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(54) DEVICE FOR MODIFYING A LAYER OF GRANULAR MEDIUM

(57) The present invention relates to a device configured to be disposed within a granular medium to raise a layer of said granular medium, the device comprising: a flexible envelope forming an internal volume; an inflatable element housed in the internal volume so as to be interposed between an upper surface and a lower surface of the envelope, the inflation and deflation of said element allowing the internal volume to be varied; an injection device configured to fill the inflatable element with a fluid; the device being configured to switch from a first configuration in which the inflatable element is inflated to occupy a first volume to a second configuration in which the inflatable element is inflated to occupy a second volume greater than the first volume so that the upper surface is deformed vertically in order to raise the layer of granular medium, and vice versa; the device further being configured to switch from the first or the second configuration to a third configuration in which the lower surface of the envelope is vertically deformed for allowing the device to ascend through the granular medium. The invention also relates to a method of deforming a layer of granular medium.

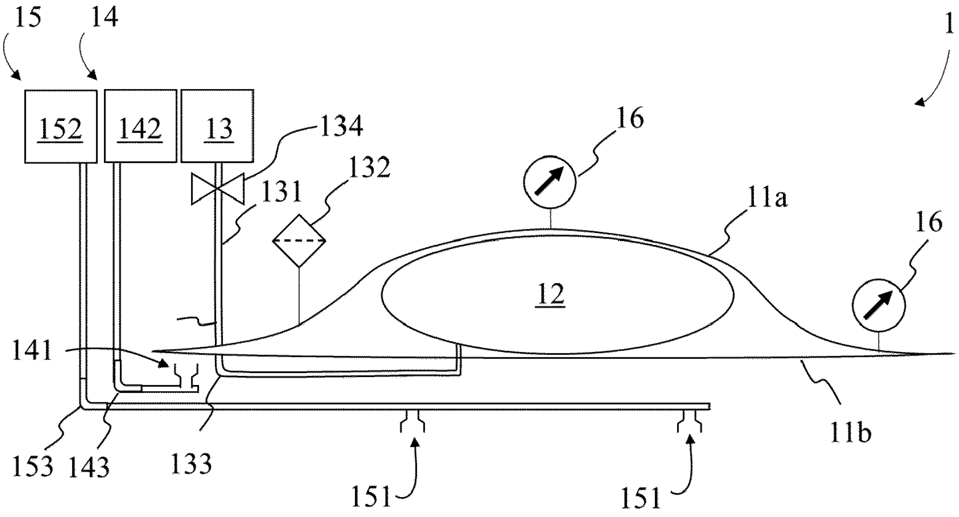


FIG. 1

Description

FIELD OF INVENTION

[0001] The present invention relates to a device configured to be disposed within a granular medium and to raise or lower a layer of said granular medium.

[0002] The present invention also relates to a method of deforming a layer of granular medium.

BACKGROUND OF INVENTION

[0003] The alteration of a seabed or a coastal area is of interest in several domains, both environmental (*e.g.*, beach nourishment, beach protection, creation of artificial reef to promote marine life), and recreational (*e.g.*, modifying the wave breaking such that it is suitable for aquatic sports, or modifying the topology of a beach to create pools, channels, dry zones, salients or tombolos).

[0004] It is desirable to obtain such alteration without transportation of materials on site, as this process is carbon intensive, expensive, and requires the use of heavy equipment which can damage the environment and cannot be used where space is limited or access routes are inappropriate.

[0005] Moreover, material transportation could have significant environmental consequences, including the travelling of the material from the initial deposition site to distant environments, depriving initial deposition site of material, or buying the local ecosystem under a thick layer of foreign material.

[0006] Therefore, there is a need of machines and methods for altering the shape of granular soils, especially sea-beds.

[0007] In this context, anchored submerged breakwaters, also called wave-breakers are known, for instance for the practice of surf.

[0008] However, the installation of this type of submerged wave-breakers is complex and require intervention of professional divers to anchor it to the seafloor. Furthermore, anchoring a structure under the sea is difficult, and removing the anchoring structure (for example before a storm) can also be a long and complex operation.

[0009] Moreover, this type of submerged wave-breakers is not suitable for places where currents are likely to occur, as they can be easily damaged by the currents and the waves.

[0010] Some attempts to overcome this problem have been made, including placing the submerged wave-breakers several meters below the lowest expected sea level. However, this is rarely possible in the practice. Furthermore, this solution hampers the use of the wave-breakers in intertidal zones, as they would represent a hazard for beach users at low tide, when there is little or no water over them.

[0011] It should also be mentioned that, in most contexts (for example in the swash zone), the currently available devices cannot be used for beach nourishment, as this involves raising and displacement of the sand.

[0012] Furthermore, these machines modify the wave breaking by displacing significant volumes of water. Therefore, they cannot be used in environments with small quantity of or no water (*e.g.*, shallow waters, river beds, or on the coast).

[0013] In this context, another type of wave-breaker is known, consisting of large rocks or large bags of sand placed on the seabed.

[0014] This type of wave-breaker is still likely to be damaged by storms, but it is more robust that the aforementioned type of wave-breaker.

[0015] Nevertheless, wave-breakers made of rocks or bags of sand are massive, expensive, and they have a large impact on the environment.

[0016] Moreover, they constitute a hazard for boats.

[0017] Furthermore, they cannot be used in shallow waters or intertidal zones, and they cannot adapt to wave height or to tides.

[0018] The objective of the present invention is to provide a device which solves the aforementioned drawbacks.

SUMMARY

[0019] It is an objective of the present invention to provide a device for modifying a granular medium, such as a seabed, a river bed, a lake or a coast, which is easy to install and operate.

[0020] Moreover, the present invention aims at providing device and methods which provide protection against currents and adverse weather, and which can leave the ground *(e.g.,* a seabed or a coast) free of obstruction, so that it does not interfere which other recreational or professional activities.

[0021] It is also an objective of the present invention to provide a device and a method of the aforementioned type which avoids operations that are damaging for the environment.

[0022] It is also an objective of the present invention to provide methods and devices for drying a portion of the seabed for environmental purposes, enabling the sea breeze to carry the dry sand towards the top of the beach, and for recreational purposes, for instance allowing users to lay on the sand.

[0023] It is also an objective of the present invention to provide methods and devices to modify the topology of a coastal area or reshape a seabed, in order to create pools, lagoons, channels, salients, tombolos and the like.

[0024] Furthermore, the present invention aims at providing a device which is versatile, and which can function in a wide number of different environments.

[0025] To this end, an object of the invention is a device configured to be disposed within a granular medium, such as sand or sediment, to raise a layer of said granular medium, the device comprising: a flexible envelope forming an internal volume; an inflatable element housed in the internal volume so as to be interposed between an upper surface and a lower surface of the envelope, the inflation and deflation of said element allowing the internal volume to be varied; an injection device configured to fill the inflatable element with a fluid; the device being configured to switch from a first configuration in which the inflatable element is inflated to occupy a first volume to a second configuration in which the inflatable element is inflated to occupy a second volume greater than the first volume so that the upper surface is deformed vertically in order to raise the layer of granular medium, and vice versa; the device being configured so that the lower surface remains substantially horizontal in the first and second configurations in order to maintain the device in position in the granular medium; the device further being configured to switch from the first or the second configuration to a third configuration in which the lower surface of the envelope is vertically deformed for allowing the device to ascend through the granular medium.

[0026] The ability to switch from the first to the second configuration, and vice versa, allows to raise or lower the layer of granular medium.

[0027] Advantageously, the device does not need to be secured to the granular media with dedicated devices. Therefore, it is versatile and can be installed in granular media such as mud, in which fixation means such as pegs or anchors do not work.

[0028] Moreover, the third configuration allows the device to move vertically within the granular media in which it is buried, thereby permitting to position it more superficially, or make it emerge therefrom, without human intervention.

[0029] The device advantageously allows to provide beach nourishment without rendering the coast a construction zone, by creating sandbars when the currents favor onshore sediment transport, for example in the swash zone or in the shoaling zone, when the conditions are favorable.

