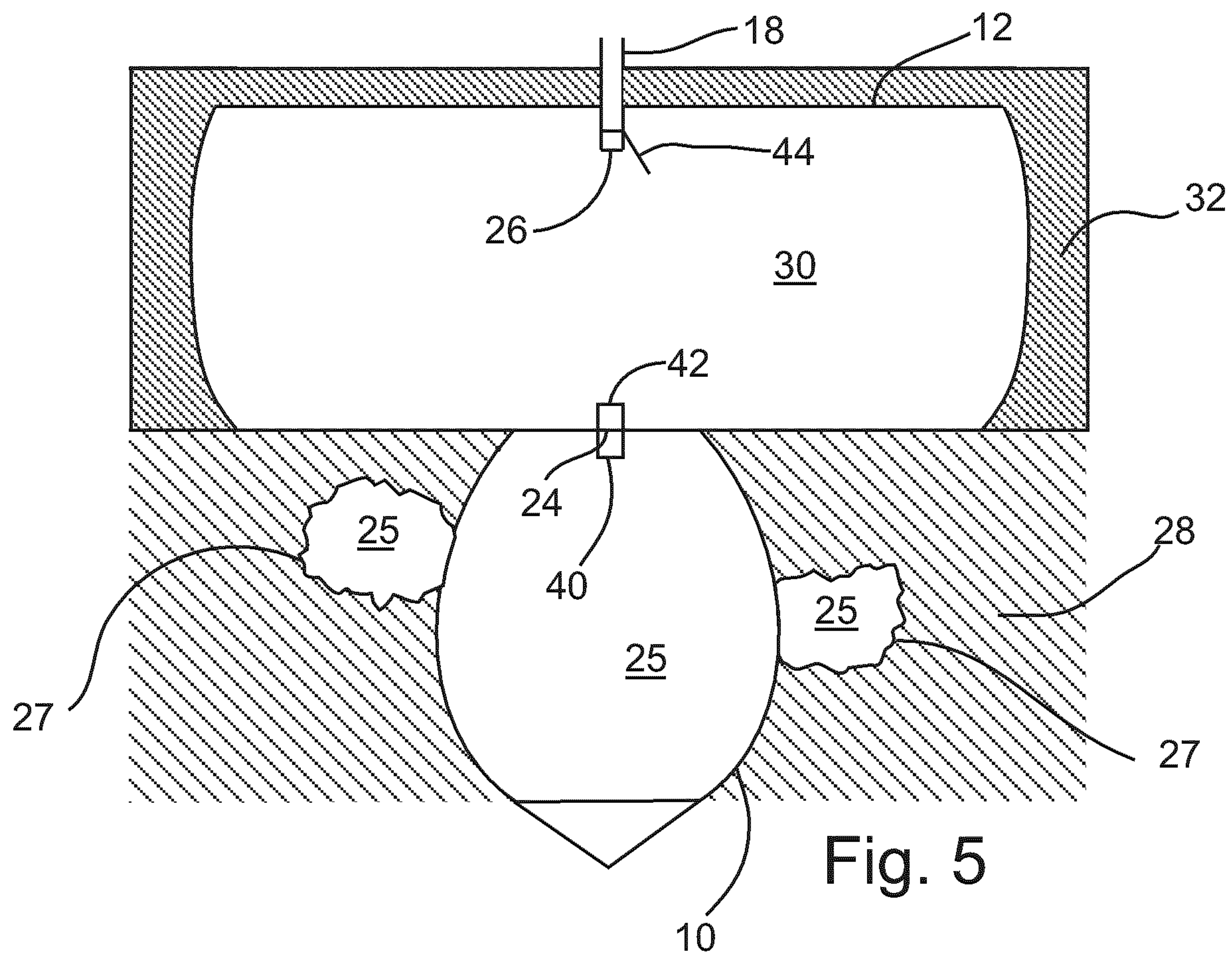


Fig. 2

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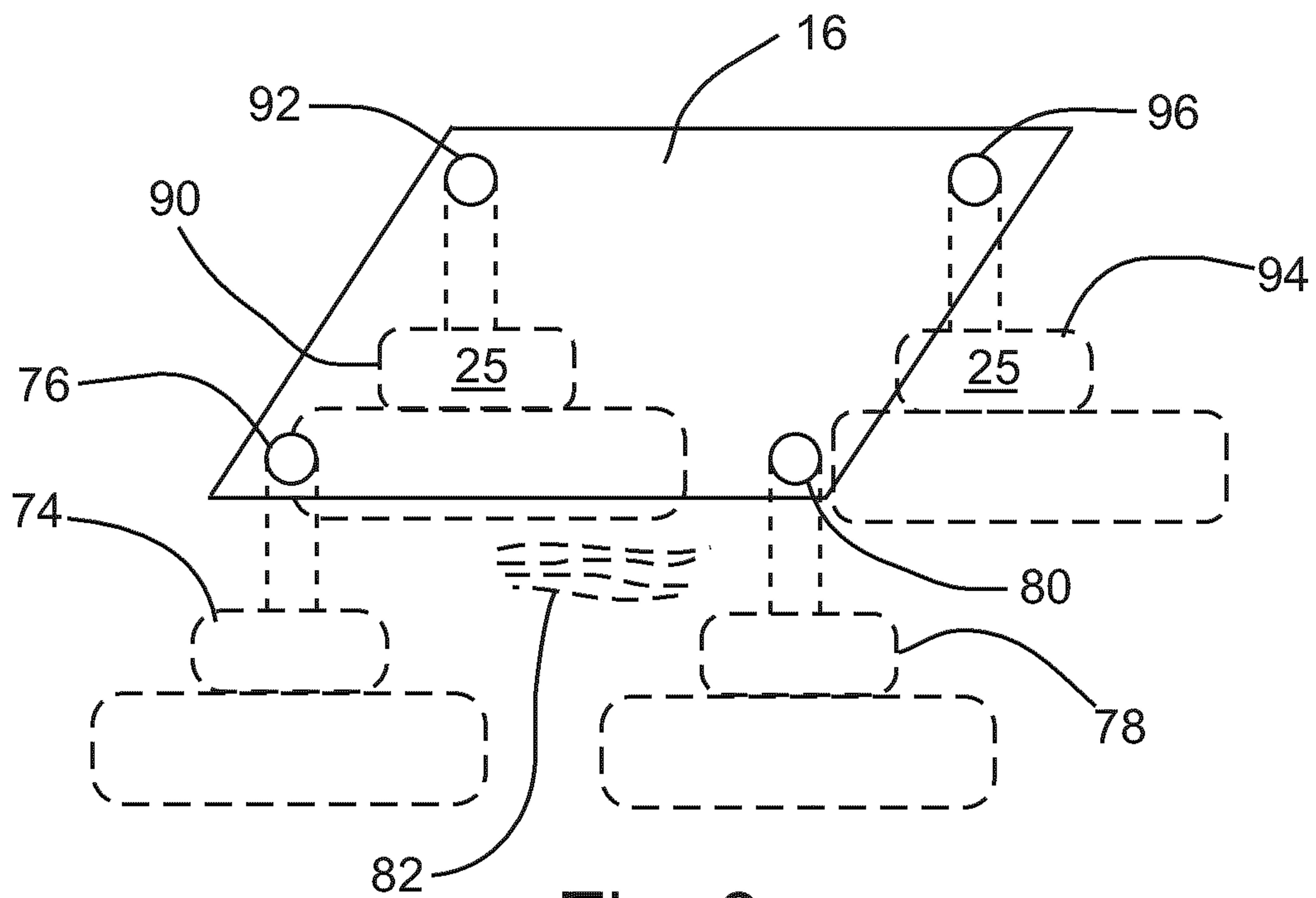


