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(54) **System for detection and monitoring of deep land subsidence**

(57) System (30) for detection and monitoring of deep settlements - subsidence phenomena - formed by:
- a number of ground wells (3), each housing a vertical measuring system, said vertical measuring system being further composed of: an anchorage point (8), called benchmark, that is installed at the deep end (5) of each well (3) and fixed to the surrounding soil; one rod (at least) (4b) fixed to said anchorage point (8), and extending upwards along the entire length of said well (3) up to the ground surface, the above said rod (4b) is lowered in a sleeve protection tube (4) to keep it free from friction due to the surrounding soil; a system measuring the displacement occurring between the said rod (4b) fixed to the deep anchorage point (8) and the soil surface, the system is characterized by the fact of comprising:
- a counterbalancing device (2), installed on the surface, composed of a scale with specific weights (11) holding one or more of said rods (4b), and keeping them in a static equilibrium, along the exact direction of their respective axis;
- a number of telescopic sleeves (6), that are integrated in the said protective casing (4), each (21) being firmly screwed on the upper part and free to slide along the lower part; each sleeve (21) houses a spacing collar to center and let the rod slide free (23);
- at least one thermal compensation sleeve (9), integrated in said protective casing (4), composed of at least two different materials with different thermal expansion coefficients. so that the measuring system (1) detects the distance between two points: one at the far end of the rod (4b) and the other at the far end of the casing (4); such a distance represents the measurement of the subsidence phenomenon occurring on the area; all the above measurements being independent of geometrical deformations of well profiles (3), and of environmental thermal variations, if any.

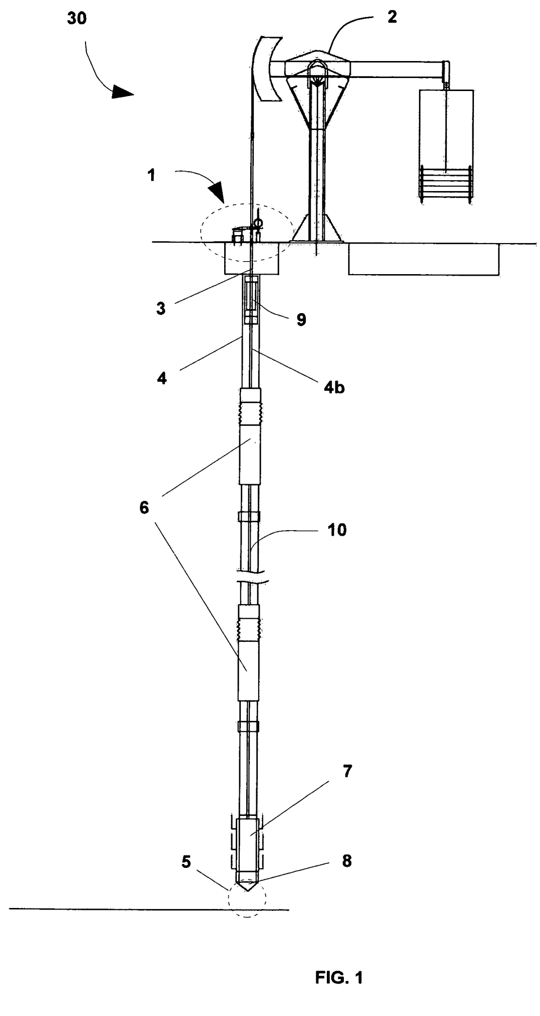

FIG. 1

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Description

[0001] The present invention relates to a system for detection of vertical displacements of deep underground soil caused by the so called subsidence phenomenon. Said system can monitor the progress of this phenomenon in time, and transmit the detected data, in real time, to a specific electronic data control unit. Subsidence is a phenomenon eventually caused by natural events, like earthquakes and landslides, or by human activities, like emptying of mineral or hydrocarbon deposits, and/or drainage of deep water table.

[0002] The detection system consists of a set of boreholes, to a variable depth up to 2.000 meters, where vertical measuring devices are installed. Each vertical measuring device is made of a deep anchorage point, installed at the bottom end or at an intermediate point along the borehole and fixed to the surrounding soil. Said anchorage point is fixed to a steel rod rising along the borehole up to the surface. This rod is inserted in a steel protection sleeve casing, through to the entire borehole, to keep it free from soil friction. A special control unit is placed on the surface to measure the displacement between said inner rod, connected to the deep anchorage point, and the surface of the surrounding soil. The detected quantity represents an accurate measurement of the deep subsidence phenomenon. Other measurements, taken in other similar boreholes, placed at a certain horizontal distance, allow the reconstruction of an accurate final profile of the sol settlement occurred in deep layers with a margin of accuracy up to few tenths of millimeter.

[0003] The state of the art discloses some special technical devices aiming at the measurement of deep soil settlements.