[0030] Moreover, when disposed in a submerged granular medium, the device can create surfing reefs which can be adapted to the waves and tide conditions.

[0031] Moreover, the device allows the creation of pools and channels when it is lowered after the granular medium above it has been eroded, for example by currents.

[0032] Moreover, when disposed under the layer of granular medium, the device does not interfere with activities at the surface of the granular medium, for example recreational activities on a beach or fishing activities in a fishing zone.

[0033] According to an embodiment, in the third configuration, the inflatable element is inflated to a third volume greater than the second volume so as to elevate the edges of the envelope for allowing the device to ascend through the granular medium.

[0034] In this embodiment, a vertical movement of the device through the granular medium is ensured by an over-inflation of the inflatable element.

[0035] According to an embodiment, the device may further comprise an additional inflatable element positioned below or embedded in the lower surface of the envelope and a pressurized fluid generator for inflating the additional inflatable element with a fluid, wherein in the third configuration said additional inflatable element is inflated so as to elevate the lower surface to allow the device to ascend through the granular medium.

[0036] In this embodiment, the vertical displacement of the device through the granular medium is ensured by the inflation of the additional inflatable element.

[0037] According to an embodiment, the envelope may be leak-tight, so as to impede the passage of the granular medium therethrough.

[0038] This embodiment is particular advantageous to avoid any damage to equipment sensitive to particles, such as for instance sensors. For instance, the envelope may be made of a waterproof material or leak-tight, which impedes the entry of both granular medium and water in the internal volume.

[0039] Alternatively, only the granular medium is kept outside, whereas water can freely move inside and outside of the envelope. In this case, the device may comprise filters configured to trap particles. This configuration is advantageous to reduce the pressure difference between the inside and the outside of the envelope.

[0040] According to an embodiment, the injection device may comprise at least one feeding pipe comprising a first portion adapted to receive a fluid and a second portion connected to the inflatable element, the first portion and the second portion being connected to each other by a bend, so as to prevent kinking of the feeding pipe between the first and the second portion.

[0041] The bend is particularly advantageous when the device is buried at a great depth, to avoid the pipe, or hose, from kinking when it is pulled down by the envelope, thereby preventing the inflation or deflation of the inflatable element.

[0042] According to an embodiment, the device may further comprise at least one conduit between the injection device and the inflatable element, and a release device comprising a pressurized fluid generator and at least one outlet configured to inject the pressurized fluid into the granular medium so as to generate proximate to the conduit a mixture of fluid and granular medium, in order to enable the conduit to move into the granular medium as the device ascends or descends therethrough.

[0043] As the device may in some cases comprise several cables, tubes, or hoses (*e.g.,* to provide power, for communication, or for fluid transport), this embodiment is particularly advantageous to avoid their shearing and/or tearing, and to prevent them from tearing the envelope or the inflatable element, which can happen if they are trapped by the granular medium during vertical displacements of the device.

[0044] According to an embodiment, the device may further comprise a burying device comprising a pressurized fluid generator and at least one outlet configured to inject the pressurized fluid into the granular medium below the lower surface of the envelope so as to generate a flow of a mixture of fluid and granular medium, in order to enable the burying of the device.

[0045] The two-phases mixture consist of: the injected fluid and the granular medium. However, it should be understood that one or both of the fluid and the granular medium may, in turn, consists of several component. For instance, the injected fluid may be a mixture of a gas and a liquid. Moreover, granular media such as sands may comprise several components. In these cases, the mixture may be a multiphase mixture.

[0046] The flow of the two-phase mixture permits the sinking of the device in the granular medium. Therefore, this embodiment advantageously allows to obtain a self-burying device.

[0047] According to an embodiment, the or each outlet may comprise a pair of nozzles, preferably the angle between the nozzles being 180°.

[0048] By providing diametrically opposed nozzles, it is possible to simultaneous eject the fluid out of the nozzles in opposite directions, thereby preventing a displacement of the fluid outlet. Alternatively, the outlet may comprise only one nozzle.

[0049] According to an embodiment, the device may further comprise at least one pressure sensor, preferably at least one pressure sensor proximate to a central area of the upper surface and at least one pressure sensor located proximate to a peripheral area of the lower surface.

[0050] For instance, the pressure sensor may be a piezoelectric sensor. This sensor may measure the total pressure of the granular medium, or using a filtering device, only the partial pressure of water. This is useful to calculate the height of the device, by measuring water pressure on the top and on the side of the device.

[0051] According to an embodiment, the device may further comprise a measuring device for measuring the height of the layer of granular medium above the device, the measuring device comprising at least one pressure sensor.

[0052] The calculation of the height of the layer of granular medium advantageously provides information about the effect of the device on a seafloor topology. Moreover, it allows to derive the depth of the device within the granular medium.

[0053] Moreover, the height of the layer which is raised or lowered by the device may influence the breaking of the waves. Therefore, this embodiment allows to provide a fine tuning of the wave breaking.

[0054] According to an embodiment, the measuring device comprises:

- at least one reference sensor located at a predefined depth in the granular medium and being configured to acquire a first environmental signal, and
- at least one target sensor located proximate to the envelope, preferably on the upper surface, and being configured to acquire a second environmental signal,

wherein the measuring device is configured to determine the height of the granular medium based on the first environmental signal and the second environmental signal.

[0055] Preferably, the at least one reference sensor and the at least one target sensor are pressure sensors, and the measuring device is configured to determine the height of the granular medium based on the phase offset and/or the reduction in amplitude of the pressure signals generated by passing waves, acquired by said reference and target sensors.

[0056] The predefined depth in the granular medium may be zero (*e.g.*the reference sensor may be installed on top of the granular medium or on a seabed) or non-zero (*e.g.,* the reference sensor is installed at a known depth).

[0057] In one embodiment, the height of the layer is regularly or periodically monitored, for instance, every minute. In this case, the device configurations may be switched accordingly, for instance via a retroactive feedback module. This embodiment advantageously allows to adapt the device configuration to the erosion of the layer of granular medium raised over the device.

[0058] According to an embodiment, the measuring device may comprise: at least one bag located near or in the envelope, preferably above the upper surface, the or each bag being connected to a pressurized gas generator and comprising a pressure sensor configured to measure the pressure in the bag, and a computing unit configured to calculate the height of the layer of granular medium based on the pressure sensor measurement and a calibration curve.

[0059] In some cases, several small bags of this type (with a typical capacity of a few hundred milliliters) may be provided above the upper surface, as well as around the burying site, at a predetermined depth. As the height of the layer may not be constant over the whole upper surface of the envelope and in its proximity, this embodiment allows to obtain a more accurate representation of the profile of the layer of granular medium (*e.g.*, to obtain the topography of a seafloor).

[0060] By providing additional small bags just below the upper surface, it is possible to measure the tension of the envelope.

[0061] According to an embodiment, the envelope may comprise a first sheet forming the lower surface and having a first area, and a second sheet forming the upper surface and having a second area, said first and second sheets being joined together along their edges so as to form the internal volume, and wherein the second area is equal or greater than the first area.

[0062] By using a smaller lower sheet joined to a larger upper sheet, it is possible to restrict horizontal movements of the upper surface and avoid excessive deformation of the envelope during the burying process. Moreover, this embodiment helps to maintain the horizontality of the envelope, during the burying process and when switching between said first and second configurations.

[0063] The present invention also relates to a method of deforming a layer of granular medium, the method comprising a step of burying at least one flexible envelope comprising a variable internal volume at a predetermined depth in the granular medium, and a step of varying the internal volume of said envelope between a first volume and a second volume greater than the first volume so as to raise or lower the layer of granular medium above the envelope.

[0064] This method may advantageously use a device as described above.

[0065] This method allows to raise or lower a layer of granular medium and to modify the topography of a seabed or a coastal area. Therefore, it is particularly advantageous to modify the wave breaking *(e.g.,* for creating waves suitable for performing aquatic sports such as surf); to protect a coastal area from erosion; for beach nourishment applications; and/or to change the topology of coastal area, for example by creating pools, lagoons, dry zones, salients or tombolos.

