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(71) Applicant: Quiet Pile Limited
Middlesbrough, Cleveland TS9 5QA (GB)

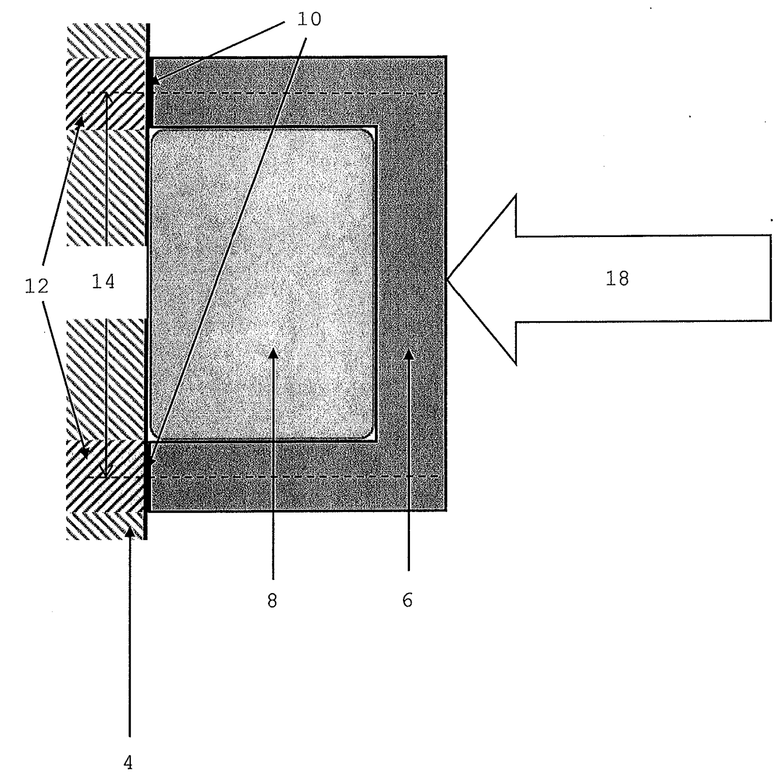
(72) Inventor: PEARCE, Colin Richard
Middlesbrough TS9 5QA (GB)

(74) Representative: Vinsome, Rex Martin
Urquhart-Dykes & Lord LLP
12th Floor
Cale Cross House
156 Pilgrim Street
Newcastle-upon-Tyne NE1 6SU (GB)

(54) DAMPING APPARATUS FOR REDUCING PILING NOISE

(57) A vibration damping apparatus (2) for damping vibration of a pile being driven into a substrate is disclosed. The apparatus comprises at least one clamp (18) for constraining a wall of the pile at at least one location thereon to adjust the resistance of the wall at that location to propagation of vibrations along the wall, in order to reflect vibrations along the wall, and a viscoelastic layer (8) for dissipating energy stored in standing waves generated in the wall as a result of interaction of reflected vibrations with further vibrations in the wall.

Figure 1



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Description

[0001] The present invention relates to an apparatus for damping vibrations, and relates particularly, but not exclusively, to a vibration damping apparatus for damping vibrations generated while driving a pile into the sea bed.

[0002] A pile is a stiff structure driven into the ground or the sea bed to provide a foundation for a building or a support for a structure such as an offshore turbine generator. There are two main types of pile defined by these mechanisms, called sheet piles and load-bearing piles. Sheet piles are frequently employed in the construction of dams and other retaining-wall structures to impede the flow of water or loose soil during excavation work. Load-bearing piles, often cylindrical in cross-section, can be driven into the sea bed to create a support for a structure to be built above the surface of the sea, such as an offshore turbine generator. A pile can be driven into an area of ground using strikes delivered by a pile hammer, or by a vibrating driver. A pile hammer works by striking the top of a pile, delivering an impulse which travels the length of the pile and into the ground, forcing the pile a distance into the ground each time it is struck. The process is repeated until the pile is driven to a depth required to safely support a given load.