[0004] Patent US 4.382.335 (Frank) reveals the standard solution for subsidence measurements where one or more probes are lowered down to a specific well and attached to specific points fixed to the surrounding soil. Each probe is connected, by a special chain, to a surface attachment. A possible soil displacement occurring in the underground would cause a downwards movement of the probe, and, consequently, of the surface attachment which, connected to a potentiometer, detects the size of the displacement.

[0005] Patent US 4.291.581 (Jacoby) describes a solution similar to the previous one, where one or more probes are fixed at different depth along a specific well; said probes are connected to the ground surface by a cable constantly kept on tension by a specific counterbalancing weight. A displacement occurring in the deep part of the rods, is immediately detected and measured by proper devices installed on the surface.

[0006] Patent US 5.005.422 (Ruscev and others) discloses a solution where a set of radioactive markers are fixed inside a well, at different levels of depth. From time to time, a mobile probe, containing a nuclear detection assembly, is lowered in the well. When the probe detects the radiation peak a measurement is taken of the cable length connecting the probe to the land's surface. A depth variation of the markers, detected in the course of time, would correspond to the soil settlements.

[0007] Patent JP 6.137.905 (Oi Yukio and others) describes a completely different concept consisting in some pressure transducers to be embedded at different depths in the underground and measure the weight of the upper water column contained in the well. Assuming that the water surface is kept at a constant level, a deep displacement would result in a difference of the water volume. The patent mentions the possibility of the well to have a telescopic extension.

[0008] Patent JP 2001.295.261 (Hayashi and others) describes a special device made of two coaxial cylinders, sliding one opposite to the other. The base of the inner cylinder is fixed to the soil deep end, while the top of the outer cylinder is fixed to the ground surface. Should a subsidence event occur it would cause the inner cylinder slide in the outer one. A measurement of the level difference between the two cylinders allows detection and quantification of the soil displacement. This solution seems to be more suitable for soil settlements at small depths (i.e. building foundations) rather than investigations of deep wells of geological interest.

[0009] With reference to the following publication: "Guidebook to studies of land subsidence due to groundwater withdrawal", International Hydrological Programme, Working Group 8.4, Ed. Joseph F. Poland, UNESCO, chapter 2 reports some interesting solutions: single or twin-pipe systems with probes anchored to surrounding soil at different depths, and respectively connected, by special rods, to a surface platform. This platform is equipped with mechanical devices and counterbalancing weights, such to keep the above rods on tension and free the entire system from possible dead weights. The same publication reports, among different solutions, some of those described in the above mentioned patents, such as, for instance, the device with radioactive markers of patent US 5.005.422 (Ruscev and others.).

[0010] All the above known solutions involve a certain number of drawbacks, some of which particularly relevant that may jeopardize the accuracy level of measurements. A first problem arises from the fact that some vertical displacements and possible soil cross-movements at different depths may affect the ideal linear profile of rods connecting the deep anchorage points to the soil surface. These rods can bend and touch the protection sleeve casings, which could also be damaged, deformed or interrupted at different levels, as a consequence of movements of the surrounding soil.

[0011] Known solutions rely on devices that keep these rods constantly tense, so to be hardly affected by cross forces that could alter their longitudinal profile. However, these solutions are not always able to keep rods constantly on tension and in a perfect vertical position, sometimes they may even cause further problems and drawbacks. Furthermore, it is common knowledge how the upper section of any borehole is significantly affected by thermal variations from soil surface. As a consequence, temperature variations, causing material deformations, may become very important in mechanical structures of hundreds of meters up to serious deformation or even breakdown.

[0012] All these problems are overcome by this invention which main goal is the detection of deep soil settlements, causing subsidence phenomena. This system would consist of some specific means to be lowered in boreholes, having a radial mechanical structure able to translate [shift the position without rotating] along the vertical direction, in order to follow the surrounding deformations of soil due to subsidence phenomenon and/or cross movements.

[0013] Another objective consists in the use of an inner rod, anchored to the bottom end of the borehole, equipped with mechanisms such to minimize the rod's friction during the translation inside the radial mechanical structure.

[0014] A further objective consists in the thermal compensation so to avoid deformation effects of materials due to temperature variations mainly occurring on the upper part of the borehole.

[0015] Another objective consists in the development of special spacers to keep the rod tense, balanced and in a perfect vertical position free to slide along the sleeve protection casing.