[0066] In an embodiment, the burying step may comprise: injecting a fluid into the granular medium below a lower surface of the envelope, so as to generate a flow of a two-phase mixture of fluid and granular medium in order to enable the burying of the envelope in the granular medium.

[0067] This embodiment advantageously allows to obtain the burying of the flexible envelope in the granular medium without drilling, excavating or dredging.

[0068] Excavating the seabed or the coast is expensive, damaging for the environment, and not implementable in all type of soils. For instance, it is difficult to dig muddy media, because the excavated material continuously flows back into the hole during the operation. Water-saturated sands *(e.g.,* the low-tide area of a beach) are also difficult to dig: during the process, the hole has a tendency to become wider rather than deeper. Moreover, many areas are not accessible to excavators.

[0069] Therefore, this embodiment allows to provide a versatile and economical burying of the envelope, without negative impacts on the environment.

[0070] According to an embodiment, the method may further comprise a step of measuring a parameter of the granular medium by at least one sensor, and wherein the variation of the internal volume during the varying step is controlled by a machine learning algorithm trained on said parameter.

[0071] In this embodiment, a machine learning model may be implemented to predict flow parameters *(e.g.,* a laminar or turbulent regimen of the water above the layer of granular medium, the direction of a current or a wave, and the like) or parameters relating to the granular medium topography *(e.g.,* a slope of a seabed, a height of the layer of granular medium above the envelope, and the like). The variation of the internal volume of the envelope may be controlled accordingly.

[0072] The present invention also relates to a method of adjusting the flow of a marine stream flowing over a seabed composed of a granular medium, the method comprising a step of varying the internal volume of at least one envelope according to any one of the embodiments described hereinabove, so as to cause a layer of the granular medium to be raised or lowered in order to create or modify a submarine relief.

[0073] This method allows to modify the slope of a seabed. Thanks to the relationship between the Iribarren number and the seafloor slope, this method allows to modify how waves break.

[0074] The method may further comprise an ascension step during which the envelope is raised within the granular medium. For instance, this step may comprise varying the internal volume, so as to raise the edges of the envelope, thereby allowing a migration of the granular medium below the envelope.

[0075] In one embodiment, the ascension step comprising several phases during which the internal volume is increased and decreased. Said phases may be repeated for a predetermined number of times, which can be calculated for instance based on a parameter characterizing the granular medium or a parameter characterizing the flow of water above the envelope.

[0076] In one embodiment, the method of the invention comprises a step of measuring the internal volume and an optimal depth of burial based on the signal collected by at least one sensor, and a step of calculating a number N of phases constituting the ascension step, based on said internal volume and depth of burial.

[0077] In one embodiment, the method further comprising a step of measuring a parameter characterizing the granular medium by at least one sensor, and the variation of the internal volume is controlled using a learning algorithm trained on the basis of said parameter.

[0078] The invention also relates to a method for adjusting the flow of a water stream flowing over a bed composed of a granular medium, the method comprising varying the internal volume of a flexible envelope according to any one of the embodiments described hereinabove, so as to cause a layer of granular medium to be raised or lowered and create or modify an underwater relief influencing the flow of the water stream.

[0079] When the goal is the creation of a surfing reef, the underwater relief is preferably a submarine relief oriented at an angle between 40 and 70 degrees relative to the direction of a sea swell.

[0080] The invention also relates to a method for modifying the slope of a seabed composed of a granular medium, the method comprising: asynchronously varying the internal volume of at least two flexible envelopes according to any one of the embodiments described hereinabove, in order to cause the layers of granular medium on said flexible envelopes to be raised or lowered so as to modify the slope of the seabed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0081] The invention will be better understood with the attached figures, in which:

Figure 1 is a schematic representation of a device 1 of the present invention according to one particular embodiment;

Figure 2A is a schematic representation of the device 1 in a first configuration;

Figure 2B is a schematic representation of the device 1 in a second configuration;

Figure 3A is a schematic representation of the device 1 in a third configuration according to a first embodiment;

Figure 3B is a schematic representation of the device 1 in a third configuration according to a second embodiment;

Figure 4 is a schematic representation of devices 1 according to an exemplary embodiment;

Figure 5 is a flowchart representing the main step of a method for of deforming a layer of granular medium 2 according to the invention.

DETAILED DESCRIPTION

[0082] This invention relates to a device 1 for raising or lowering a layer of granular medium 2.

[0083] Unless otherwise specified, the terms *"lower", "upper", "above", "under", "below"* are intended with respect to the position of the device when it is in its in-use configuration.

[0084] The layer of the granular medium 2 preferably has a height h_G comprised between 10 centimeters and 5 meters.

[0085] The device 1 is advantageously configured to raise or lower a layer of granular medium 2 having a height hG as little as a few dozen centimeters or as large as a few meters.

[0086] By *"granular medium"* it is meant an assembly of solid particles, such as sand, sediments, soil. Granular media are often made of macroparticles (*i.e.,* larger than 100 μm); however, they may also comprise finer particles, as it is the case for silt and fine sand.

[0087] The device 1 of the invention is configured to be disposed within a granular medium 2. The granular medium 2 may be on a land, such as a coast or a beach. In some cases, the granular medium 2 may be submerged *(e.g.,* the bed of a river or a sea).

[0088] In this case, the device 1 is advantageously adapted to be installed both close to the shore and in open sea. Having the device 1 disposed in a seabed close to the shore allows to modify how waves break, to modify how waves transport sediment, to allow people riding a surfboard or a Stand Up Paddle to follow them easily when they peel, or to deprive waves of some of their energy before they break.

[0089] **Figure 1** schematically illustrates he device 1 of the invention, according to a preferred embodiment.

[0090] The device 1 comprises a flexible envelope 11 forming an internal volume 110, and an inflatable element 12 (several inflatable elements 12 may also be used) housed in the internal volume 110 so as to be interposed between an upper surface 11a and a lower surface 11b of the envelope 11. In this example, the upper surface 11a has an area which is greater than the area of the lower surface 11b.

[0091] Moreover, the device 1 of **figure 1** comprises several sensors, a release device 14 and a burying device 15. These components will be later described in further details.

[0092] An injection device 13 is configured to fill the inflatable element 12 with a fluid, or to empty the same. The inflation and deflation of the inflatable element 12 respectively allow to increase and decrease the internal volume 110.

[0093] For instance, the injection device 13 may be a compressor (for example a rotary screw compressor), a blower (for example a side channel blower) or a pump (for example a centrifugal pump).

[0094] The injection device 13 may be fluidly connected with a storage tank comprising a fluid, such as air or water (not illustrated).

[0095] The injection device 13 may comprise a feeding pipe 131 for conducting the fluid to the inflatable element 12. Preferably, the pipe 131 is flexible so that it can follow the movements of the device 1 inside the granular medium 2. In the example of **figure 1,** the feeding pipe 131 passes through the lower surface 11b of the envelope 11. In an alternative embodiment (not illustrated) the feeding pipe 131 may pass through the envelope 11 where the upper surface 11a and the lower surface 11b meet. By providing a feeding pipe 131 that passes through the lower surface 11b, or through a position in which the upper and lower surface 11b meet, it is possible to avoid damages to said pipe 131 or other problems which may be caused by the movements of the upper surface 11a.

[0096] The feeding pipe 131 may comprise an upstream portion, adapted to receive the fluid, and a downstream portion, connected to the inflatable element 12. Preferably, said portions are connected by means of a bend 133. This allows to increase the resistance to deformation of the feeding pipe 131 at the bend location. This is particularly advantageous when the device 1 is buried at a great depth, as it impedes that the pipe collapses under the weight of the superimposed granular medium 2.

[0097] Moreover, the local rigidity provided by the bend 133 ensures that the pipe easily follows the movements of the device 1 inside the granular medium 2 even at great depths.

[0098] As can be seen in **figure 1,** the injection device 13 may also comprise a valve 134 to control the circulation of the fluid inside the feeding pipe 131. This valve 134 is preferably located proximal to the injection device 13, so that it is easily accessible for maintenance purposes.

[0099] **Figure 2** illustrates two distinct configurations of the device 1 of the invention.