[0003] As a consequence of the struck pile vibrating, the action of pile driving generates noise. Regulations exist that determine how much noise can be emitted in a given location during piling operations. In addition to emitted noise travelling through the air, piles being driven into a sea or river bed generate large-amplitude pressure waves that propagate through the water. Further regulations have been put into place to mitigate the damaging effects these pressure waves have on local wildlife. As a consequence, noise reduction strategies are required for piling operations taking place in many locations around the world.

[0004] The vibration of a struck pile, and the noise emitted by it as a result, comprises a spectrum of different frequencies. Given equal amplitudes, a lower frequency vibration propagating down the pile toward the ground will contribute more to the driving action than a higher frequency. It would therefore be advantageous to provide a damping mechanism that would act to damp higher frequency vibrations to a greater extent than lower frequencies, thereby reducing the total amplitude of emitted noise without sacrificing the efficiency of the driving action.

[0005] Preferred embodiments of the present invention seek to overcome one or more of the above disadvantages associated with the prior art.

[0006] According to the present invention, there is provided a vibration damping apparatus for damping vibration of a pile being driven into a substrate, the apparatus comprising:

first constraining means for constraining a wall of the pile at at least one location thereon to adjust the resistance of said wall at said location to propagation of vibrations along said wall, to reflect said vibrations along said wall; and

energy dissipation means for dissipating energy stored in standing waves generated in said wall as a result of interaction of at least some of said reflected vibrations with further vibrations in said wall.

[0007] By providing a vibration apparatus comprising constraining means for constraining a wall of the pile at at least one location thereon to adjust the resistance of said wall to propagation of vibrations along said wall to reflect said vibrations along said wall, and energy dissipation means for dissipating energy stored in standing waves generated in said wall as a result of interaction of at least some of said reflected vibrations with further vibrations in said wall, the frequency of the standing waves can be chosen via appropriate placement of the constraining means, thereby allowing the energy dissipation means to dissipate the kinetic energy of the standing waves. This provides the advantage of allowing a frequency of vibration propagating inside the pile to be selectively damped, thereby improving the efficiency of noise reduction during piling without compromising the driving action.

[0008] The energy dissipation means may comprise at least one viscoelastic element adapted to convert energy contained in said standing waves into heat.

[0009] This provides the advantage of introducing a simple and cost effective means of dissipating the kinetic energy associated with piling in a form other than noise.

[0010] The apparatus may further comprise second constraining means for constraining at least one said viscoelastic element. This allows a constrained-layer damping mechanism to be created at the surface of the pile, providing the advantage of increasing the efficiency of the energy dissipation process.

[0011] The first constraining means may be adapted to constrain the wall at a plurality of said locations.

[0012] This provides the advantage of simplifying the apparatus. In addition, the advantage is provided that the spacing between the locations at which the wall is constrained can be reliably set.

[0013] The apparatus may further comprise a layer of pliant material placed between said first constraining means and said wall. This provides the advantage that the physical contact between the first constraining means and the wall is made more consistent.

[0014] At least one distance from at least one boundary of said pile to at least one said location and/or at least one distance from at least one said location to at least one further said location may be substantially equal to one quarter of a wavelength, or substantially equal to an integer multiple of quarter wavelengths, of at least one of said vibrations.

[0015] This sets up at least one standing wave having a wavelength substantially equal to four times the respective distance between the boundary and the location and/or the respective distance between the location and the further location, providing the advantage that at least one frequency of vibration, or band thereof, corresponding to that wavelength can be chosen to be damped.

[0016] The first constraining means may comprise clamping means for clamping to said wall.

[0017] This provides the advantage that the dimensions of the at least one location at which the wall of the pile is constrained can be determined by the dimensions of the clamping means, allowing the resistance of the wall at the at least one location to be easily altered.

[0018] The clamping means may comprise at least one hydraulic actuator.