Fig. 8

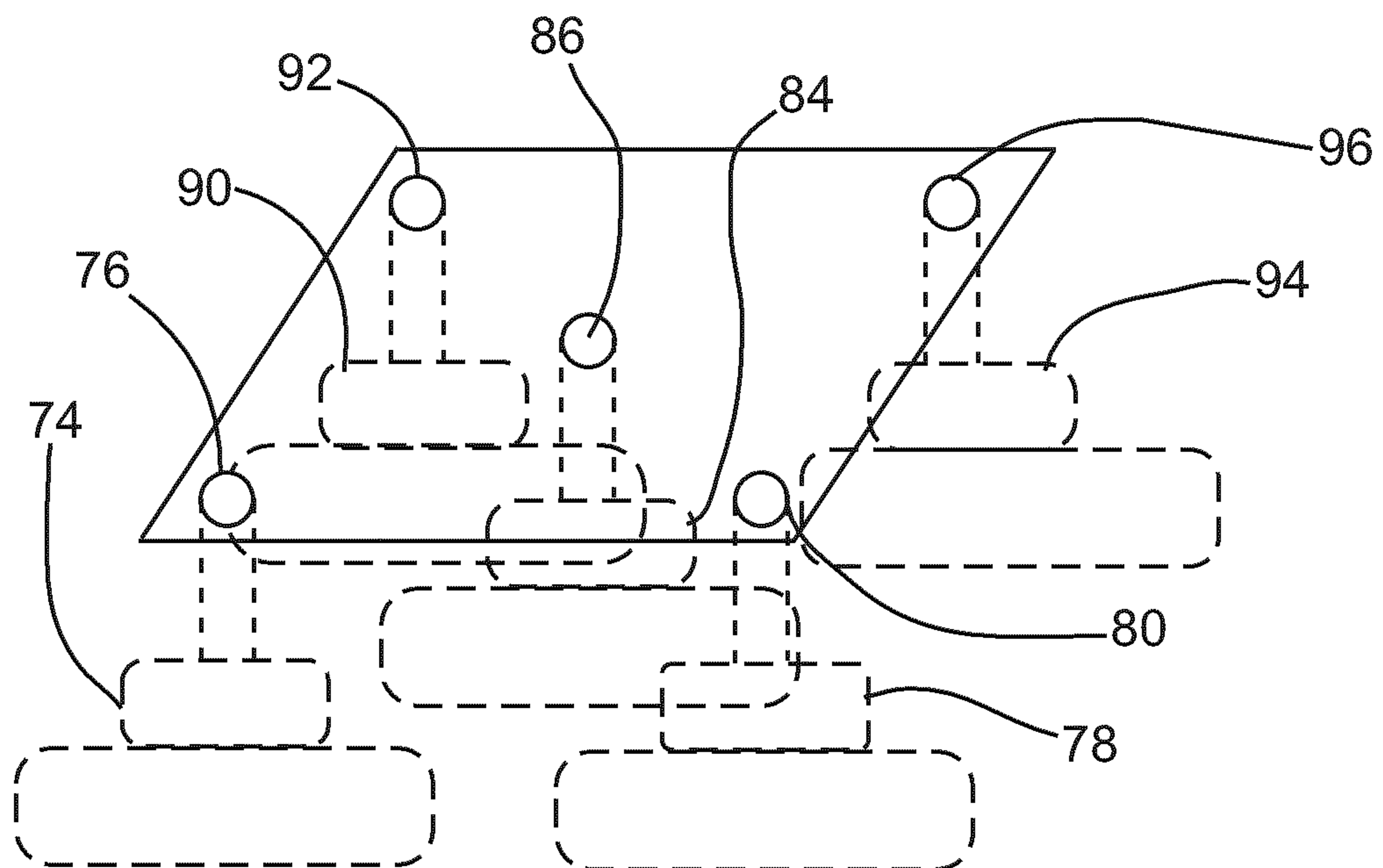


Fig. 9

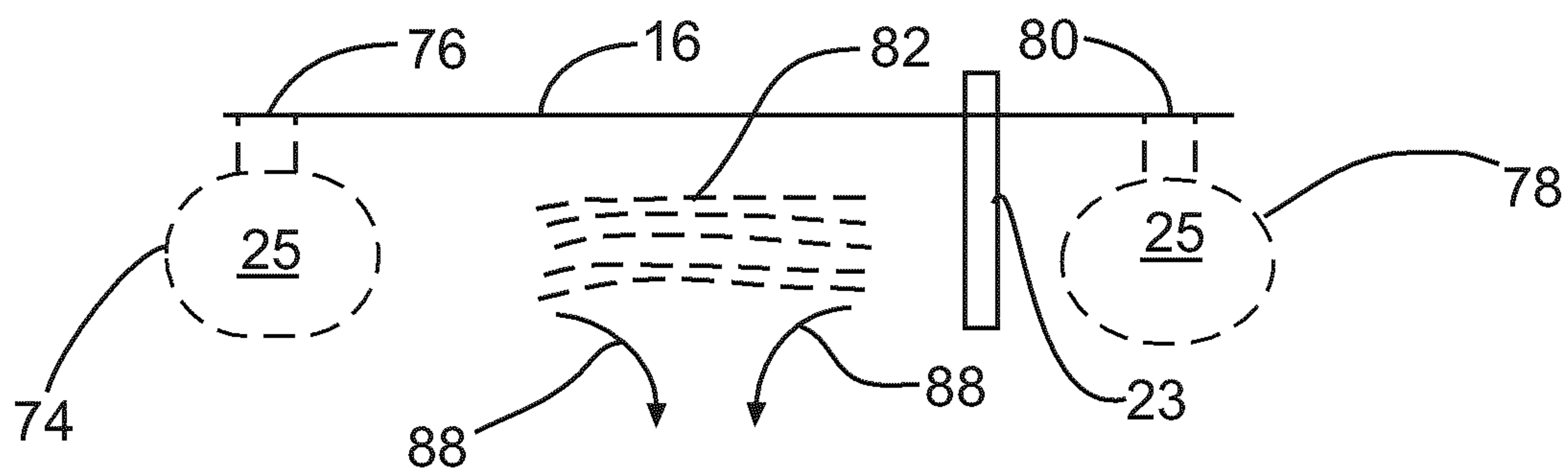


Fig. 10

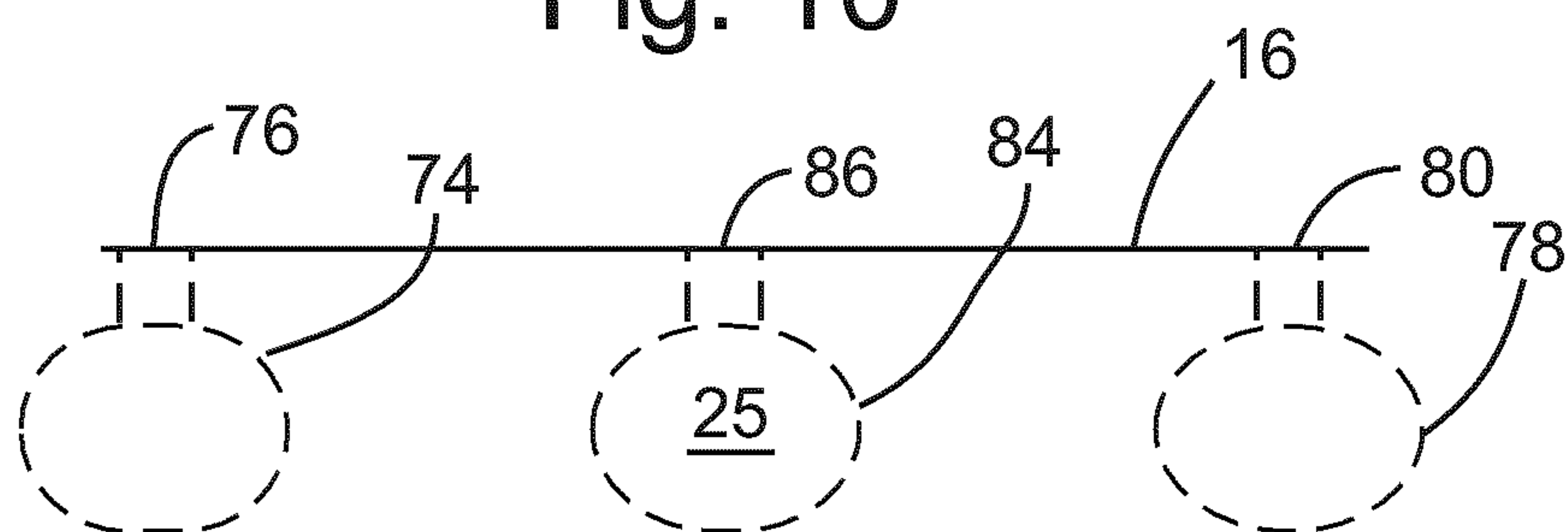