[0100] More precisely, the device 1 is configured to switch between a first configuration (**figure 2A**), in which the inflatable element 12 occupies a first volume and a second configuration (**figure 2B**), in which the inflatable element 12 occupies a second volume greater than the first volume.

[0101] In the second configuration, the upper surface 11a is deformed vertically so as to raise a layer of granular medium 2. Accordingly, by switching from the first to the second configuration and vice-versa, it is possible to raise or lower the layer of granular medium 2.

[0102] As can be seen in **figure 2,** the lower surface 11b of the envelope 11 is substantially horizontal in the first and second configurations of the device 1. This provides stability to device 1, and further ensures that it remains at the same depth inside the granular medium 2 while switching between the first and second configurations.

[0103] Advantageously, the device 1 of the invention is flexible and it is not secured to the granular medium 2. Therefore, it can move inside the granular medium 2 as needed.

[0104] More precisely, the device 1 is capable of moving vertically inside the granular medium 2. Preferably, the vertical displacement of the device 1 within the granular medium 2 is permitted by a third configuration, distinct from the aforementioned first and second configurations.

[0105] The third configuration is better shown in **figure 3.** The third configuration differs from the first and second configurations in that the lower surface 11b of the envelope 11 is vertically deformed, thereby allowing the device 1 to ascend through the granular medium 2.

[0106] For instance, as shown in **figure 3A,** the inflatable element 12 may be overinflated in the third configuration, so that it occupies a third volume above the second volume.

[0107] This configuration allows to elevate the edges 111 of the envelope 11 thereby creating an available volume below the lower surface 11b which can be occupied by the granular medium 2 (as schematically illustrated by the black arrow in **figure 3A**). In particular, the edges 111 of the envelope 11 are elevated thanks to the tension created on the upper surface 11a by the inflation of the inflatable element 12. As the granular medium 2 migrates and occupies said volume, the raised device 1 cannot further descend due to the presence of the granular medium 2 which has migrated below the lower surface 11b.

[0108] The third volume may be selected on the basis of the difference between the current depth of the device 1, and a target depth. In this case, one or more sensors may be provided on the device 1 to measure its depth (or the height hG of the granular medium 2 above the upper surface 11a).

[0109] Moreover, the switching between the first or second configuration and the third configuration may be repeated several times. In this case, the ascension of the device 1 within the granular medium 2 is intermittent. This embodiment is particularly advantageous for large vertical displacements (for instance for causing a device 1 which is buried at a great depth in the granular medium 2 to ascend closer to the surface of the same, or completely emerge therefrom).

[0110] Moreover, in this embodiment, the characteristics of each configuration of the device 1 *(e.g.,* the first and second volumes) are independent of the target displacement of the device 1. In other words, the configurations of the device 1 do not need to be modified based on the extent of the desired displacement, and only the number of repetitions of the switching between one configuration to another is modified.

[0111] Such number of repetitions may be calculated for instance based on the ratio between the maximum height of the inflatable element 12 (*i.e.,* its height when fully inflated) and the depth at which the device 1 it is buried.

[0112] For intelligibility purposes, only the migrated medium 2 is depicted in **figure 3A,** the layer of granular medium 2 above the upper surface 11a of the envelope 11 is not illustrated.

[0113] **Figure 3B** illustrates the third configuration according to an alternative embodiment, in which the device 1 comprises one or more additional inflatable elements 17.

[0114] In this example, the vertical deformation of lower surface 11b and of the edges 111 of the envelope 11 in the third configuration (and, consequently, the vertical ascension of the device 1) is provided by the inflation of said additional inflatable element 17.

[0115] The additional inflatable element 17 may be attached to the lower surface 11b, for example under the lower surface 11b.

[0116] Alternatively, the lower surface 11b may be made of a double layer, and the additional inflatable element 17 may be embedded within said layers (as shown in **figure 3B**).

[0117] Preferably, the upper surface 11a and the lower surface 11b of the envelope 11 have an area which is larger than 1 m^2.

[0118] For instance, these surfaces may have a width comprised between 1 and 50 meters, and a length comprised between 1 and 50 meters. The width and the length may be similar, or one of these dimensions may be larger than the other one.

[0119] As shown in **figures 1** to **3,** the upper surface 11a of the envelope 11 may have an area which is greater than the area of the lower surface 11b.

[0120] However, in alternative embodiments, the upper surface 11a and the lower surface 11b have the same area. In these cases, the edges 111 of the upper and lower surfaces 11b are preferably folded inwardly (*i.e.,* towards the internal volume 110) in the first configuration. When the device 1 is in its second configuration, the upper surface 11a is raised vertically and said edges 111 are unfolded, whereas the lower surface 11b remains substantially horizontal.

[0121] In this alternative embodiment, the envelope 11 may have a polygonal shape, in which each corner is connected to at least another corners (for example, with straps) in order to bring the connected corners closer to each other, and obtain a folded configuration.

[0122] Having a device 1 with folded edges 111 in the first configuration is particularly advantageous for envelopes 11 of large dimensions, for instance having upper and lower surfaces 11b larger than 5 square meters.

[0123] Indeed, the folding of the edges 111 allows to reduce the space occupied by the device 1 when it is in the first configuration or when laid flat.

[0124] In all the embodiments described hereinabove, the envelope 11 may be made of a single body.

[0125] Alternatively, the envelope 11 may comprise two sheets (for instance two tarpaulins) joined together on their edges 111. In this case, the two sheets may be made of different materials in order to provide different properties to the upper and lower surfaces 11b.

[0126] The envelope 11 is advantageously made of a flexible material, such as coated textile, fabric or non-woven fabric.

[0127] Examples of suitable materials for the envelope 11 include, without limitation: plastic polymers such as PVC or polypropylene.

[0128] The envelope material may be selected so that the envelope 11 may form a barrier to the granular medium 2, to water, or both. For instance, it may be made of waterproof materials.

[0129] If the envelope material does not obstruct the passage of granular medium 2, one or more filters may be provided to avoid the entry of particles in the internal volume 110 (**figure 1**).

[0130] As aforementioned, the device 1 may further comprise one of more sensors. For instance, the device 1 may comprise one or more of the following sensors:

- a pressure sensor 16 (such as the Seametric PS9800);
- a flowmeter or a velocimeter (such as the Mass Flow MV-308);
- a tilt sensor (such as the Shanghai Zhichuan Electroni ZCT205M-LPS);
- an acoustic sensor, preferably a hydrophone (such as the Aquarian AS-1);
- a force sensor (such as the Interlink 402).

[0131] These sensors advantageously allow to measure environmental parameters, for instance parameters characterizing the granular medium 2 or the flow of water above the envelope 11. Examples of environmental parameters comprise flow, velocity or turbulence of the water, wind speed and direction $\overline{d}$, pressure exerted by the water and/or the granular medium 2 above the device 1, and the like (**figure 4**).

[0132] For instance, at least one pressure sensor 16 may be configured to measure the pressure of the water above the device 1. This may be achieved by isolating the sensor 16 from the sediments, but not from the water. The pressure of the water may then be used to calculate the height hw of water between the water surface level and the level of the sensor 16.

[0133] At least one pressure sensor 16 may be provided on the device 1 to measure a pressure inside the inflatable element 12. If additional inflatable element 12s are present, these elements may also comprise pressure sensors 16.

[0134] Several pressure sensors 16 may be provided at different locations of the device 1. For instance, at least one pressure sensor 16 may be located proximate to a central area of the upper surface 11a and at least one pressure sensor 16 proximate to a peripheral area thereof (**figure 1**). This embodiment allows to calculate the height h_G of the layer of granular medium 2 on the device 1 based on the difference between the measurements of these pressure sensors 16.

[0135] In alternative or in addition to the pressure sensor 16 described hereinabove, the device 1 may comprise a measuring device for measuring the height h_G of the layer of granular medium 2. Preferably, said measuring device comprises:

- at least one bag connected to a pressurized gas generator, the bag being located in the envelope 11 or, preferably, external to the envelope (*e.g.*, above);
- a pressure sensor 16 configured to measure the pressure in the at least one bag: and
- a computing unit configured to calculate the height hG of the layer of granular medium 2 based on the pressure sensor measurement when the bag is inflated and deflated, and on a calibration curve.