[0019] This provides the advantage of allowing the strength of the coupling between the wall of the pile and the constraining means and/or the energy dissipation means to be adjusted.

[0020] The apparatus may further comprise area adjustment means for adjusting an area of contact of said first constraining means with said wall at at least one said location.

[0021] This provides the advantage of allowing the surface areas of the locations at which the wall is constrained to be adjusted, thereby allowing adjustment of the bandwidth of a band of frequencies of vibration to be damped simultaneously.

[0022] The area adjustment means may comprise at least one first layer of material adapted to be secured to said first constraining means.

[0023] The apparatus may further comprise mass increasing means for increasing a mass of the apparatus.

[0024] This provides the advantage of increasing the efficiency of operation of the energy dissipation means.

[0025] The mass increasing means may comprise at least one second layer of material adapted to be secured to said first and/or second constraining means.

[0026] The apparatus may further comprise stiffness adjustment means for increasing a stiffness of the apparatus.

[0027] The said stiffness adjustment means may comprise at least one hydraulic accumulator.

[0028] The stiffness adjustment means may comprise at least one third layer of material adapted to be secured to said first and/or second constraining means.

[0029] A preferred embodiment of the invention will now be described, by way of example only and not in any limitative sense, with reference to the accompanying drawings, in which

Figure 1 is a schematic diagram of part of a damping apparatus embodying the present invention;

Figure 2 is a view of the entire apparatus of Figure 1; and

Figure 3 is a detailed perspective view of part of the apparatus of Figures 1 and 2.

[0030] Referring to Figures 1 and 3, a damping apparatus 2 embodying the present invention is shown secured to a pile 4 by means of first constraining means in the form of at least one clamp 18. The damping apparatus comprises second constraining means in the form of a constraining layer element 6, in contact with a surface of the pile 4 at contact areas 10, and energy dissipation means in the form of a viscoelastic layer 8 held within the confines of the constraining layer element 6, also in contact with the surface of the pile 4. A layer of pliant material such as rubber may be placed at each contact area 10 to improve the consistency of the physical contact between the constraining layer element 6 and the surface of the pile 4. Adjacent each contact area 10 is a corresponding volume 12 of increased stiffness inside a body of the pile 4. The amount of additional stiffness inside the volumes 12 may be controlled by the actuation of the clamps 18. The contact areas 10, and corresponding volumes 12, are separated by a distance 14.

[0031] Referring to Figure 2, the damping apparatus 2 embodying the present invention is shown secured to the pile 4, one end of the pile being embedded in a stratum 24 below a body of water 22. A top 16 of the pile 4 is struck with a driving hammer (not shown), causing an impulse to be imparted to the top 16 of the pile 4 and to consequently propagate through the pile 4 toward a bottom 16 of the pile 4. As the impulse propagates, it causes the pile 4 to vibrate, the vibrations having frequency content largely related to the geometry and mechanical properties of the pile 4. These vibrations cause the pile to emit noise into the surrounding air 20, water 22, and sediment 24.

[0032] As the impulse from a hammer strike propagates downward through the pile 4, it meets an impedance difference at each of the interfaces between the body of the pile 4 and the volumes 12 of increased local stiffness within the pile 4, causing a portion of the impulse to be reflected by each volume 12 that it meets. These volumes 12 are separated by distances 14 chosen to correspond to frequencies of vibration that are to be damped by the apparatus. As the impulse propagates, the pile 4 vibrates, and standing waves are set up between the volumes 12 as a consequence of the periodicity introduced by the increased local stiffness induced in these volumes via the contact areas 10 and by means of the clamps 18. Each standing wave set up between a pair of volumes 12 oscillates at a frequency equal to a central frequency, which is directly proportional to the distance 14 between those two volumes 12, the frequency of oscillation having a bandwidth largely proportional to axial dimensions of the volumes 12. In this way, each pair of volumes 12 with which the impulse interacts as it propagates down the pile 4 acts as a band stop filter, attenuating any frequency content of the impulse within the bandwidth of the central frequency corresponding to the distance between that pair, preventing its propagation toward the water 22 and sediment 24. It should be noted that, although Figure 2 shows the entirety of the damping apparatus 2 secured to the pile 4 above the surface of the water 22, the apparatus 4 can also be partially or wholly submerged in the water 22. Each bandwidth can be adjusted by securing at least one first layer of material 26 to the element 6, thereby changing the geometry of the contact areas 10 and altering the distribution of increased stiffness inside the volumes 12.