[0016] As a matter of fact, this invention's specific goal is a system for the detection and monitoring of deep soil settlements, formed by:

- a number of wells each housing a vertical measuring device; said vertical measuring device being further composed of: an anchorage point called benchmark, firmly fixed to the deep end of the well, one or more rods fixed to said anchorage point, and extending upwards along the entire length of the well, up to the ground surface, the above said rod is free to slide alongside being inserted in a sleeve protecting casing; a measuring unit of the displacement occurring between the deep bottom end of the measuring rod and its upper end at ground surface.

and characterized by the fact of comprising:

- a counterbalancing device, installed on the ground surface, composed of a scale with some specific weights holding one or more of said rods, and keeping them in a static equilibrium, exactly towards their respective axis;
- a number of telescopic couplings, integrated in said sleeve protecting casing, each of said coupling being fixed and screwed to the upper part, and being free to translate along the lower part; each coupling houses a spacing collar to allow the rod slide freely;
- at least one thermal compensating coupling, integrated in said sleeve protecting casing, composed of at least two different materials with different expansion coefficient, so to allow the measuring device detect the distance between two points: one placed at the lower end of the rod, and the other placed at upper end of the rod, said distance representing the measure of the deep subsidence phenomenon; all the above measurements being independent from geometrical deformations along well profiles and from environmental thermal variations.

[0017] If compared to similar known devices, this invention is characterized by a certain number of further advantages such as: very high accuracy of measurements (detected vertical displacements up to 0.1 mm); length of the vertical measuring device up to 2 kilometers; integral resilience of structures; use of standard components, leading to a cost effective final product, reliable, long lasting and high quality device.

[0018] The present invention is now being described by way of illustration, still not restrictive, with particular reference to the figures of the enclosed drawings, wherein:

figure 1 is a schematic side view of a deep settlement monitoring device, together with its borehole and a deep anchoring point connected to the surface by its rod.

figure 2 is a side view of the same system as in figure 1, where the tensing and balancing particular connecting the rod is focused.

figure 3 is a side cross view of a telescopic sleeve, that is part of the system shown in figure 1;

figure 4 is a side cross view of a thermal compensation sleeve, that is part of the system shown in figure 1.

[0019] The following description underlines some of the many embodiments of the present invention just as an example. In fact many others are the possible embodiments depending on the technical solution adopted. The different figures show the same components with the same reference numbers.

[0020] The overall structure of system 30, core of the present invention, is schematically represented in figure 1. This system 30 is essentially composed of a part installed above ground surface and a part installed underground, more precisely down in a well which depth can reach up to 2.000 meters. The part above ground comprises a special measuring device 1 for displacements, and a special device 2, consisting of an accuracy balancer to hold a set of rods. The part underground, inserted in the deep well 3, is composed of a number of rods 4b and coaxial casings 4, down to the deep bottom end 5 of the well. Some telescopic couplings 6 are installed at a spaced distance, to connect the rods 4b to the sleeve outer casing 4, so to center their position along the casing and let them slide frictionless. At the bottom end of the rod-casing system, a special anchorage device 7 is firmly grouted to the well bottom with concrete. The anchorage holds and fixes together the rod-casing string system, thus becoming the down-the-well absolute reference point 8, called benchmark: any differential surface measurement between the rod and the casing will refer to the same benchmark.

[0021] The rod string 4b connects the anchorage point 8 to the surface: this connection is neither affected by thermal variations by means of special thermal compensation sleeves 9, nor by mechanical factors by means of the above said telescopic sleeves 6. The rod 4b is free to slide along the protection sleeve casing and couplings 6, so to "transmit" the exact position of the deep benchmark 8 up to the surface. The crop-ends of the protection casing are mechanically connected by means of the telescopic couplings 6 so to adapt the length of the casing to the well length variation in accordance with occurring soil settlements or bulges. This fact permits a quick adjustment of the measuring rod system, error free, both in the long and short term, independently from the soil movements, whatever direction movements occur.

[0022] The sleeve casing is filled with a neutral lubricating liquid 10, such as silicone oil, petroleum jelly, or other similar materials. The telescopic joints 6 make the same casing watertight, so that no liquid is lost in the soil. The lubricating liquid is further suitable to compensate the hydrostatic pressure pressing the casing and elastic joints from the outside. In such a way, the differential pressure on the gaskets of the elastic sleeves is almost totally annulled, thus making the rod sliding smoother and preventing structural deformations of the components subjected to hydrostatic pressure.

[0023] Figure 2 shows the accuracy counterbalancing device 2, composed of a weights scale 11, holding a number of said rods 12 and keeping them in a static equilibrium. The rods end, in their upper part, with an eyebolt 13, to which a chain 14 is hooked so to connect the rod string to the saddle of the counterbalancing device in a flexible and tangent way. This solution guarantees a stable transmission of the counterbalancing weight, exactly along the direction of the rod's axis, along the entire travel of the device. The weight to hold is exactly equal to the total weight of rods and compensation sleeves. This weight can be increased in case of excessive sliding friction. The compensation of rods proper net weight by using an accurate counterbalancing device 2, guarantees a high stability and sensitivity of the instrument in respect to very small displacements, i.e. of a hundredth of millimeter on a maximum length of 2.000 meters. At the upper end of the well, immediately under the counterbalancing device 2, a measuring device 16 is installed to detect the distance between two points: one placed on the rod 17, and the other placed on the plate at the end of the casing string 18 grouted on to the surface. This distance depends on the vertical soil displacements, meant as overall distance variation of the soil layer between the deep benchmark and the ground surface.