[0136] Alternatively, the height hG of the layer of granular medium 2 may be derived from the pressure waveforms collected by one or more pressure sensor 16, and a wave detector *(e.g.,* a camera or a webcam). In this case, said height hG may be calculated using a model which describes a relationship between a wave passage and a corresponding change in the amplitude and/or phase of the pressure waveform, wherein the change in the amplitude and/or phase is a function of depth in the granular medium 2.

[0137] In alternative, the measuring device may comprise at least two sensors: a first reference sensor, installed on the seabed or slightly buried at a known depth, said first sensor acquiring a signal relating to the pressure variation, which is affected by the passing waves, and a second target sensor (or several target sensors) at the location at which the height hG of the granular medium is to be determined. This second target sensor is buried under a layer of granular medium of unknown depth. In this embodiment, the height hG of the granular medium 2 may be determined by processing the phase offsets and amplitude variations (*e.g.*, the amplitude decrease) of the signals acquired by the reference and target sensor(s).

[0138] The measurement of the height hG of the layer of granular medium 2 advantageously allows to provide information about the granular medium topology, and on the effect of the device 1 thereon. Moreover, it allows to monitor the depth of the device 1 within the granular medium 2. Therefore, by measuring the height hG of the layer it is possible to predict and prevent an unwanted protrusion of the device 1 therefrom (especially when the layer of granular medium 2 is eroded by currents) and to avoid that the device 1 is buried too deep. A measurement of the water pressure may also be performed to avoid that the device 1 is buried too deep.

[0139] For instance, if a raised layer of sand has been eroded by currents, it may be desirable or necessary to regenerate it. In this case, it may be advantageous to: decrease the internal volume 110 (to create a depression on the surface of the granular medium 2); measure the height hG of the layer of granular medium 2, to determine if said depression has been filled by currents, and if a new layer of granular medium is available so that the process can start again.

[0140] For instance, if the device 1 comprises one or more hoses, the height monitoring allows to verify that the depth of the device 1 within the granular medium 2 does not exceed the hose lengths.

[0141] The device 1 may also comprise a camera sensor for acquiring images. This embodiment is particularly advantageous to estimate the location and/or the type of wave breaking. For instance, the images may be sent to a computing device for segmentation and analysis via an image analysis algorithm. The image analysis algorithm may be configured to detect wave breaking in the images and to label or classify them into a given number of classes (*e.g.*, non-breaking, spilling, plunging, collapsing, and surging).

[0142] The device 1 may comprise a computing unit. For instance, the computing unit may be configured to receive signals and/or images from the sensors, and to calculate the environmental parameters therefrom.

[0143] The computing unit may also be configured to control the variation of the internal volume 110 *(e.g.,* by controlling the injection device 13 or the switching of the device 1 from one configuration to another) on the basis of measured or reference parameters (*e.g.*, a target depth of the device 1 within the granular medium 2 or a target height of the layer of granular medium 2).

[0144] The device 1 may also comprise a memory, preferably a processor-readable non-transitory memory. The memory may be configured to store the calculated and/or reference parameters. The memory may also comprise instructions which are readable and executable by the computing unit.

[0145] As aforementioned, the device 1 of the invention may comprise a release device 14. One exemplary release device 14 is shown in **figure 1.**

[0146] The release device 14 of figure 1 comprises a single outlet 141 near the bend 133 of the feeding pipe 131.

[0147] Alternatively, the release device 14 may comprise more than one outlet 141, for instance several small outlets 141 along the conduit 131. This is particularly advantageous to prevent the lower part of the conduit 131 from getting stuck during ascension of a device 1 buried at a large depth.

[0148] The release device 14 ensures that any conduit connected to the device 1 moves into the granular medium 2 as the device 1 ascends or descends therethrough.

[0149] Examples of conduits comprise: hoses, power wires, pipes, cables, cords and the like. For instance, as aforementioned, a feeding pipe 131 may be connected to the inflatable element 12. In this case, the release device 14 may have an outlet 141 in proximity of said feeding pipe 131. Moreover, if the device 1 comprises sensors and/or a computing unit, these may comprise dedicated cables ensuring power supply or data transfer.

[0150] In all these embodiments, the release device 14 ensures that the conduits follow the device movements, thereby minimizing the risk of damaging said conduits.

[0151] The release device 14 preferably comprises a pressurized fluid generator 142 and at least one outlet 141 configured to inject the pressurized fluid into the granular medium 2, in proximity of the conduit. Optionally, several outlets 141 may be provided. Optionally, the release device 14 and the conduit may be tied or clamped together, in order to ensure that the outlet 141 of the former is maintained close to the latter.

[0152] The injection of fluid in the granular medium 2 through the outlet 141 generates a mixture of fluid and granular medium 2. Said mixture exhibits fluid-like properties; therefore, the movement of a conduit therein is easier than inside a static granular medium 2.

[0153] The injection of fluid may be synchronous with the device configuration. For instance, it may be injected when the device 1 moves vertically within the granular medium 2 *(e.g.,* in the third configuration, or during the burying of the device 1), and not when the device 1 is in a stable position in the granular medium 2 *(e.g.,* in the second configuration). This embodiment allows to limit the number of injections of fluid and, therefore, the power consumption.

[0154] The device 1 of the invention may comprise a burying device 15.

[0155] Said burying device 15 preferably comprises a pressurized fluid generator 152 and at least one outlet

151 configured to inject the pressurized fluid into the granular medium 2 below the lower surface 11b of the envelope 11 (**figure 1**).

[0156] Optionally, the burying device 15 may be tied or clamped together with one or more conduits.

[0157] The burying device 15 advantageously allows the sinking of the device 1 in the granular medium 2. More precisely, the injection of fluid in the granular medium 2 through the outlet 151 generates a flow of a mixture made of fluid and granular medium 2. Preferably, the burying device 15 is configured to inject a mixture of air and water. This may be obtained for instance with a compressor and a pump both of which feeding a same conduit of the burying device 15. The pump and the compressor may comprise a non-return valve in order to protect them *(e.g.,* from backflow and reverse flow).

[0158] The flow of said two-phase mixture away from the lower surface 11b of the envelope 11 allows the sinking of the device 1 in the granular medium 2.

[0159] This embodiment advantageously allows to obtain a device 1 which is self-burying and capable of reaching a desired depth within the granular medium 2, without any excavation.

[0160] The burying device 15 is advantageously capable of promoting the burying of the device at large depths, for instance up to 3 meters with respect to the ground level (*e.g.,* the seafloor or the coast surface). Greater depths, for instance up to 10 meters, may be reached by increasing the pressure of the injected fluid.

[0161] In some cases, a predefined weight or pressure, for example of 0.02 bar, may be applied on top of the upper surface to facilitate the burying process when it begins, which is particularly advantageous in wet granular media.

[0162] The maximum depth of the device 1 in the granular medium 2 may be determined based on the length of the tubes, hoses and cables, and the pressure of the fluid.

[0163] Preferably, the pressurized fluid generator 152 of the burying device 15 is configured to inject a fluid at a pressure which is at least equal to the pressure of the granular medium 2 at the target depth plus 0.5 bar.

[0164] For example, the density of a wet a granular medium 2 such as wet sand being around 2000 kg/m^3, the pressure of the injected fluid injected may be around 0.2 bar + 0.5 bar under one meter of wet sand (with no water on top), whereas higher pressures may be selected for burying the device 1 at grater depths. For instance, under 10 meters of wet sand (with no water on top) the pressure is typically around 2 bar. Therefore, in order to bury the device 1 in wet sand at 10 meters, the pressure of the injected fluid is preferably at least 2.5 bar (plus the pressure of the column of water on top of the granular medium if any).

[0165] The pressurized fluid generator 152 of the burying device 15 may be configured to inject the pressurized fluid at a controlled pressure, ranging between 0 bar and 12 bar.

