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(54) **PILE DRIVING RIG**

PFAHLRAMME

ENGIN DE BATTAGE DE PIEUX

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(73) Proprietor: **CP TEST A/S**
DK-7100 Vejle (DK)

(72) Inventor: **SKOV, Rikard**
DK-7100 Vejle (DK)

(74) Representative: **Nielsen, Henrik Sten et al**
Budde, Schou & Ostenfeld A/S
Vester Søgade 10
1601 Copenhagen V (DK)

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Description

[0001] The present invention concerns pile driving and pile driving rigs as well as a method for determining the load-bearing capabilities of various underground strata.

[0002] Piles are widely used for forming foundations to support various structures on the ground for land applications as well as on the sea bottom in marine applications. Piles are advantageous in cases of soft grounds, where it is necessary to go down to a substantial depth below the surface, in order to find sufficient load-bearing capability. Pile-driving methods for the forming of foundations, in fact, tend to be increasingly competitive in relation to digging methods due to the development of increasingly effective pile-driving equipment.

[0003] The proper determination of the load-bearing capability is naturally a crucial factor for any kind of foundation. In the case of pile foundations, the accurate determination of the load-bearing capability of a pile tends to be somewhat difficult since the subsoil strata which effectively determine the load-bearing capability are not readily accessible. Another risk can be that an occasional fracture of a pile may go unnoticed since it is not easily detectable.

[0004] The load-bearing capability of underground strata may vary considerably as the underground may include very soft layers, perhaps more or less floating layers, with practically no permanent stability interchanging with hard layers. These circumstances are, in principle, relevant to any kind of foundations, but have a particular relation in the contexts involving pile foundations, which tend to be used in geologically difficult situations in which other foundation methods fail. It is generally desired to drive down the piles to a depth in which the tip of the pile is supported on a solid layer. Although friction at the sides of a pile will also have an effect, it is generally preferred to rely mainly upon the resistance forces offered against further penetration of the pile tip.

[0005] When driving down a pile by hammering, the subsidence of the pile effected by a blow of the hammer will depend widely on the resistance to the pile tip at its current position, so that an accurate observation of the progress of the driving may, in fact, reveal a rather detailed information about the underground load-bearing capabilities along the route of pile driving. If the impact force delivered by the hammer in a hammer blow, and the corresponding subsidence of the pile is known, the resistance to penetration of the pile and thus the pile load-bearing capability may be calculated directly. Since this direct calculation is affected by a number of uncertain factors, some affecting the determination of the force pulse actually transmitted into the pile, and others being related to settling in the subsoil strata over time, it is generally preferred to verify the calculation by load test experiments on selected piles. Since load test ex-

periments may be complicated and time-consuming, it is generally not practical to test load each one among a large number of piles, test load experiments being preferably carried out on selected piles only, in order to establish correction factors, which may then be applied in the calculations of the load-bearing capabilities of the other piles based on pile by pile-observations obtained during the ramming operation.

[0006] The monitoring of the ramming operation and the calculation of the pile load-bearing capability are prescribed in various building codes, which are applied as prescribed by the relevant national regulations. The German standard DIN 4026 e.g. prescribes that a log must be kept with recordings of the hammer energy and of the pile subsidence. The level of the pile must be measured once for every ten hammer blows, for some of the piles during the entire ramming operation, and for the remaining piles just during the last thirty hammer blows. The hammer energy is calculated as the stroke of the drop load times the force of gravity on the drop load. The energy is plotted versus the depth of pile penetration to produce a plot from which readings may be taken regarding total energy per meter of pile penetration or total energy during the ramming of the pile. These data sets are used to verify that the ramming operation has proceeded as intended and are used to calculate the load-bearing capability by comparing them to similar data sets obtained for piles, in which the load-bearing capabilities have been verified by other methods.

[0007] Other building codes may differ from the DIN 4026 on various points, but generally all building codes concerned with pile foundations comprise requirements for the recording of the hammer-blow energy and of the corresponding pile subsidence in one way or another.