[0024] The measurement of this distance is provided by two instruments: a mechanical and an electronic one. The mechanical instrument consists of a dial gauge, with a visible 0.01 mm graduated dial for direct reading. Instead, the electronic instrument consists of a displacement transducer and a standard digital static memory recorder, also called datalogger. Said datalogger is also connected to a number of temperature sensors 19, for thermal compensation of the upper part of the rod-casing string which is most affected by soil temperature variations.

[0025] Figure 3 represents a cross view of an elastic sleeve. This component provides the mechanical connection between rods 4b and casing 4, allowing the relative translation, such as the linear extension or compression of rods along their respective axis, and free sliding of rods along the casing. The measurement rods 4b are connected each other using a steel nipple 20 having, preferably, a diameter of 1.27 cm (i.e. 0.5 inches). Rods, in the lower part of the string where temperature is assumed to be constant, are made of steel, instead in the upper part of the string, let's say some 20 meters below the ground surface, are made of invar®, that is less affected by thermal variations. The outer sleeve protecting casings 4 have, preferably, a diameter of 5.08 cm (i.e. 2 inches) and are usually made of steel. The casing crop ends have usually a length ranging between 3 and 9 meters, and can be adjusted to the geological features of the site.

[0026] The casing crop ends 4 are connected by means of elastic sleeves, so to allow the adjustment of rods in accordance with the soil movements, either settlements or bulging. This feature is vital to achieve a correct and reliable measurement of the distance between the surface 18 and the deep benchmark 8, mainly in the long run, i.e. some years, with significant displacements, higher than 0.1 meters. Figure 3 also shows the special device allowing adjustment of the casing length, consisting of a coupling 21 screwed and fixed to the casing upper part, whereas is free to slide along the lower part. The coupling translation 21 along the lower part of the casing is limited by a mechanical stop ring, the so called limit stop 22, that can hold the weight of the entire rod string during its installation. The coupling 21 houses a centering and spacing collar to ease rod 23 sliding, and is composed of a ball bushing 25. This device is extremely important in order to avoid interference of casing movements 4, due to soil displacements and thermal variations, with the free sliding of rods 4b which elongation is exclusively due to thermal adjustments.

[0027] The outer part of coupling 21 is coated with a rubber sheath 26, fixed and constrained against the casing by two additional elastic collars 23. This rubber sheath 26 protects the sliding parts from soil, during installation, and from calcareous deposits in the long term. Each telescopic joint is filled with lubricating oil, water tightness being obtained by two sliding O-rings 24, placed at the lower sliding part of the coupling 21.

[0028] A special connecting nipple has been designed, as shown in figure 4, in order to compensate rod 4b length variations as a consequence of temperature variation. In the drawing, the two rods are mechanically jointed by a special invar® coupling 27, coupled to an aluminum shell 28. This pair of elements, made of different materials, generates a movement as a function of temperature, and this movement is equal in magnitude and opposite to the movement generated by the invar® rod 26.

[0029] The elongation of the aluminum component 28 is function of the thermal expansion coefficient of the invar component, whereas the elongation of the invar component 26 is function of the thermal expansion coefficient of the aluminum component 28.

[0030] By so doing the association of elements made of different metals produces a movement effect, as a function of temperature variation, equal in magnitude and opposite to the movement generated by the rod made of invar® 26, thus resulting in a automatic compensation of the difference between the lowest and the highest temperature in a 24 hours period due to environmental effects.

[0031] Therefore, the above examples show that the present invention achieves all the proposed objectives. In particular, it discloses a special system for the detection of deep land subsidence, said system comprising some specific means, installed in their respective wells in soil, having a radial mechanical structure able to translate along the vertical direction, in order to follow the surrounding deformations of soil due to subsidence phenomenon and/or transversal motion.

[0032] In addition, according to this invention, said means comprise an inner rod, attached to a deep anchorage point, having some mechanisms to minimize the rod's friction during the translation inside the radial mechanical structure.

[0033] Furthermore, the same specific system comprises a special device to compensate thermal deformation effects on materials, mainly on the first part of the down-the-hole rod string, which is most affected by the ground difference between the lowest and the highest temperature in a 24 hours period.

[0034] Last but not least, said system comprises another special device to keep said rods on a linear and balanced tension, in a perfect vertical position, so to smooth their sliding along said radial mechanical structure (casing).

[0035] The present invention has been described by way of illustration, still not restrictive, in accordance with embodiments that better suit our needs; however possible changes and/or modifications may be introduced by those skilled in the art without departing from the relevant scope, as defined in the enclosed claims.