[0166] The outlet 151 of the burying device 15 may comprise nozzles directed towards different directions. Those nozzles are preferably organized by pairs so that the nozzles of each are separated by an angle of 180°, *i.e.,* they are diametrically opposed. This ensures that the forces and torques exerted by the pressurized fluid exiting from said outlet 151 are in opposite directions, thereby avoiding that the outlet 151 is displaced over time.

[0167] In the example of **figure 1,** the device 1 comprises a release device 14 and a burying device 15 which are connected to respective generators 142, 152 of pressurized fluid. In this case, the injected fluids may be different *(e.g.,* one generator 142, 152 may be configured to generate pressurized air and another generator 142, 152 may be configured to generate pressurized water).

[0168] However, the burying device 15 and/or the release device 14 may be connected to a same generator 152, 142 of pressurized fluid. This allows to reduce the weight and volume of the device 1.

[0169] The release device 14 and/or the burying device 15 may comprise a pipe connecting the generator of pressurized fluid 142, 152 with the outlets 141, 151. These pipes may comprise a bend 143, 153 similar to the bend 133 of the feeding pipe 131.

[0170] As aforementioned, the device 1 may comprise one or more sensors. In this case, the burying device 15 may be controlled on the basis of the sensor measurements.

[0171] **Figure 4** illustrates an ensemble of devices 1 of the aforementioned type installed at a predetermined depth under a seafloor.

[0172] In this case, the inflation and deflation of the devices 1 may be asynchronous. This allows to obtain complex profiles and slopes of the layer of granular medium 2. Therefore, it is particularly advantageous to provide a fine tuning of the wave breaking.

[0173] Alternatively, the inflation and deflation profile may be the same for the whole ensemble.

[0174] The present invention also relates to a method of deforming a layer of granular medium 2.

[0175] **Figure 5** is a flowchart illustrating the main steps of the method.

[0176] The method comprises a burying step during which at least one flexible envelope 11 comprising a variable internal volume 110 is buried at a predetermined depth in the granular medium 2. This step may be implemented in response to a user input.

[0177] In some cases, the method may comprise a preliminary step for applying a predefined weight or pressure on top of the upper surface.

[0178] Preferably, during the burying step, a pressurized fluid is injected in the granular medium 2 below a lower surface 11b of the envelope 11 so as to generate a flow of a mixture of fluid and granular medium 2.

[0179] The method may also comprise a step of measuring a height h_G of the layer of granular medium 2 above the envelope 11.

[0180] The measured height hG may be compared with a target height. In this case, the burying step may be implemented in response to a retroactive feedback, as illustrated in **figure 5.**

[0181] The method also comprises a step of varying the internal volume 110 of the envelope 11 between a first volume (**figure 2A**) and a second volume (**figure 2B**) greater than the first volume, so as to raise or lower the layer of granular medium 2 above the envelope 11.

[0182] The method may also comprise a step of measuring a flow parameter relating to the water above the buried envelope 11. The flow parameter may relate for instance to wave height, wavelength, period, steepness, peel angle, and the like.

[0183] In this case, the step of varying the internal volume 110 of the envelope 11 may also be implemented in response to a retroactive feedback, as illustrated in **figure 5.** In some cases, this varying step may be user-initiated.

[0184] The method may further comprise a step of retrieving the device (not illustrated in **figure 5**).

[0185] During the varying step, the internal volumes 110 of several envelopes 11 may be varied in order to provide a complex topography to the granular medium 2.

[0186] The method of the invention advantageously permits to deform the topography of a seabed and create or modify a submarine relief **(figure 4**).

[0187] The deformation of the seabed topography allows to modify the flow of a marine stream flowing over said seabed. For instance, the slope of underwater reliefs influences the Iribarren number, which is associated to the way in which waves break.

[0188] Of note, for the practice of surf, the peel angle is preferably higher than a threshold value. Indeed, zero or low peel angles correspond to waves which close out on the whole crest quasi-simultaneously, thereby providing an insufficient time to a surfer to ride the wave. Therefore, the method of the invention allows to obtain a wave breaking that it is adapted for the practice of aquatic sports. For instance, different wave breakings may be produced depending on the experience of the surfers.

[0189] The deformation of the seabed topography further allows to modify sediment transport, which is particularly important for beach nourishment.

[0190] Preferably, when used as a surfing reef, the submarine relief is created or modified such that it forms an angle between 40 degrees and 70 degrees with respect to the direction of a sea swell. This allows to obtain a peel angle that allows the wave to be followed easily by someone using a surf board, a foil board, or a SUP.

[0191] An angle between 40 degrees and 70 degrees is particularly advantageous for providing a device 1 for creating an artificial surfing reef, so that the waves can peel in such a way that they can be followed easily by surfers.

[0192] The method may optionally comprise an ascension step during which the envelope 11 is raised within the granular medium 2. This step may comprise, for instance: increasing the internal volume 110 to a third volume greater than the second volume, so as to raise the edges 111 of the envelope 11, thereby allowing a migration of the granular medium 2 around said edges 111 below the envelope 11 (**figure 3A**).

[0193] For instance, the second volume may be the maximum volume which can be obtained without pulling upward the edges of the envelope 11. However, the second volume may take multiple values, for instance depending on the desired height.

[0194] This ascension step may comprise several phases.

[0195] For instance, this step may comprise a first phase of increasing the internal volume 110 to a third volume and a second phase of decreasing said internal volume 110 to a fourth volume smaller than the third volume. In this case, the granular medium 2 which migrates below the envelope 11 during the first phase prevents allows the device to stabilize higher within the granular medium during the second phase. These first and second phases may be alternated and repeated for a predetermined number N of times, until the envelope 11 reaches the desired depth within the granular medium 2 or emerges therefrom.

[0196] As aforementioned, the method may further comprise a step of measuring a parameter of the granular medium 2 and/or a step of measuring flow parameter by at least one sensor.

[0197] In this case, the number N of times constituting the ascending step may be calculated based on said parameter of the granular medium 2 and/or flow parameter. For instance, the number N of times or the variation of the internal volume 110 constituting the ascension step may be controlled using a machine learning algorithm trained on said parameter.

[0198] Preferably, the parameter of the granular medium 2 is a height hG of the layer of granular medium 2 above the envelope 11 (**figure 4**).

[0199] Other parameters which may be derived from sensor measurements, and optionally be used to control one or more steps of the method (such as the variation of the internal volume 110) comprise:

- an absolute or a relative pressure exerted by the granular medium 2;
- an absolute or a relative partial pressure exerted by fluids in the granular medium 2 (for example the partial pressure of water in wet sand);
- a sediment transport velocity;
- a tidal coefficient;
- a granularity parameter (*e.g.*, grain average size or size distribution) of the layer of granular medium 2;
- a height hw of a water column or a water level relative to a reference point;
- a direction of the sea flow;
- a parameter relating to turbulence, such as kinetic energy or viscous dissipation;
- an acoustic intensity;

- a wind direction, orientation, speed and/or force;
- a wavelength (W), height (H), direction ($\vec{d}$), period and/or steepness of a wave;
- a slope of the sea floor or of the shoreline
- a type of tide;
- a type of wave breaking; and/or
- a deformation of a surface of the envelope 11.

[0200] The present invention also relates to a computer program comprising program code instructions which, when executed by a computer, cause the computer to carry out at least the step of varying the internal volume 110 according to any one of the embodiments described hereabove.

REFERENCES

[0201]

1 -	device
11 -	envelope
11a -	upper surface
11b -	lower surface
110 -	internal volume
111 -	edges
12 -	inflatable element
13 -	injection device
131 -	conduit
132 -	filter
133, 143 -	bend
134 -	valve
14 -	release device
141, 151 -	outlets
142, 152, 172 -	pressurized fluid generator
15 -	burying device
16 -	pressure sensor
17 -	additional inflatable element
2 -	granular medium

Claims

1. A device (1) configured to be disposed within a granular medium (2), such as sand or sediment, to raise a layer of said granular medium (2), the device (1) comprising:

- a flexible envelope (11) forming an internal volume (110);
- an inflatable element (12) housed in the internal volume (110) so as to be interposed between an upper surface (11a) and a lower surface (11b) of the envelope (11), the inflation and deflation of said element allowing the internal volume (110) to be varied;
- an injection device (13) configured to fill the inflatable element (12) with a fluid;

the device (1) being configured to switch from a first configuration in which the inflatable element (12) is inflated to occupy a first volume to a second configuration in which the inflatable element (12) is inflated to occupy a second volume greater than the first volume so that the upper surface (11a) is deformed vertically in order to raise the layer of granular medium (2), and vice versa;

the device (1) being configured so that the lower surface (11b) remains substantially horizontal in the first and second configurations in order to maintain the device (1) in position in the granular medium (2);

the device (1) further being configured to switch from the first or the second configuration to a third configuration in which the lower surface (11b) of the envelope (11) is vertically deformed for allowing the device (1) to ascend through the granular medium (2).