[0033] At the surface of each part of the pile 4 containing these standing waves, a viscoelastic layer 8 is held by the constraining layer element 6, creating a constrained-layer damping mechanism for converting the kinetic energy of the standing waves into heat via shearing action of the viscoelastic layer 8. This allows the energy present within the standing waves to be dissipated in a manner other than the emission of noise, reducing the total quantity of sound energy emitted by the vibrating pile 4 by selectively damping a section of the frequency spectrum of vibration. The mass of the constraining layer element 6 can be adjusted by securing a second layer of material 28 to the element 6 to tune the damping characteristics of the constrained-layer damping mechanism according to the requirements of a given piling operation. Figure 2 shows one second layer 28 extending the full length of the element 6, but any number of said second layers of any geometry may be secured to the element 6 in any desired arrangement.

[0034] Furthermore, the damping apparatus 2 allows the propagation of frequencies of vibration down the pile that contribute more to the driving action of the pile 4 than other frequencies, while simultaneously damping the other frequencies and dissipating their associated energy in the form of heat rather than noise.

[0035] It will be appreciated by persons skilled in the art that the above embodiment has been described by way of example only, and not in any limitative sense, and that various alterations and modifications are possible without departure from the scope of the invention as defined by the appended claims. For example, first constraining means of different separation or periodicities can be included at the same time in one device, in order to attenuate more than one wavelength or wavelength range.

Claims

1. A vibration damping apparatus for damping vibration of a pile being driven into a substrate, the apparatus comprising:

first constraining means for constraining a wall of the pile at at least one location thereon to adjust the resistance of said wall at said location to propagation of vibrations along said wall, to reflect said vibrations along said wall; and
energy dissipation means for dissipating energy stored in standing waves generated in said wall as a result of interaction of at least some of said reflected vibrations with further vibrations in said wall.

2. An apparatus according to claim 1, wherein said energy dissipation means comprises at least one viscoelastic element adapted to convert energy contained in said standing waves into heat.

3. An apparatus according to claim 1 or 2, further comprising second constraining means for constraining at least one said viscoelastic element.

4. An apparatus according to claim 3, wherein said first constraining means is adapted to constrain said wall at a plurality of said locations.

5. An apparatus according to one any of the preceding claims, further comprising a layer of pliant material placed between said first constraining means and said wall.

6. An apparatus according to any one of the preceding claims, wherein at least one distance from at least one boundary of said pile to at least one said location and/or at least one distance from at least one said location to at least one further said location is substantially equal to one quarter of a wavelength, or substantially equal to an integer multiple of quarter wavelengths, of at least one of said vibrations.

7. An apparatus according to any one of the preceding claims, wherein said first constraining means comprises clamping means for clamping to said wall.

8. An apparatus according to claim 8, wherein said clamping means comprises at least one hydraulic actuator.

9. An apparatus according to any one of the preceding claims, further comprising area adjustment means for adjusting an area of contact of said first constraining means with said wall at at least one said location.

10. An apparatus according to claim 9, wherein said area adjustment means comprises at least one first layer of material adapted to be secured to said first constraining means.

11. An apparatus according to any one of the preceding claims, further comprising mass increasing means for increasing a mass of the apparatus.

12. An apparatus according to claim3 and 11, wherein said mass increasing means comprises at least one second layer of material adapted to be secured to said first and/or second constraining means.

13. An apparatus according to any one of the preceding claims, further comprising stiffness adjustment means for increasing a stiffness of the apparatus.