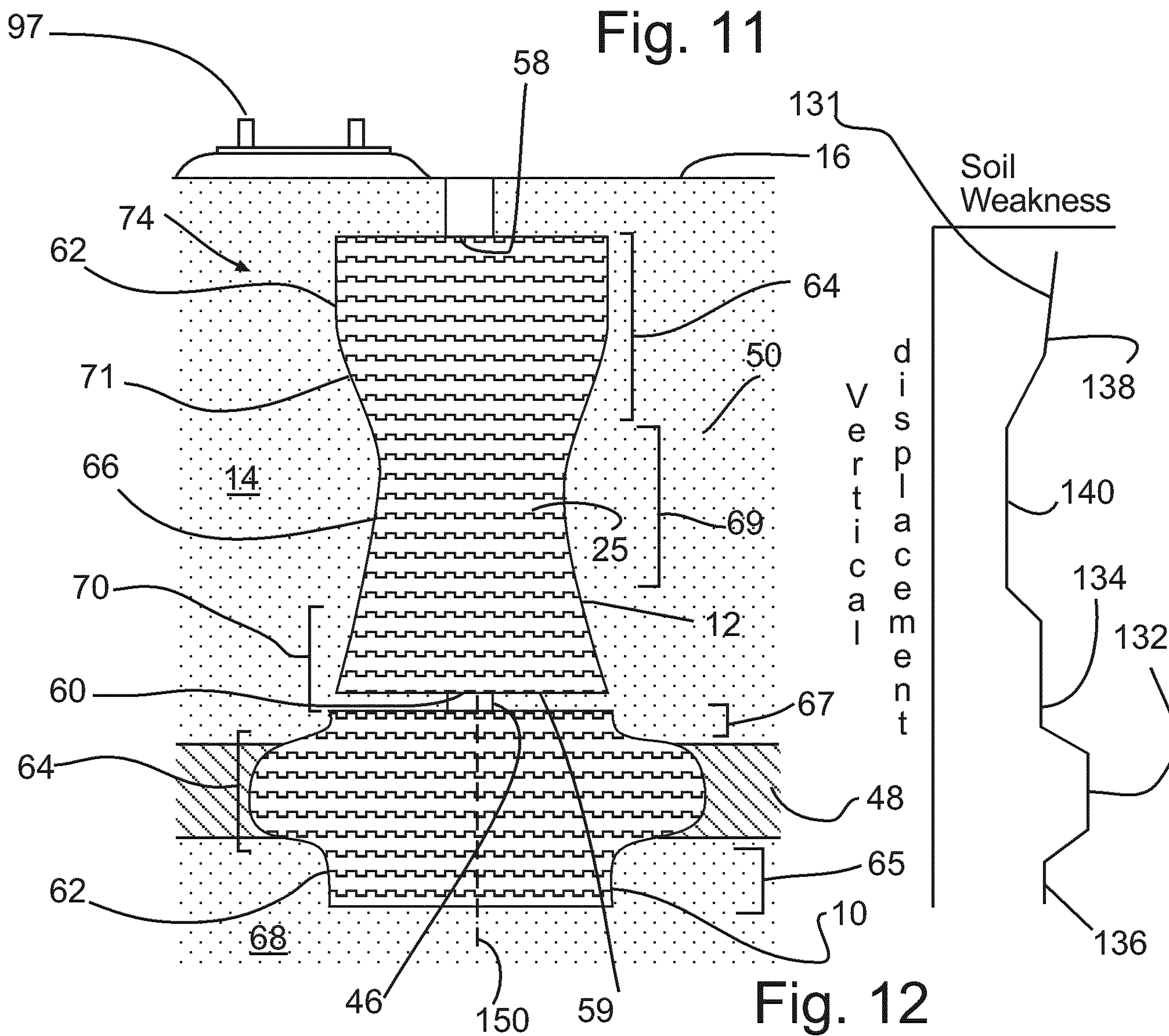


Fig. 11



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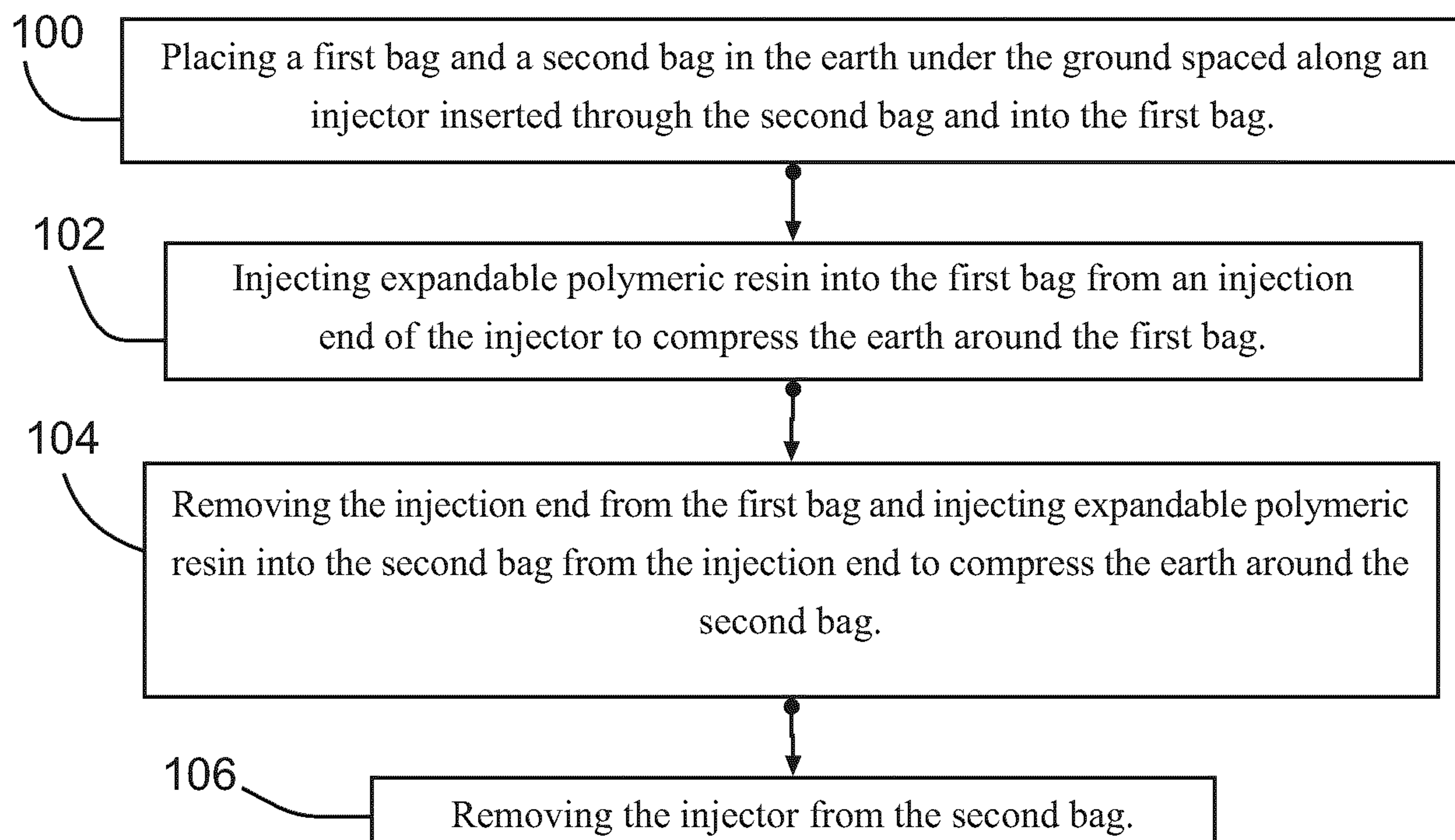