2. The device (1) of claim 1, wherein, in the third configuration, the inflatable element (12) is inflated to a third volume greater than the second volume so as to elevate the edges (111) of the envelope (11) for allowing the device (1) to ascend through the granular medium (2).

3. The device (1) of claim 1, further comprising an additional inflatable element (17) positioned below or embedded in the lower surface (11b) of the envelope (11) and a pressurized fluid generator (172) for inflating the additional inflatable element (12) with a fluid, wherein in the third configuration said additional inflatable element (17) is inflated so as to elevate the lower surface (11b) to allow the device (1) to ascend through the granular medium (2).

4. The device (1) of any one of claims 1 to 3, wherein the envelope (11) is leak-tight, so as to impede the passage of the granular medium (2) therethrough.

5. The device (1) according to any one of claims 1 to 4, wherein the injection device (13) comprises at least one feeding pipe (131) comprising a first portion adapted to receive a fluid and a second portion connected to the inflatable element (12), the first portion and the second portion being connected to each other by a bend (133), so as to prevent kinking of the feeding pipe (131) between the first and the second portion.

6. The device (1) of any one of claims 1 to 5, further comprising at least one conduit (131) between the injection device (13) and the inflatable element (12), and a release device (14) comprising a pressurized fluid generator (142) and at least one outlet (141) configured to inject the pressurized fluid into the granular medium (2) so as to generate proximate to the conduit (131) a mixture of fluid and granular medium (2), in order to enable the conduit (131) to move into the granular medium (2) as the device (1) ascends or descends therethrough.

7. A device (1) according to any one of claims 1 to 6, further comprising a burying device (15) comprising a pressurized fluid generator (152) and at least one outlet (151) configured to inject the pressurized fluid into the granular medium (2) below the lower surface (11b) of the envelope (11) so as to generate a flow of a mixture of fluid and granular medium (2), in order to enable the burying of the device (1).

8. The device (1) of claim 6 or 7, wherein the or each outlet (141, 151) comprises a pair of nozzles, preferably the angle between the nozzles being 180°.

9. The device (1) of any one of claims 1 to 8, further comprising at least one pressure sensor (16), preferably at least one pressure sensor proximate to a central area of the upper surface (11a) and at least one pressure sensor located proximate to a peripheral area of the lower surface (11b).

10. The device (1) according to any one of claims 1 to 9, further comprising a measuring device for measuring the height (h_G) of the layer of granular medium (2) above the device (1), the measuring device comprising at least one pressure sensor (16).

11. The device (1) according to claim 10, wherein the measuring device comprises:

- at least one bag located near or in the envelope (11), preferably above the upper surface (11a), the or each bag being connected to a pressurized gas generator and comprising a pressure sensor configured to measure the pressure in the bag, and
- a computing unit configured to calculate the height (hG) of the layer of granular medium (2) based on the pressure sensor measurement and a calibration curve.

12. A device (1) according to any one of claims 1 to 11, wherein the envelope (11) comprises a first sheet forming the lower surface (11b) and having a first area, and a second sheet forming the upper surface (11a) and having a second area, said first and second sheets being joined together along their edges (111) so as to form the internal volume (110), and wherein the second area is equal or greater than the first area.

13. A method of deforming a layer of granular medium (2), the method comprising a step of burying at least one flexible envelope (11) comprising a variable internal volume (110) at a predetermined depth in the granular medium (2), and a step of varying the internal volume (110) of said envelope (11) between a first volume and a second volume greater than the first volume so as to raise or lower the layer of granular medium (2) above the envelope (11).

14. The method of claim 13, wherein the burying step comprises: injecting a fluid into the granular medium (2) below a lower surface (11b) of the envelope (11), so as to generate a flow of a two-phase mixture of fluid and granular medium (2) in order to enable the burying of the envelope (11) in the granular medium (2).

15. The method according to claim 13 or claim 14, further comprising a step of measuring a parameter of the granular medium (2) by at least one sensor, and wherein the variation of the internal volume (110) during the varying step is controlled by a machine learning algorithm trained on said parameter.