14. An apparatus according to claim 13, wherein said stiffness adjustment means comprises at least one hydraulic accumulator.

15. An apparatus according to claim 3 and claim 13 or 14, wherein said stiffness adjustment means comprises at least one third layer of material adapted to be secured to said first and/or second constraining means.

Figure 1

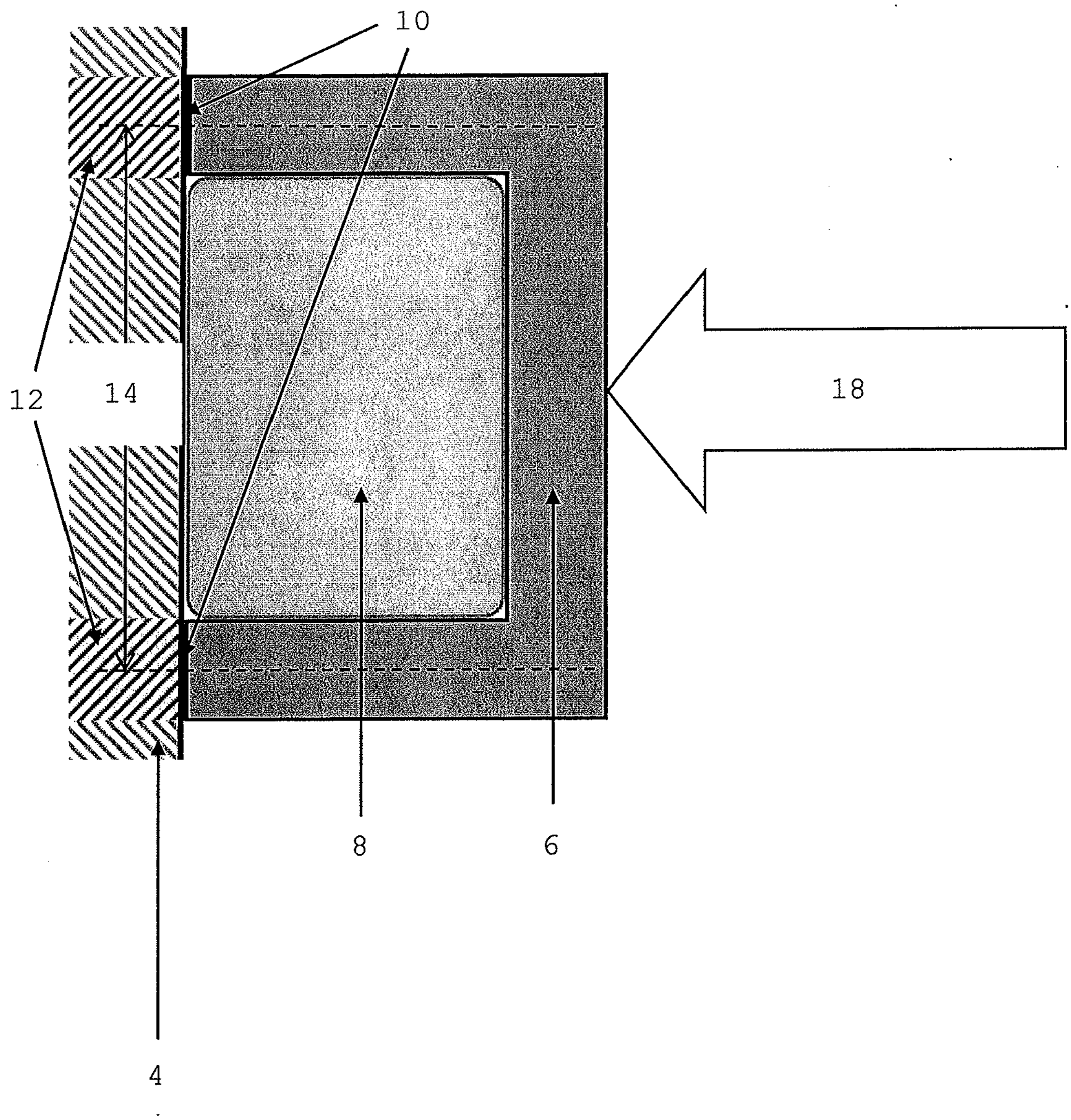


Figure 2

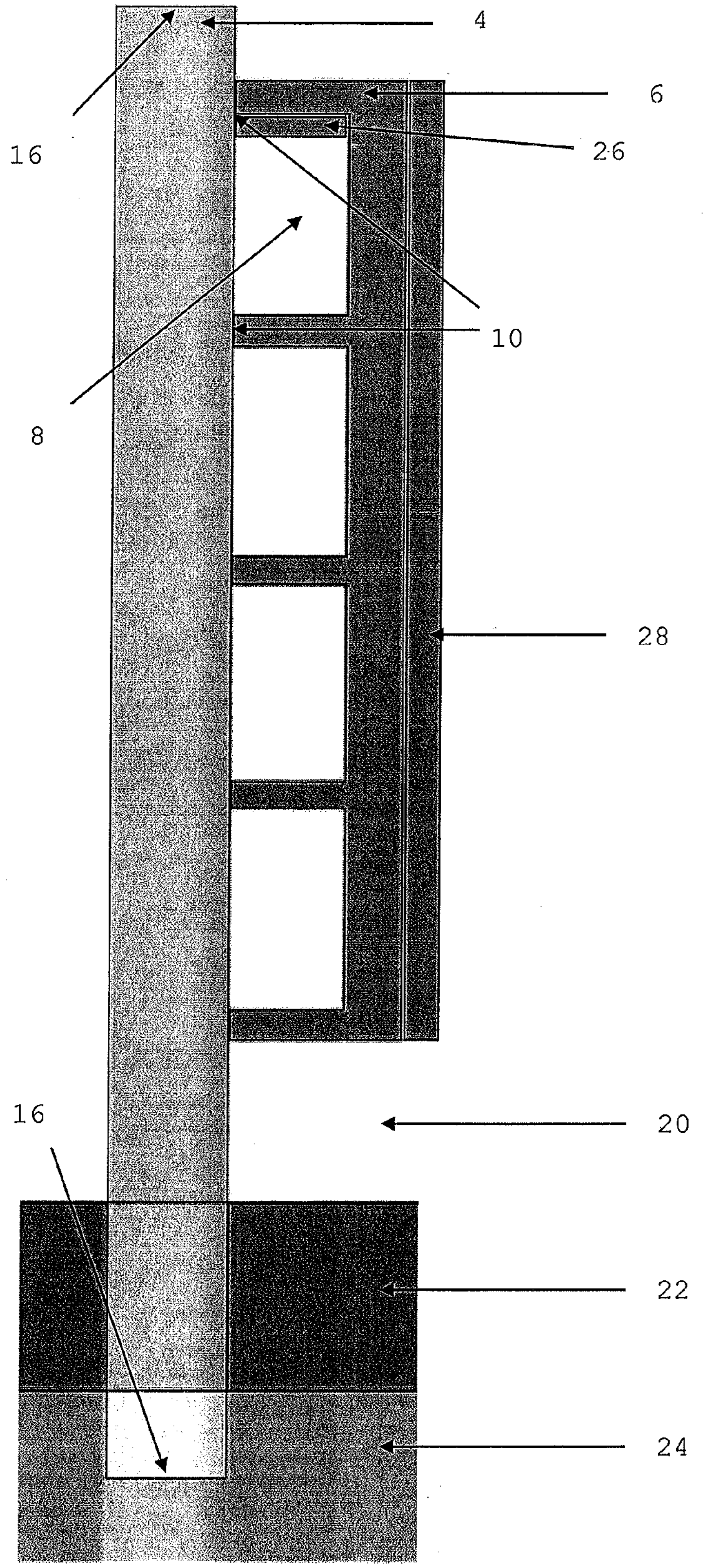