Fig. 13

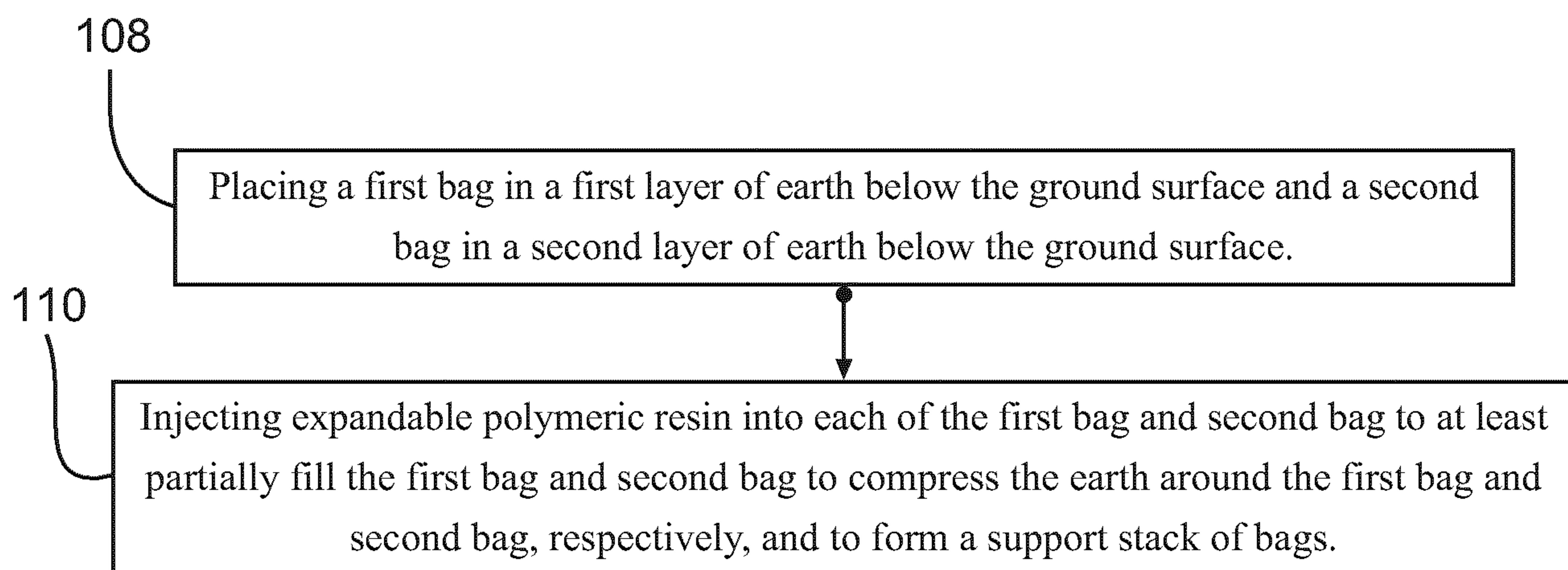


Fig. 14

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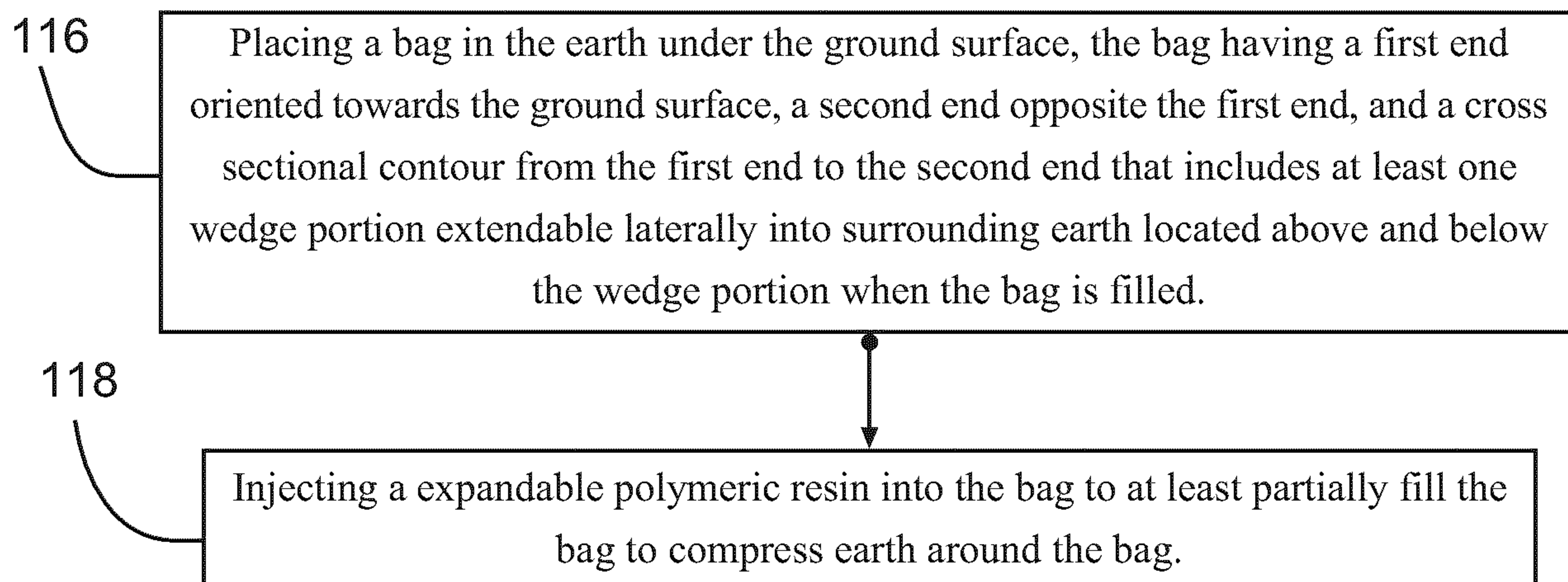