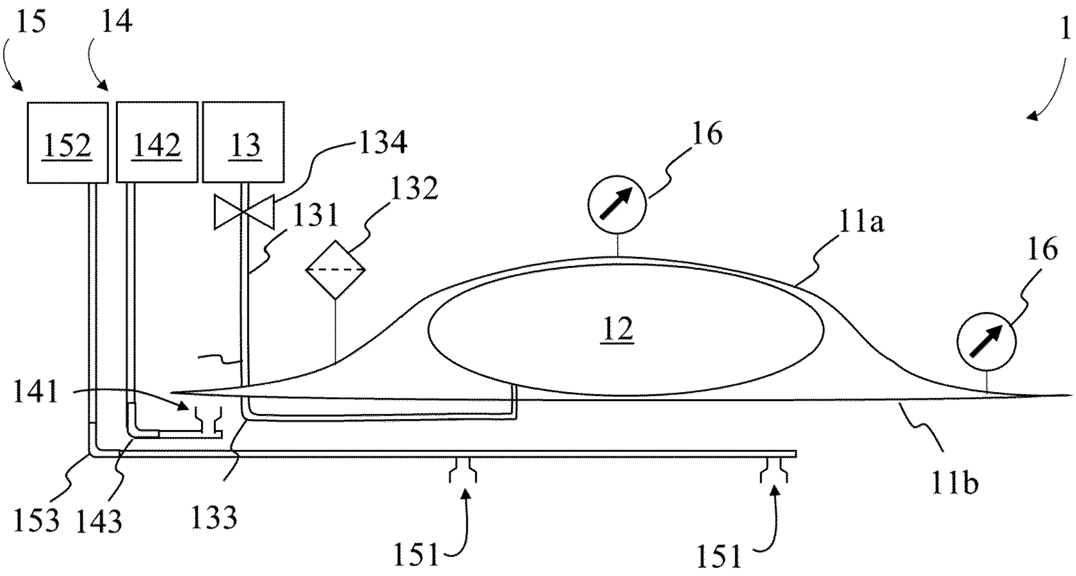

15
14
1
152
142
13
134
132
131
16
11a
16
12
141
153
143
133
11b
151
151

FIG. 1

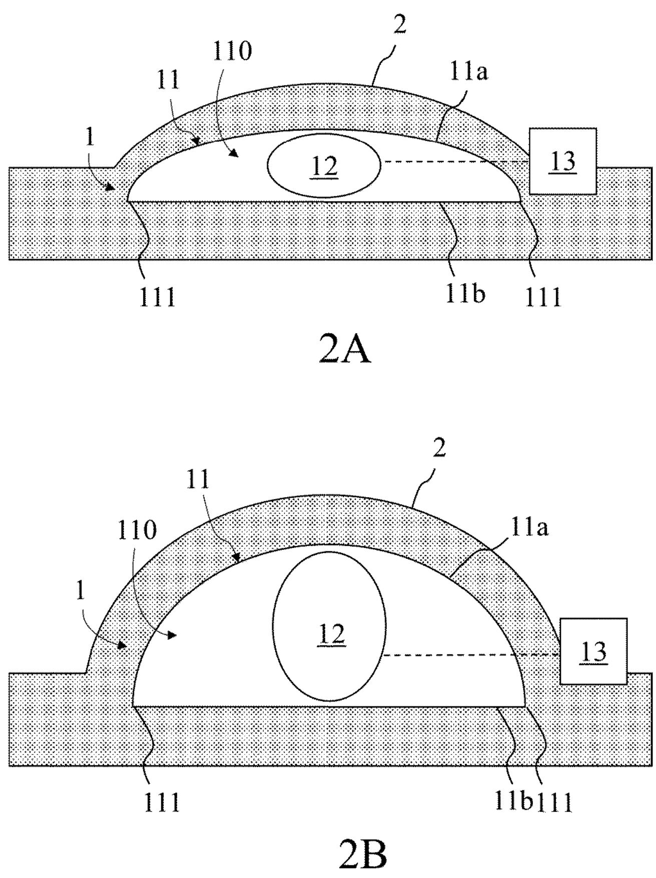
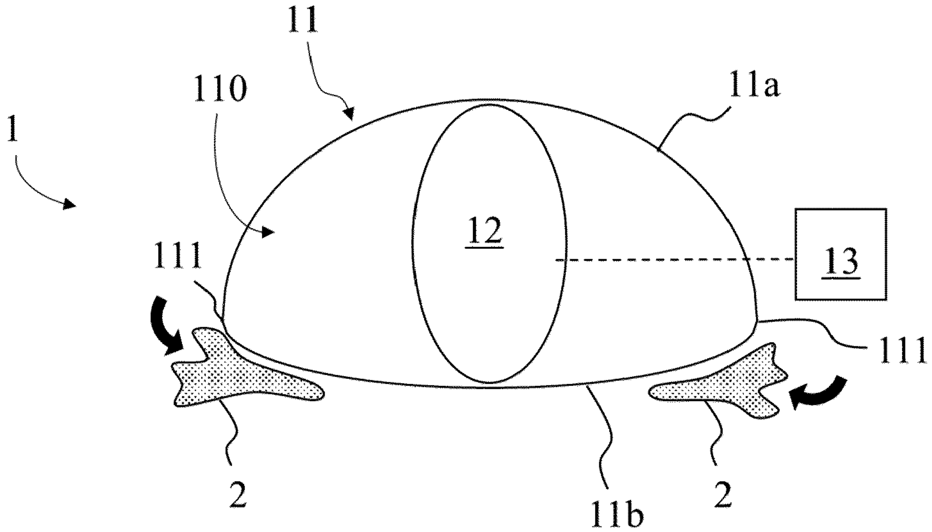
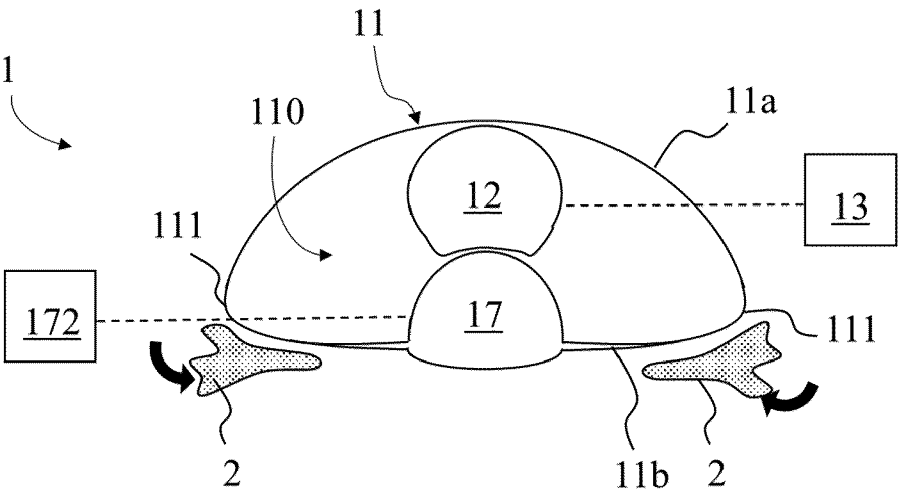

2
110
11a
11
1
12
13
111
11b
111
2A
2
11
11a
110
1
12
13
111
11b111
2B

FIG. 2


11
110
11a
1
12
13
111
111
2
11b
2

3A


11
1
110
11a
12
13
111
172
17
111
2
11b
2

3B

FIG. 3

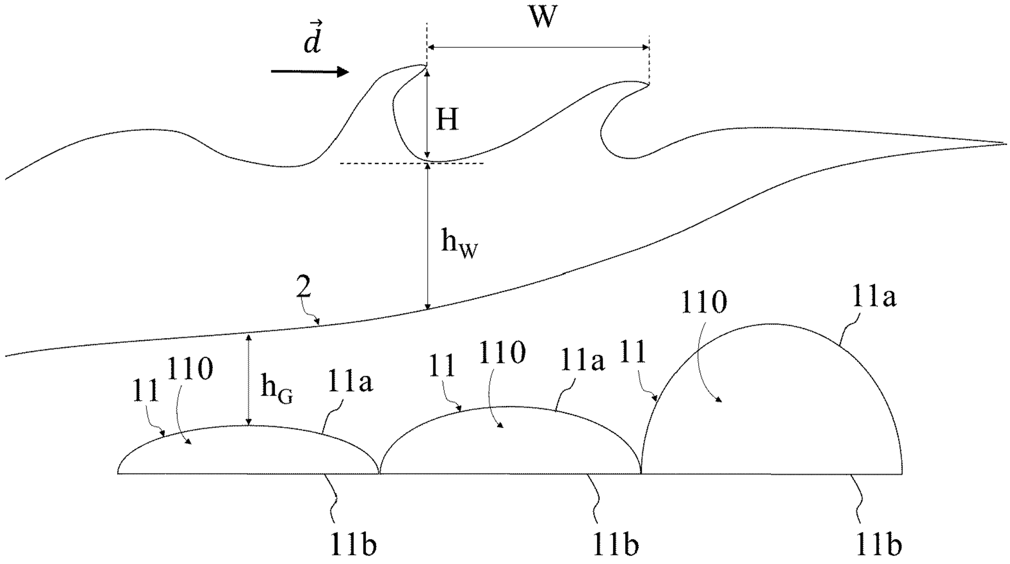

d
W
H
h_W
2
110
11a
11
110
11a
11
110
h_G
11a
11
11b
11b
11b

FIG. 4

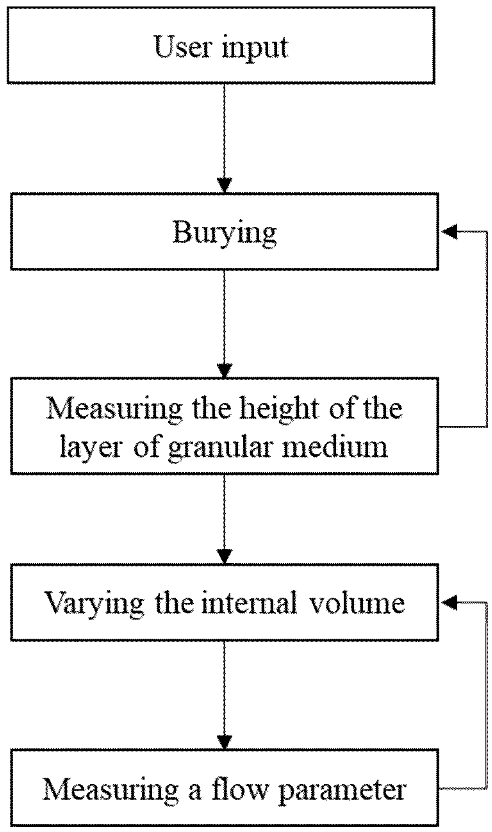

User input
Burying
Measuring the height of the layer of granular medium
Varying the internal volume
Measuring a flow parameter

FIG. 5

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 3566

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	US 2007/243020 A1 (AKIYAMA HITOSHI [JP]) 18 October 2007 (2007-10-18) * paragraph [0005]; figure 6 *	1,2, 4-10,12 3,11	INV. E02B3/04 A63B69/00 A63C19/02 A63G31/00 ADD. E02B3/18 E02B7/00
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TECHNICAL FIELDS SEARCHED (IPC)
E02B A63B A63C A63G E04H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	11 May 2022	Van Bost, Sonia

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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