[0008] The hammer-blow energy is generally established by measuring the drop height of the drop load and by multiplying the drop height with the calculated force of gravity effecting the drop load, whereby the potential energy is obtained, which may be assumed to be transformed into an equivalent amount of kinetic energy in the drop load, provided that the drop load falls without any restraints. Corrections may be applied, e.g. in case the direction deviates from the vertical direction, and to account for friction and other factors influencing the operation. In the case of diesel hammers, i.e. hammers in which the drop load is formed as a piston which compresses a fuel-air mixture as it drops, and in which the drop load lifting force is provided by a sudden combustion of the fuel-air mixture, a reduction factor must be applied to take account of the fact that a portion of the energy of the moving drop load is effectively extracted for the diesel drive system, so that the potential energy of the drop load is not fully applied to the driving of the pile. In general, the driving force transmitted in the impact blow from the drop load into the pile top must also be corrected by some empirical factors, taking account of among other things the degree of energy absorption in the pile-driving cap and in the shock-absorbing impact

piece generally interposed between the dropload and the pile top.

[0009] The drop height and thus the energy delivered by the hammer in each blow is generally a parameter which may be adjusted within a given range, in order to make it possible to account for varying resistance in the ground, varying pile sizes, etc. When the resistance to the pile tip is low, as it will be the case during the initial stages of ramming, the shock waves generated in the pile by the hammer impact may produce substantial tension stresses, which represent a kind of load carrying a high risk of fracturing concrete piles. During the initial stages of ramming, the drop height must, therefore, be comparatively low in order to avoid excessive stresses in the pile. When, on the other hand, the resistance to the penetration of the pile tip increases, as it is generally the case at greater depths, it often becomes necessary to increase the hammer impact energy, i.e. the drop height, in order to drive down the pile at an acceptable pace. The drop height used must naturally be correlated with the current pile level and with the observed step by step-pile subsidence, in order to provide meaningful information.

[0010] An accurate measurement of the drop height may, however, be somewhat difficult due to the Instances involved and due to the dynamic nature of the process. Most often the drop height is observed and noted in the records, the subsequent calculations being then based on the assumption of a perfectly regular operation of the hammer. This does not, however, take into account variations in the hammer operation, which variations may occur, e.g. in the case of hydraulically driven hammers, in which the pressure in the hydraulic drive system may actually vary, or e.g. in the case of diesel-driven hammers, in which the drive pulse energy tends to vary considerably.

[0011] The measurement of the subsidence of the pile may also be somewhat difficult. Generally personnel cannot be allowed to go very near to the pile during hammering for safety reasons, as it may e.g. happen that the pile fractures under a hammer blow. A frequently used method is to observe the motion of the hammer in relation to the rail post or perhaps the motion of the pile in relation to the rail post from a distance, which, however, limits the accuracy obtainable. During the operation, personnel may find time between two hammer blows to make a quick score on the pile, so as to produce a set of scores which are then available for a later and more accurate measurement to be taken while the hammering operation is temporarily stopped for that purpose. The need of stopping the hammering operation, however, adds to the time necessary for completing the pile-driving operation. The practical difficulties in the accurate logging of the pile-driving operation may also tempt the personnel to skip the requested recordal wholly or partially.

[0012] The prior art comprises a pile-driving rig with an instrument in the driver's cabin, said instrument mon-

itoring the winding/unwinding of the winch associated with the hammer wire, so that the displacement of the hammer may actually be monitored from the driver's cabin. The hammer wire is, however, affected by disturbing influences, e.g. from wind forces and from frictional forces, whereby the accuracy to which the hammer subsidence may be determined by monitoring the unwinding of the winch, is, in fact, not satisfactory for the calculation of the pile load-bearing capability to any reasonable degree of accuracy.

[0013] The invention provides a pile-driving rig as defined in Claim 1. With this pile-driving rig, the pile penetration is automatically recorded for each hammer blow so that a total picture of the pile load-bearing capability along the whole path described by the pile tip may be accurately estimated. The automatic recordal also provides the proof of the pile-driving operation having been completed as intended without any failures.

[0014] By the detection of the kinetic energy of the load delivered in each hammer blow, a comparatively greater accuracy in the calculations may be obtained as the proper value of the kinetic energy may be entered into the calculations even in such cases where the motion of the hammer drop load is not perfectly periodical such as it may occur due to variations in the hammer drive system, e.g. variations of the pressure in a hydraulic drive system.

[0015] According to the invention, the means for detecting the position of the hammer comprises means rigidly connected with the rail post and adapted for remote measurement of the distance to the hammer means. The mounting of the position-detecting means on the rail post is a practical solution and generally accurate as the rail post is generally supported on the ground during the ramming operation. The remote measurement to the hammer means permits normal handling of the pile-driving rig, e.g. dismantling of the hammer to proceed as usual without any complications.

[0016] The laser instrument operates very efficiently and is well suited for relaying the obtained data to a computer.