Fig. 15

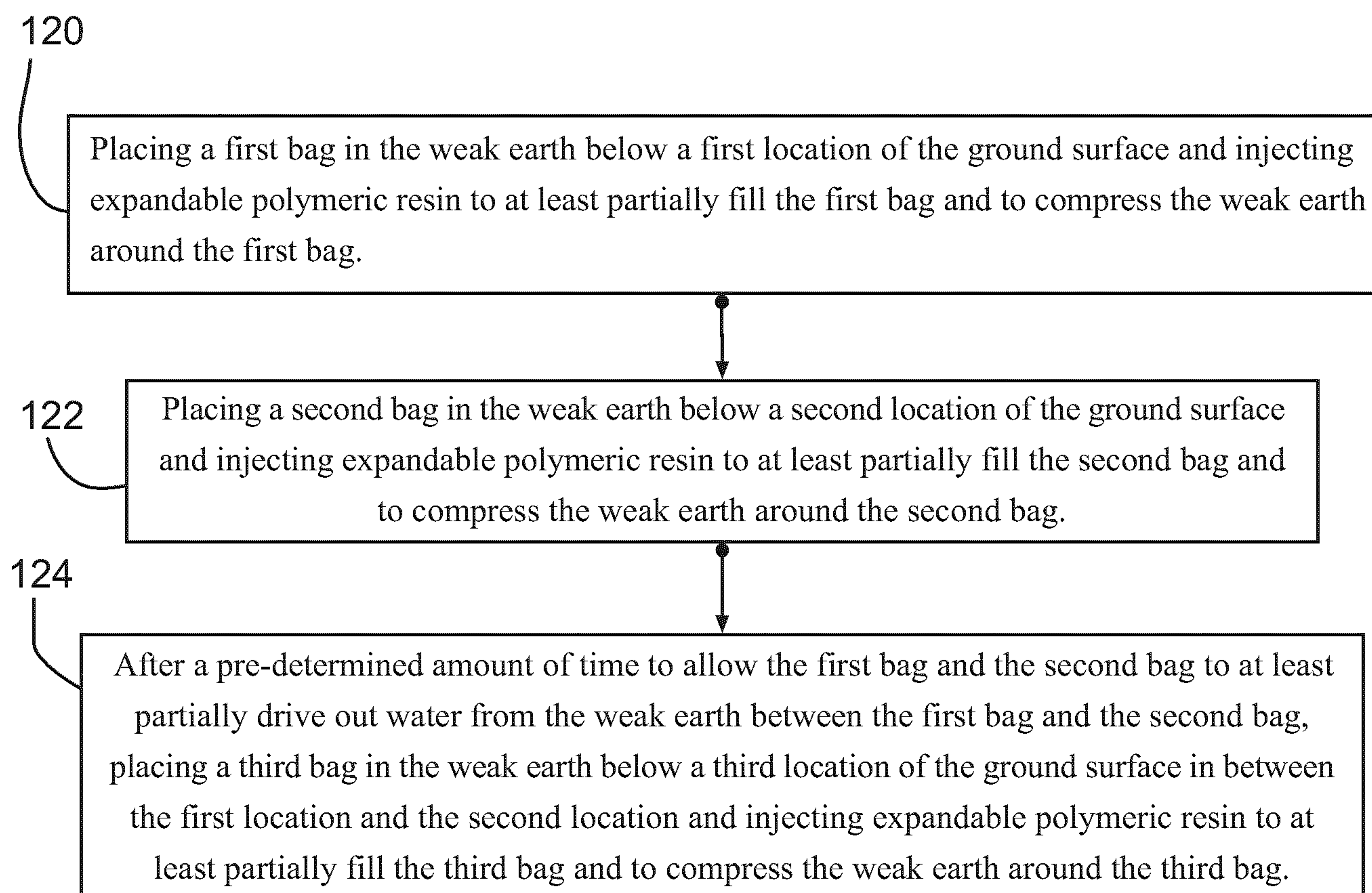


Fig. 16

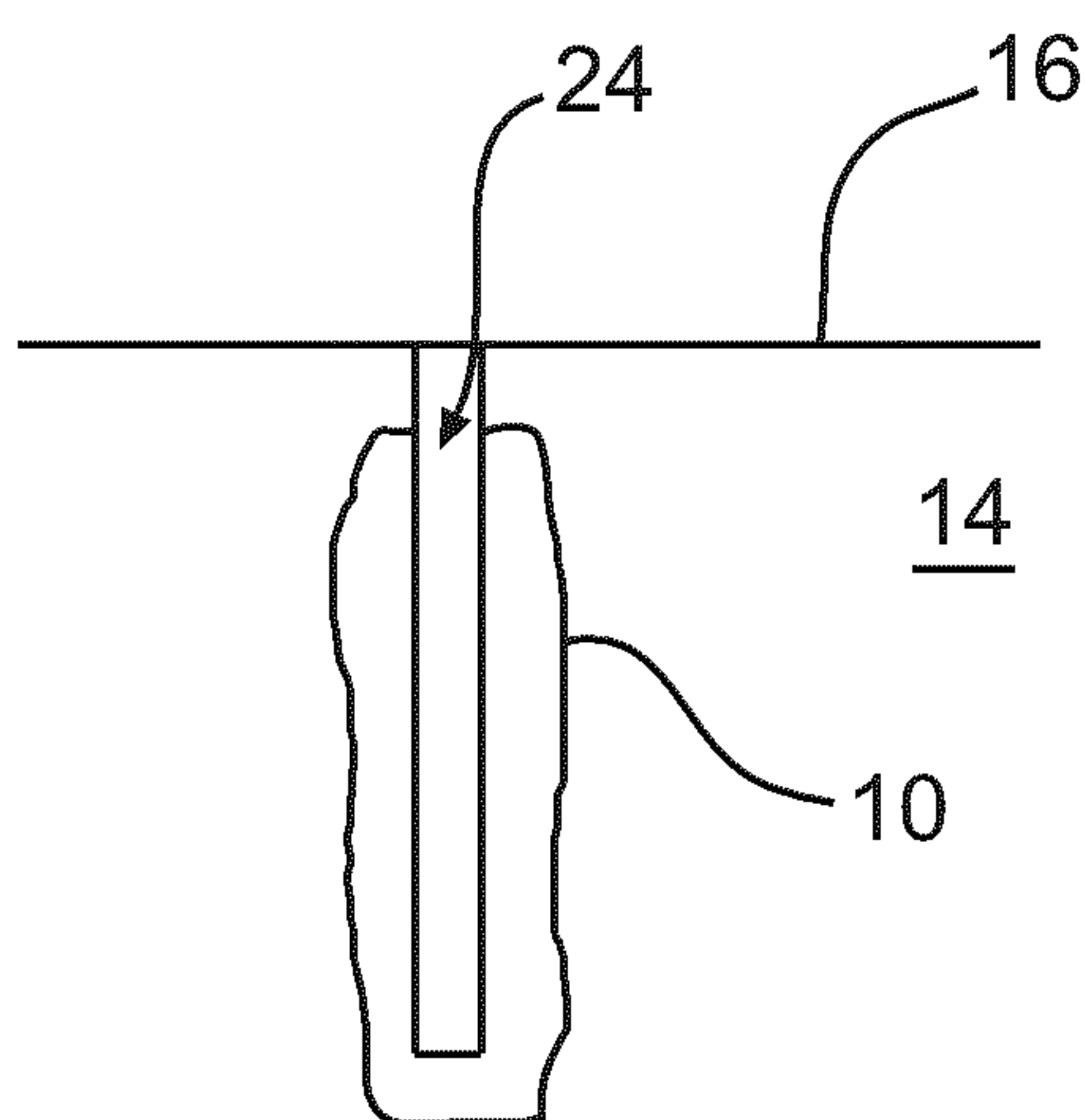


Fig. 17A

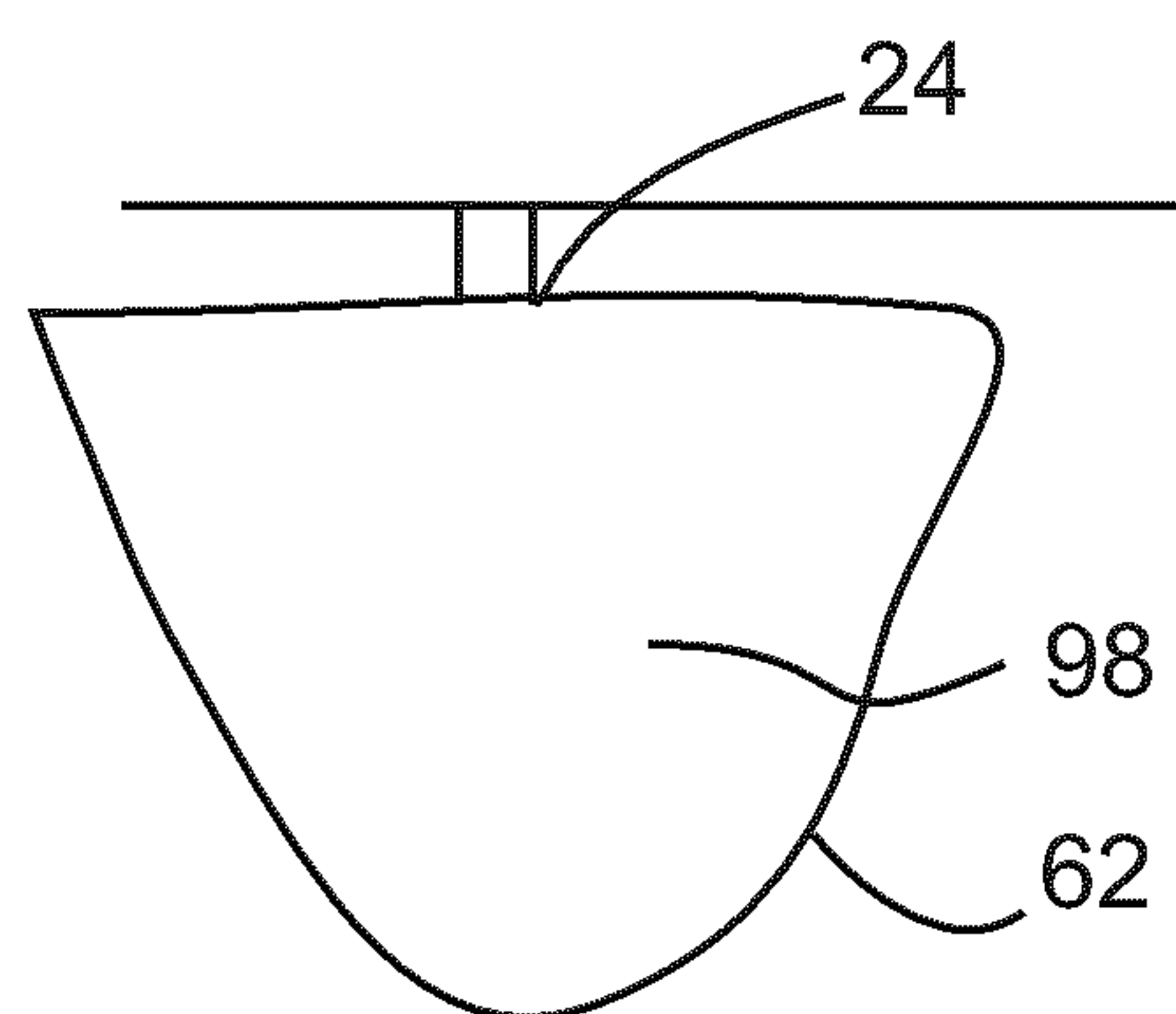