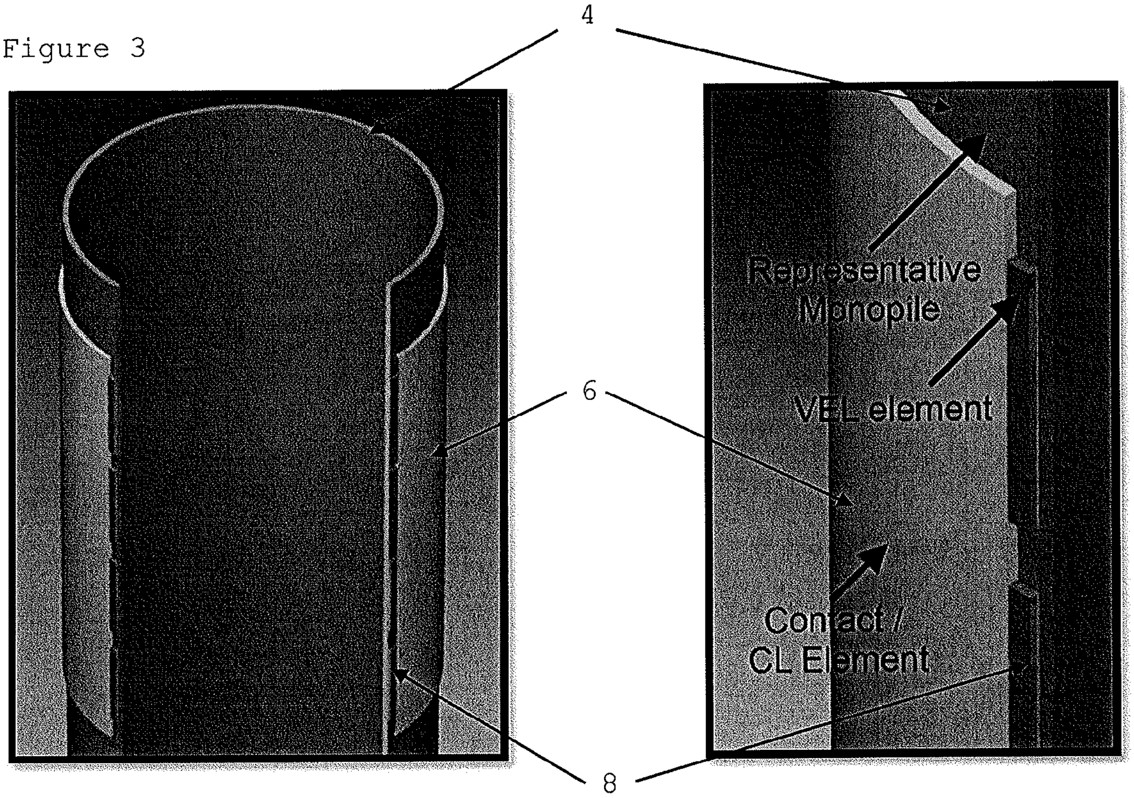


Figure 3


4
Representative
Monopile
VEL element
6
Contact /
CL Element
8

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EUROPEAN SEARCH REPORT

Application Number
EP 15 17 4258

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	WO 2007/150028 A2 (GUNDERBOOM INC [US]) 27 December 2007 (2007-12-27) * abstract * * paragraphs [0048], [0049], [0056] - [0058]; figures 1-3,6 * -----	1,3-15 2	INV. E02D13/00
X A	EP 2 884 006 A2 (RWE INNOGY GMBH [DE]) 17 June 2015 (2015-06-17) * abstract * * paragraphs [0011], [0017], [0033], [0034]; figures 1-3; compound 5 * -----	1-3,6 4,5,7-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	30 November 2015	Koulo, G

CATEGORY OF CITED DOCUMENTS

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EP 2884006 A2	17-06-2015	DE 102013019288 A1	21-05-2015
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