Claims

1. System (30) for detection and monitoring of deep settlements - subsidence phenomena - formed by:

   - a number of ground wells (3), each housing a vertical measuring device, said vertical measuring device being further composed of: an anchorage point (8) - so called benchmark - fixed at the deep end (5) of each well (3), and grouted to the surrounding soil; at least one rod (4b), fixed to said anchorage point (8), and extending upwards along the entire length of said well (3), up to the ground surface, the above said rod (4b) being independent in respect of the surrounding soil, as lowered in a protective casing (4); a device (1) measuring the displacement between said rod (4b), attached to said deep anchorage point (8), and the surface of the surrounding soil,

   and **characterized by** the fact of comprising:

   - a counterbalancing device (2), installed on the ground surface, composed of a scale with some specific weights (11) supporting one or more of said rods (4b), and keeping them in a static equilibrium, along the exact direction of their axis;
   - a number of telescopic sleeves (6), that are integrated in said protective casings (4), each of said sleeves (21) being fasten screwed to the upper part, and being free to translate along the lower part; each sleeve (21) houses a centering and sliding mechanism for said rods (23);
   - at least one thermal compensation sleeve (9), that is integrated in said protective casing (4), composed of at least two different materials, having their different thermal dilating coefficient, so that the measuring device (1) detects a distance between two points: the first placed at the rod bottom end (4b), and the second placed at the casing upper end (4), said distance representing a measure of the deep subsidence phenomenon; all the above measurements being independent from geometrical deformations along the well profile (3), and not affected by environmental thermal variations.

2. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to the previous claim, **characterized by**:

   - said rod string (4b) ends, it its upper part, with an eyebolt (13) to which a chain (14) is attached, to connect above said rod string to the saddle point (15) of said counterbalancing device (2), in a flexible and tangent way. This to guarantee a stable transmission of the counterbalancing weight (11), exactly along the direction of the rod (4b) axis and along the entire travel of the device, so to provide extreme stability and accuracy in detecting very minute settlements - some hundredths of millimeter - on a max distance of 2.000 meters.

3. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- said distance measurement is taken by two instruments: one mechanical and one electronic; the mechanical instrument is made of a dial gauge, with graduation of 0.01 mm, for manual readings; instead the electronic instrument is made of a displacement transducer and a standard static memory digital recorder, also called data logger. Said data logger is connected to a number of temperature sensors (19), to provide thermal compensation on the measurements taken in the upper part of the rod string (4b) which is most affected by temperature variations induced by the ground surface.

4. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- said measurement rods (4b), connected one another by a nipple (20), have a diameter of 1.27 cm - 0.5 inches; are made of steel in their deeper section whereas are made of invar® for upper 20 meter section as this part is more affected by thermal variations.

5. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- said protection sleeve casing (4) has a preferable diameter of 5.08 cm - 2 inches - and is usually made of steel; the length of each crop-end having a length between 3 and 9 meters, to better suit the site geological features.

6. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- each of said telescopic sleeves (6) has a limited translation motion, stopped at its lower end by a mechanical stop ring, called limit stop (22), holding the weight of the entire rod string during installation; the outer part of sleeve (21) is coated by a rubber sheath (26), that is fixed and constrained to the casing by two additional elastic collars (23); each telescopic sleeve is filled with lubricating oil, water tightness being obtained by two sliding O-rings (24), placed at the lower sliding part of the coupling (21).

7. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- each sleeve (21) houses a centering and sliding mechanism for said rods (23) made of a ball bushing to avoid interference of casing movements (4), due to soil displacements and thermal variations, with the free sliding of rods (4b) which elongation is exclusively due to thermal adjustments.

8. System (30) for detection and monitoring of deep settlements - subsidence phenomena - according to one or more of previous claims, **characterized by**:

- said thermal compensation sleeve (9) is partly made of invar® (27), and partly in aluminum (28); the elongation of the aluminum component (28) is function of the thermal expansion coefficient of the invar component, whereas the elongation of the invar component (26) is function of the thermal expansion coefficient of the aluminum component (28). By so doing the association of parts made of different materials generates a motion effect function of temperature, equal in magnitude and opposite to the motion generated by the rod made of invar® (26), with automatic compensation of thermal variation effects.