Fig. 17B

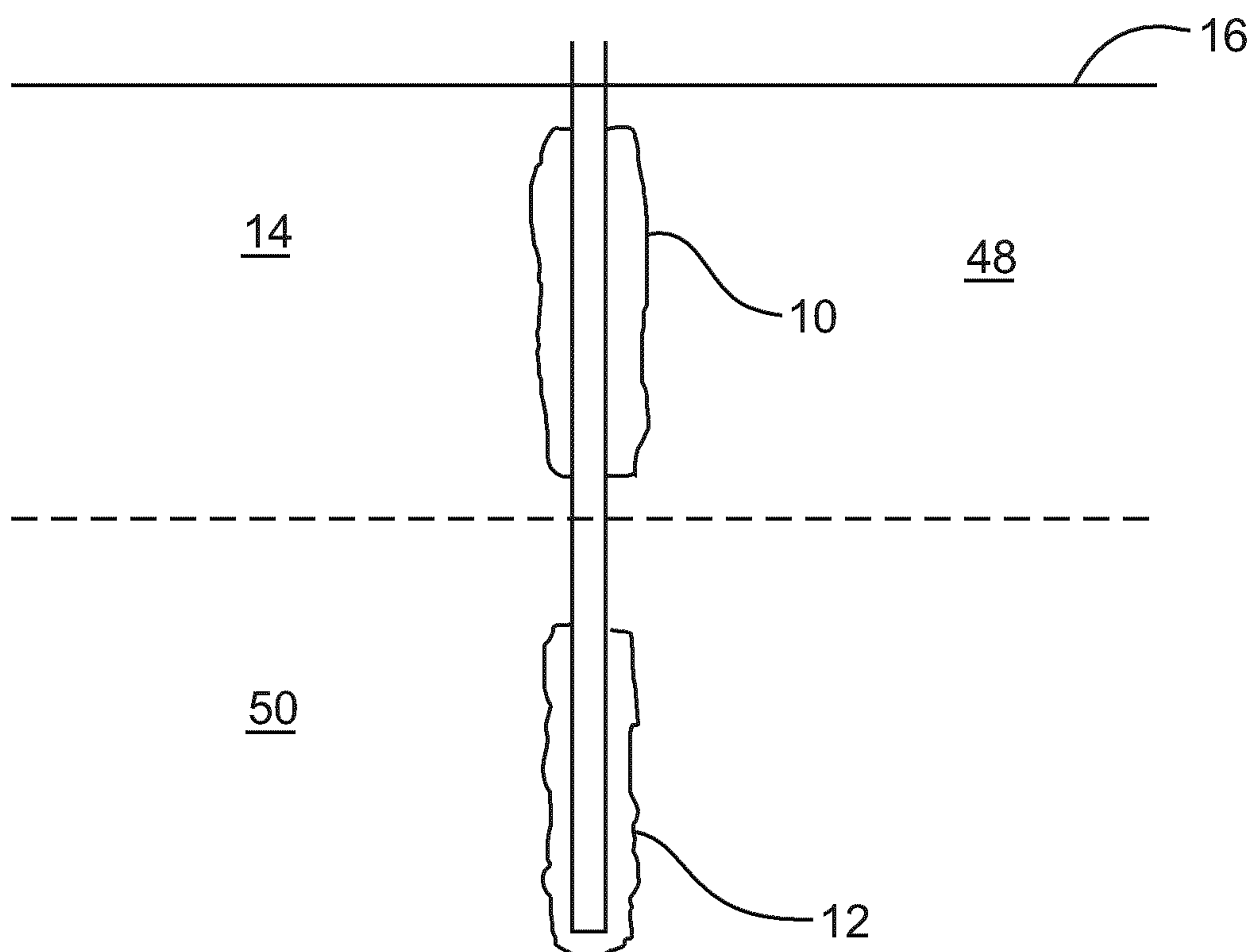
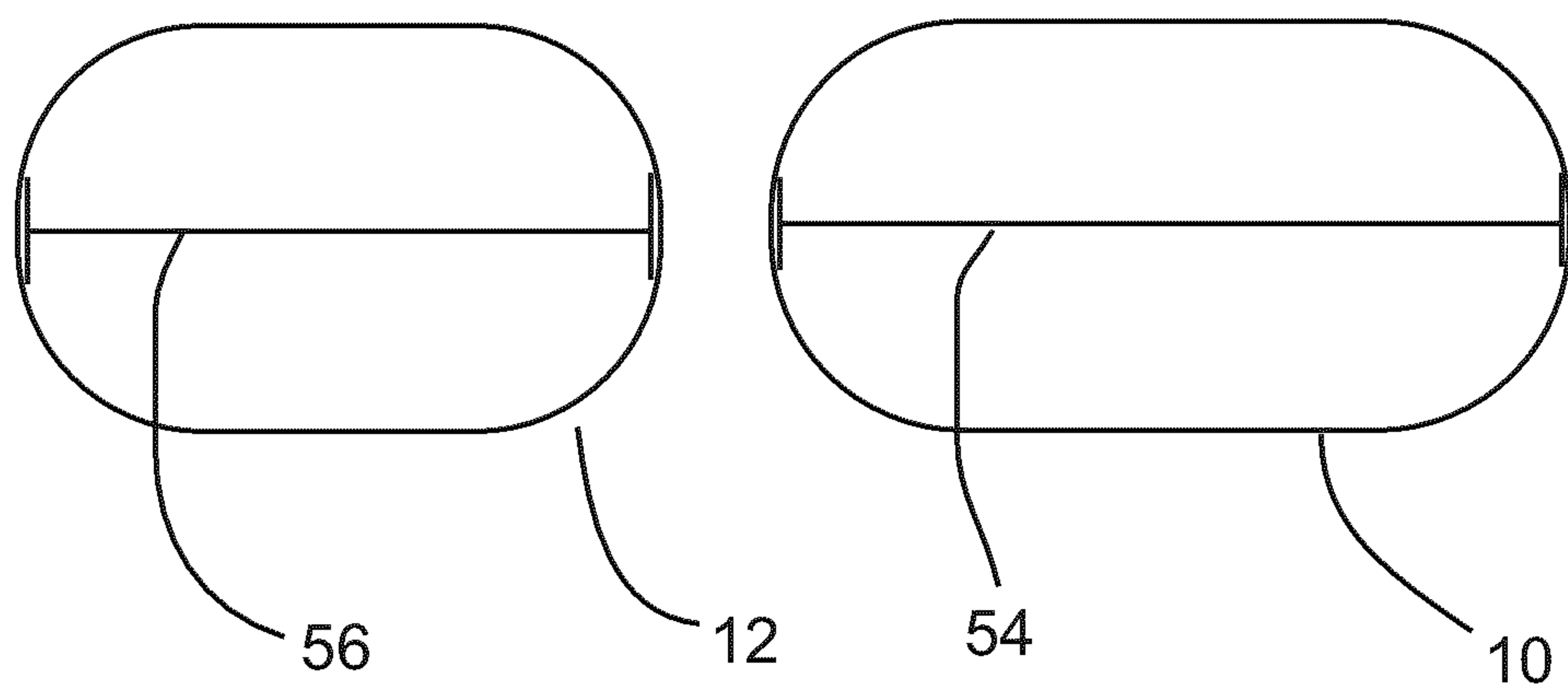
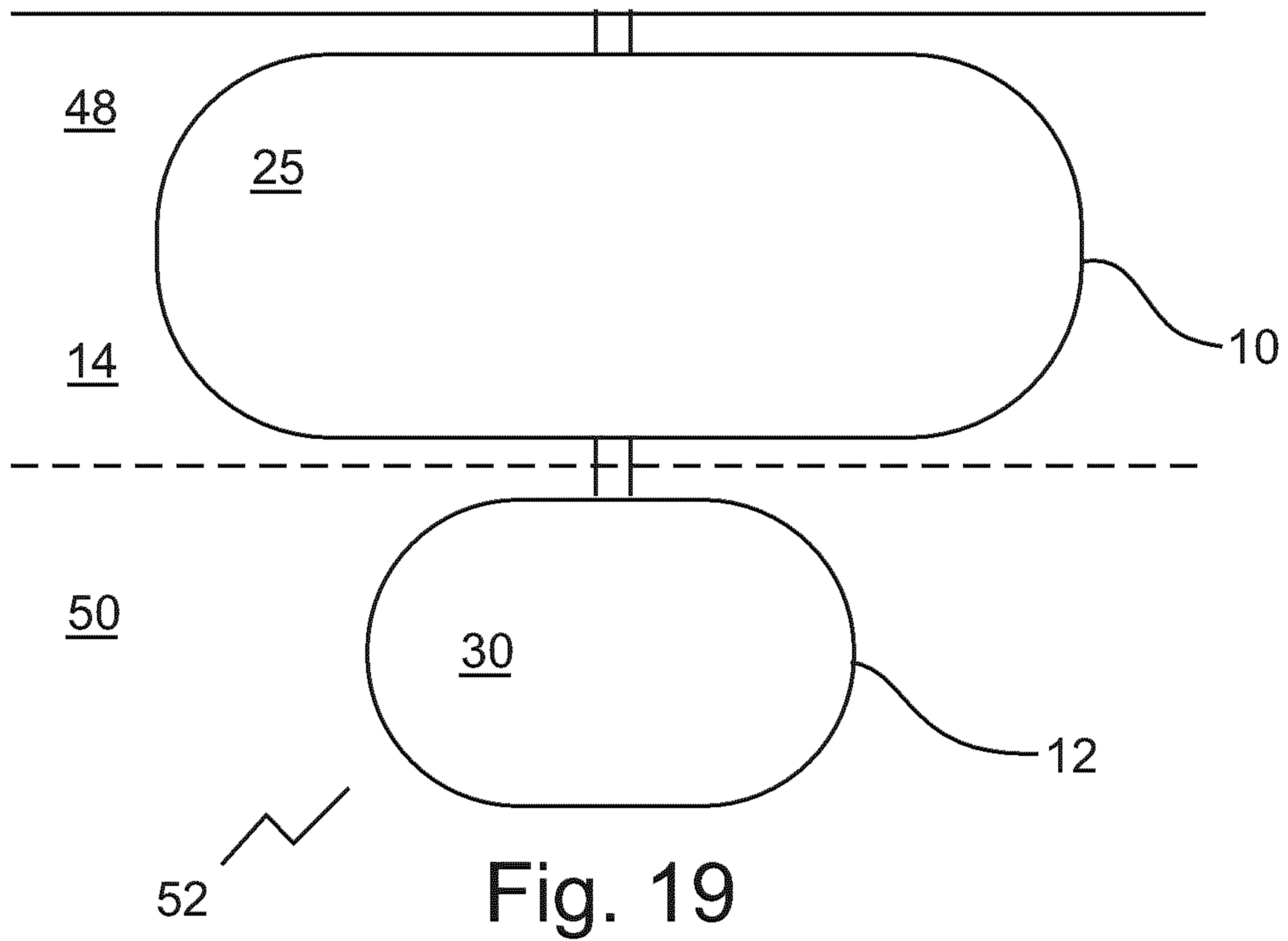


Fig. 18

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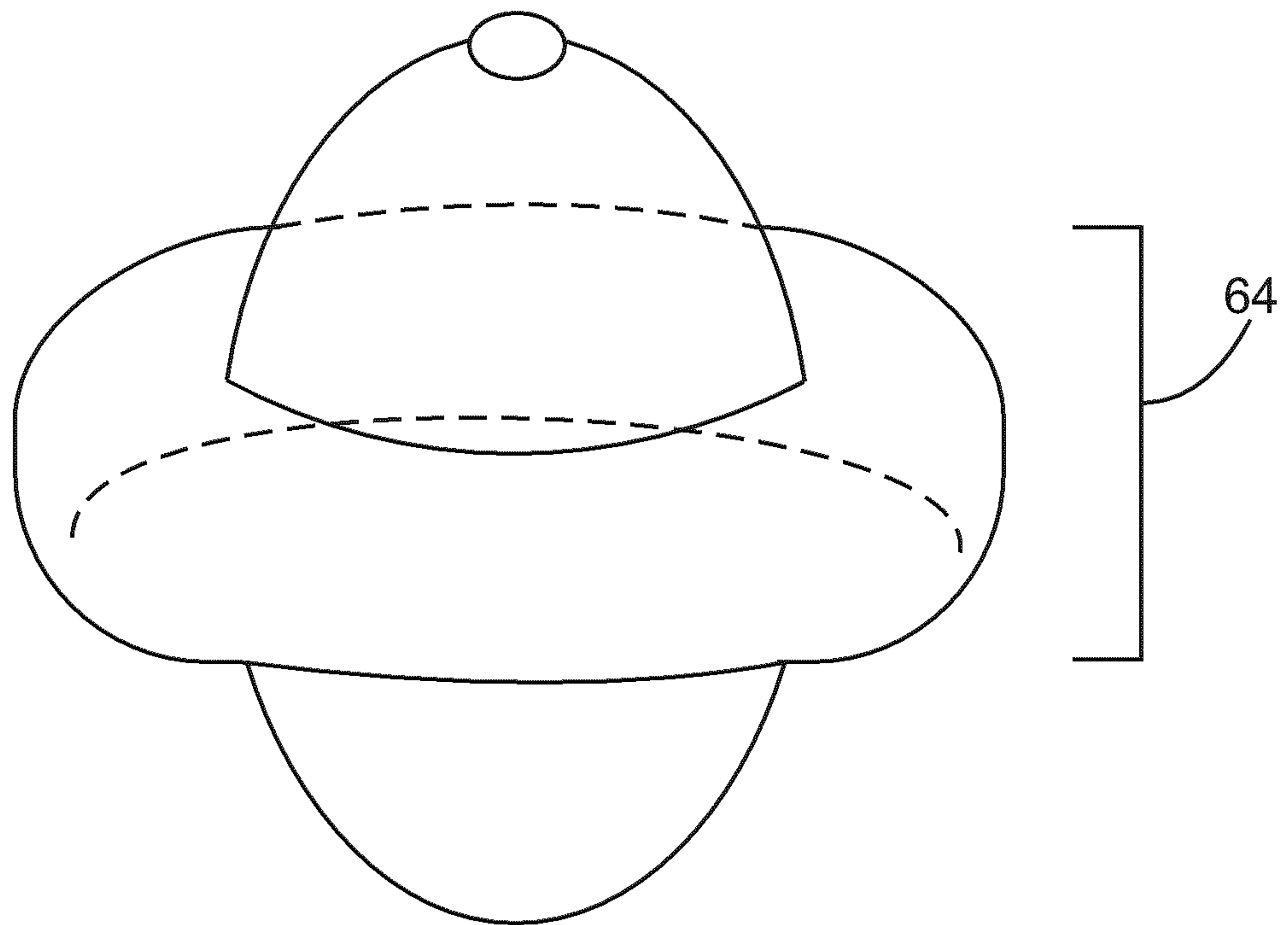