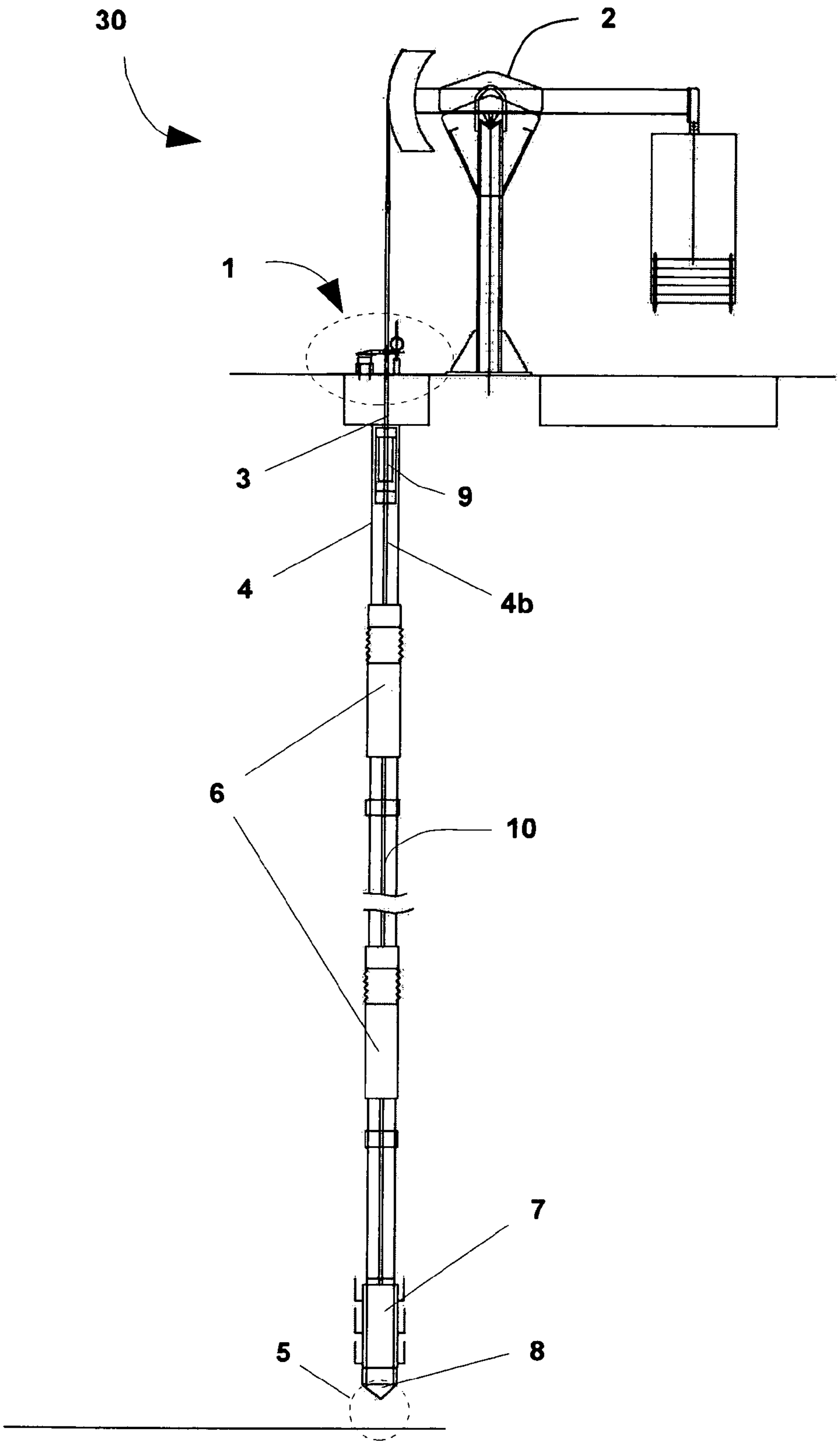

FIG. 1

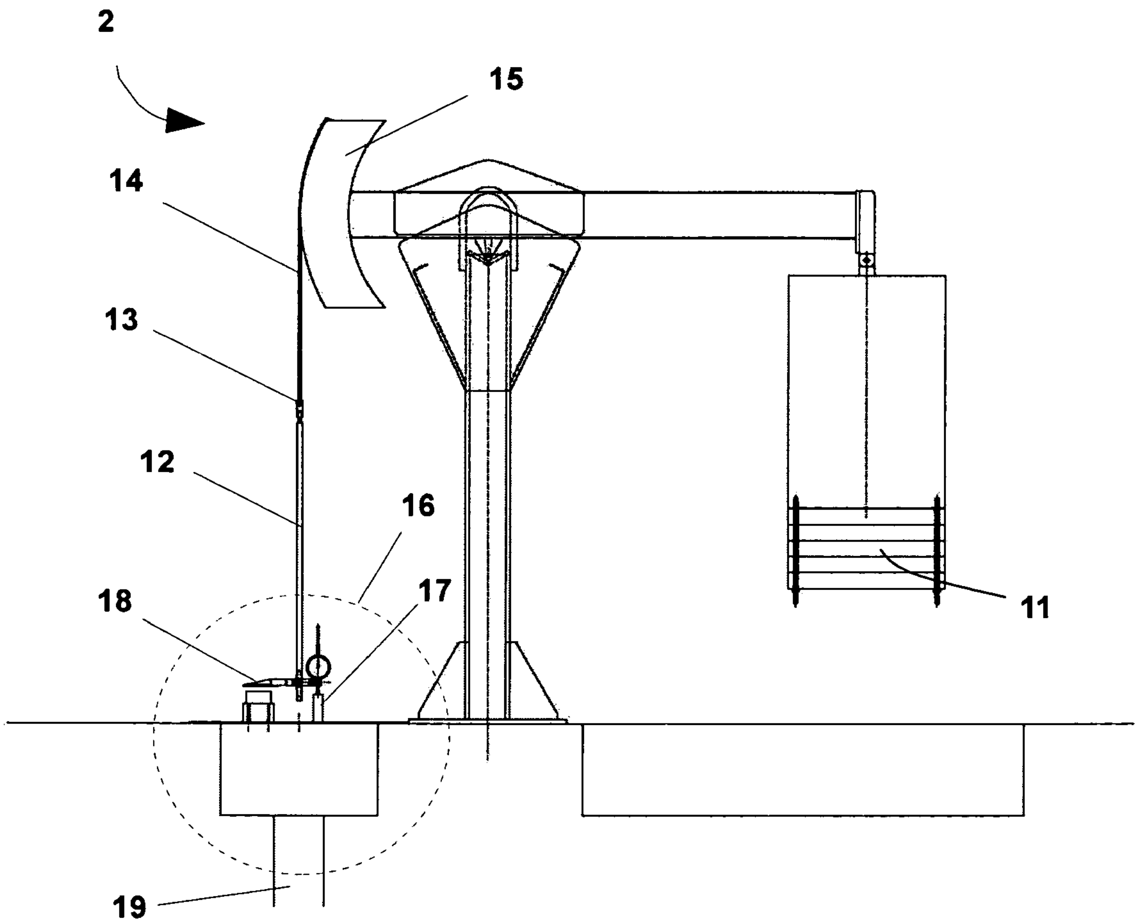

FIG. 2

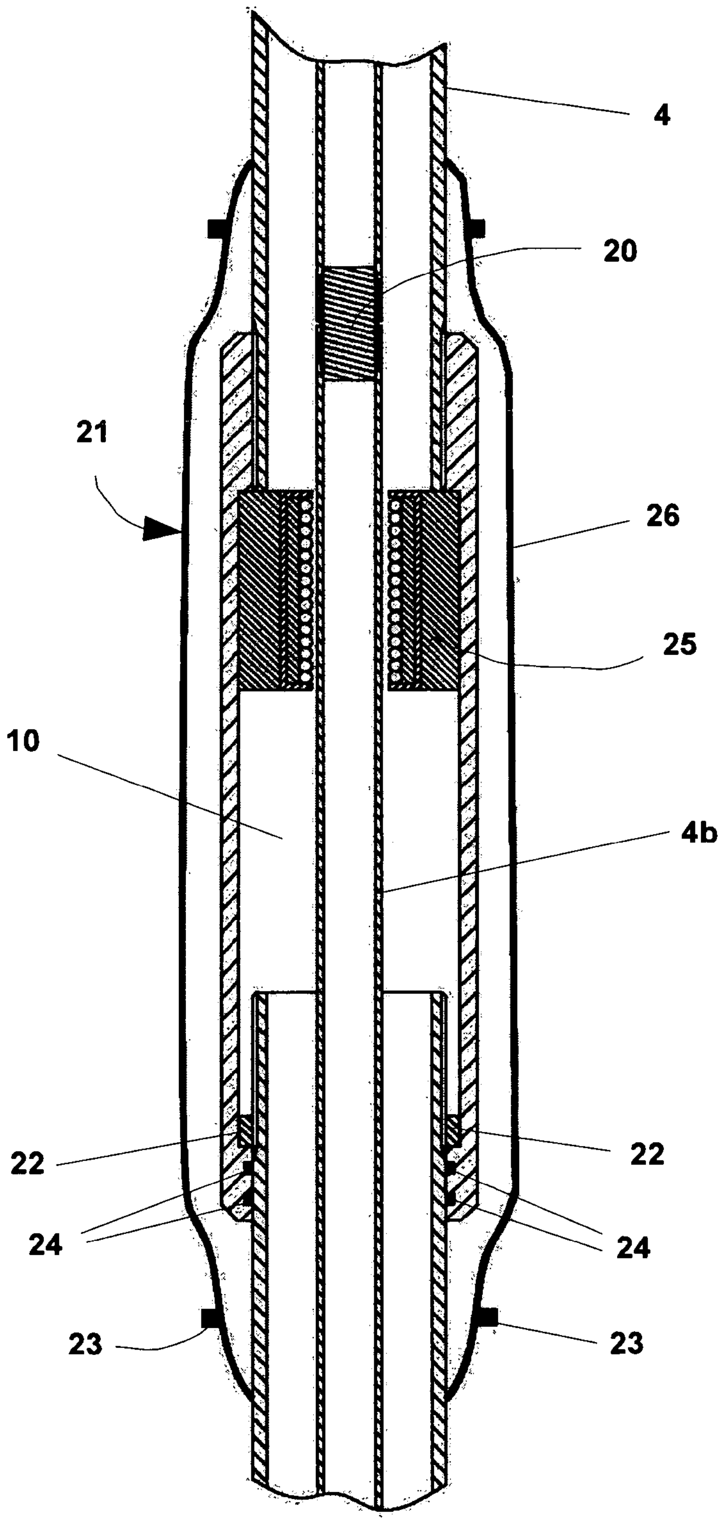

FIG. 3

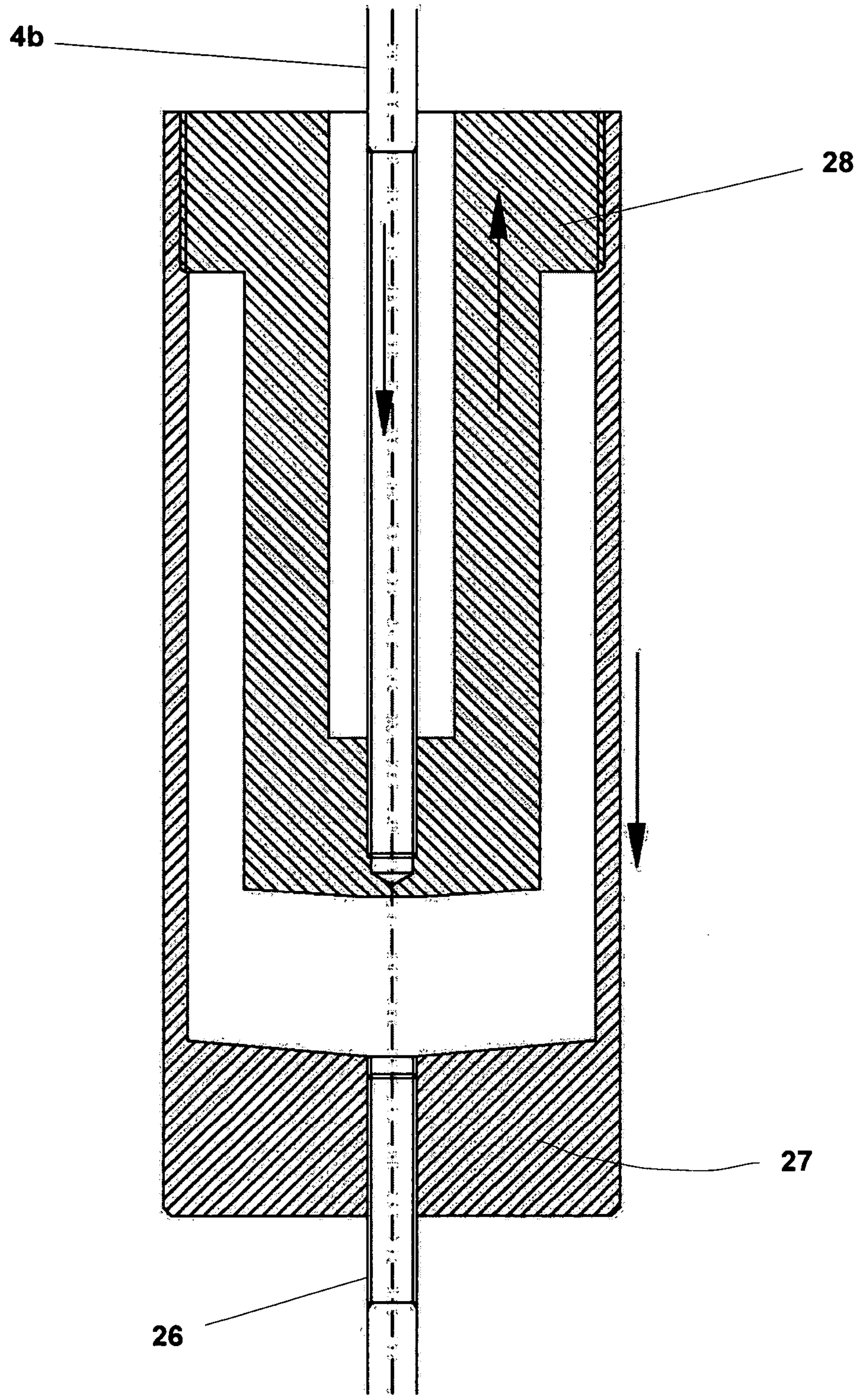

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 09 42 5290

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	ROBOTTI F. & CREAM M.: "Ground subsidence control by deep-well special survey system" 3RD INT. CONFERENCE ON PROTECTION OF STRUCTURES AGAINST HAZARDS, 28 September 2006 (2006-09-28), pages 243-250, XP008116033 Venice * pages 244-246 * * the whole document * -----	1-5,7	INV. E21B47/04 E21B49/00 E02D1/02 G01V11/00 E21B17/07

TECHNICAL FIELDS SEARCHED (IPC)

E21B
E02D
G01V

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	15 January 2010	van Berlo, André

CATEGORY OF CITED DOCUMENTS

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