Fig. 21

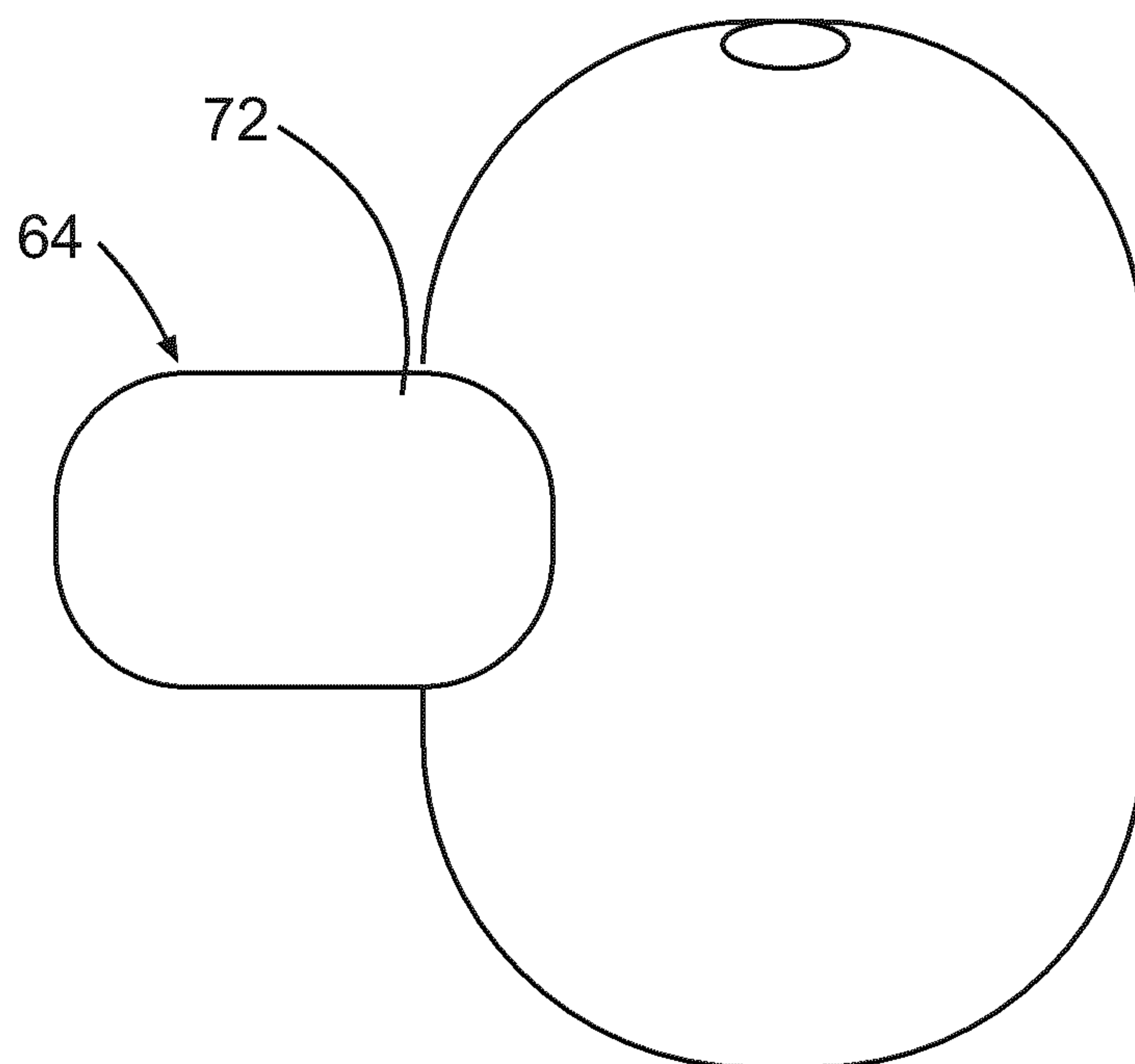


Fig. 22

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Carrying out a geotechnical survey on the weak soils to determine a soil weakness profile.

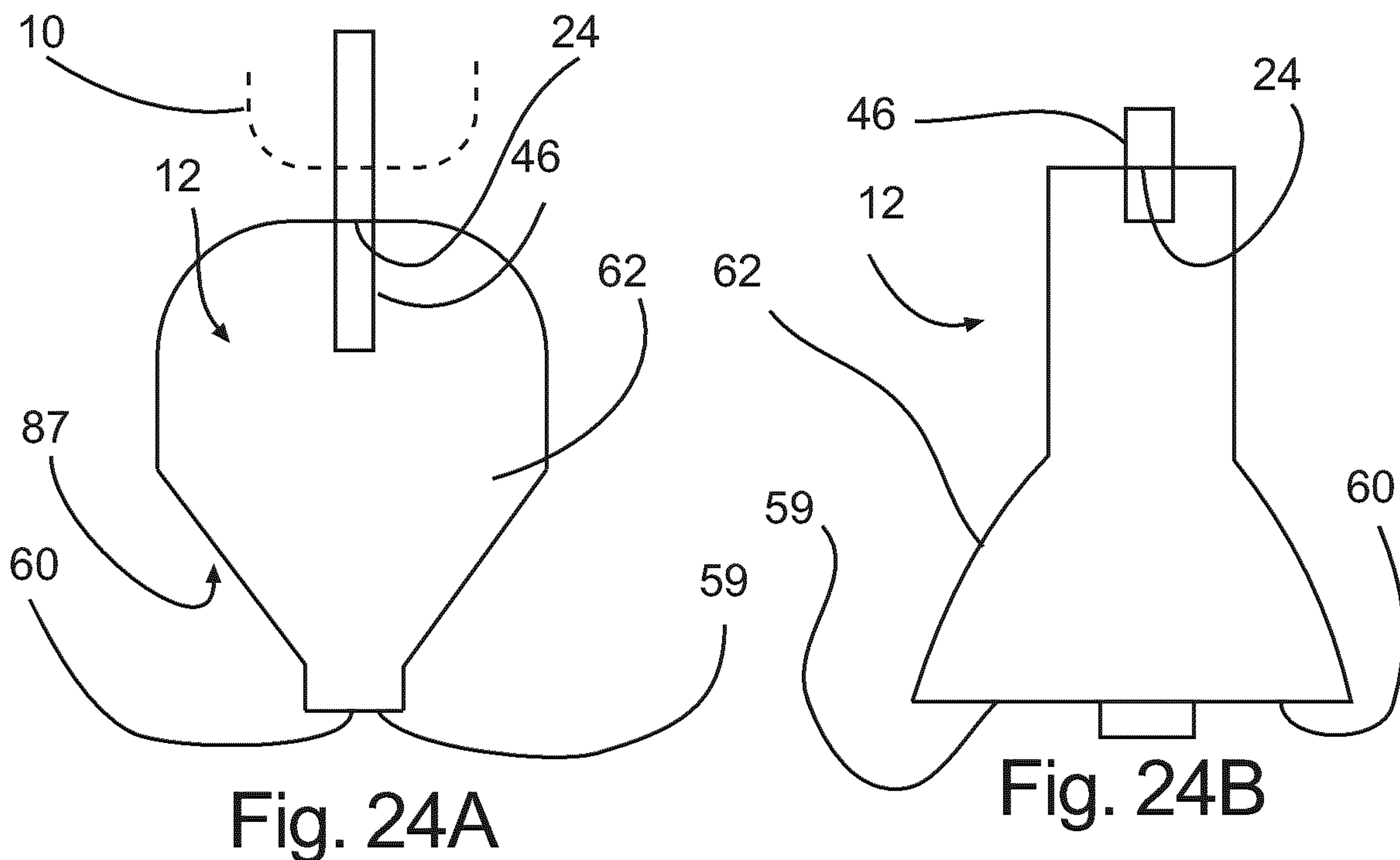
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Placing a bag or stack of bags in the weak soils, the bag or stack of bags being selected to have a shape that conforms to the soil weakness profile such that a portion of the bag or stack of bags placed in a weaker layer of the weak soils has a greater diameter than another portion of the bag or stack of bags placed in a stronger layer of the weak soils.

130

Injecting expanding polymeric resin into the bag or stack of bags to compress the weak soils around the bag or stack of bags.

Fig. 23



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Placing a bag in the earth under the ground surface, the bag having a base end, a first end opposite the base end, and a cross sectional contour from the base end to the first end, at least a portion of the cross sectional contour being configured to taper conically outwards from the base end when the bag is filled.

132



Injecting expandable polymeric resin into the bag to at least partially fill the bag to compress earth around the bag.

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Fig. 25