[0017] The optical reflector, the distances to which are measured, is actually arranged in association with the movable load, so that the position of the hammer means is only determined indirectly by determining the motion of the movable load. Hereby a complete trace of the motion of the movable load may be obtained in the computer, whereby the computer may record data not only about the gradual, downward motion of the hammer, but also about the stroke of the drop load, e.g. stroke height and drop-load velocity, just before impact.

[0018] The invention also provides a method as defined in Claim 4.

[0019] By the determination of the pile subsidence by the indirect measurement of the position of the hammer, it becomes possible to obtain precise measurements in a relatively simple manner, irrespective of e.g. the type of pile used.

[0020] The invention further provides a method as recited in Claim 8.

[0021] By hammering down a pile while detecting the kinetic energy delivered in each hammer blow, and recording the pile subsidence upon each blow of the hammer, an accurate mapping of the load-bearing capabilities of various underground strata may be obtained at comparatively low added cost.

[0022] Further objects, advantages and features of the invention will appear from the following detailed part of the specification covering exemplary embodiments of the invention. In the detailed part of the specification, reference is made to the drawings, in which

Figure 1 shows a side elevational view of a pile-driving rig,

Figure 2 shows a top plan view, partially in section, of the hammer,

Figure 3 shows a vertical section through the hammer,

Figure 4 shows a schematic view of the laser instrument,

Figure 5 shows a trace of the drop load motion, and

Figure 6 shows a log of pile driving.

[0023] All Figures are schematic and not to scale and illustrate only details essential to the understanding of the invention, other details being omitted from the drawings for the sake of clarity. Throughout the Figures, identical parts are designated the same reference numerals.

[0024] Reference is first made to Figure 1, showing a side elevational, overall view of a pile-driving rig according to the invention. The pile-driving rig, designated as a whole by reference numeral 1, essentially comprises a drive carriage 2 equipped with a rail post 3, the rail post comprising a lower portion 6, which is the portion connected with the drive carriage 2, and a rail post extension 4 connected to the rail post lower portion in a telescoping fashion and serving the purpose of effectively doubling the effective length of the rail post, or to put it differently, allowing a substantial contraction of the rail post in order to facilitate transportation and relocation of the unit

[0025] To the topmost end of the rail post extension 4, a top boom 5 is connected, the top boom serving as the mount for wire pulleys and cable attachments, which together with a pair of winches mounted on the drive carriage provide the pile-driving rig with a double crane-lifting capability. The outermost of the crane wires is the pile wire 7, serving the purpose of hoisting a pile 49, while the innermost wire, the hammer wire B, serves the purpose of lifting the hammer 10 slidably connected with the rail post 3, so that it is guided by the rail post in a manner so that it is displaceable substantially along the axis of the rail post. The hammer 10 is at its lowermost portion connected with a helmet or pile-driving cap 23, providing the interface to the pile 49.

[0026] The drive carriage 2 is provided with powering

means, such as a hydraulic powering system, providing hydraulic driving power through flexible hoses to the rail post and from there to the hammer 10. The hydraulic system is also connected for operating the winches and various actuators, serving to extend the rail post extension and to incline or lower the rail post as appropriate, and provides driving power to the drive carriage, and the drive carriage is provided with a driver's cabin, housing a control panel, from which the functions of the pile-driving rig may be controlled.

[0027] According to the invention, a laser instrument 30 is mounted by means of a laser support arm 31 to the top boom 5, the laser being oriented so as to emit a beam downwardly along the axis 32, which is oriented substantially parallel to the rail post 3. The hammer 10 is on a top side associated with a reflector plate 13, the laser beam axis 32 and the reflector plate 13 being mutually arranged so that the laser beam strikes the reflector plate 13 to be reflected there. The reflected beam is detected by a receiver incorporated in the laser instrument 30.

[0028] Reference is now made to Figure 2, showing a horizontal sectional view through the rail post extension 4, the Figure also showing the hammer as seen from above. The lower part of Figure 2 shows a section through the rail post extension 4, showing the rail post extension substantially in the form of a rectangle with the leaders 48 at the two uppermost corners, as shown in Figure 2. The leaders 48 are in the form of round bars extending in the longitudinal direction of the rail post extension and serve the purpose of providing slide guides for the hammer.

[0029] The hammer 10 comprises a framework 45 comprising solid, transverse beams 46 arranged to form a quadrangle with solid, longitudinal beams 47 (shown in section in Figure 2) in the corners and connected with a pair of slide claws 16 adapted to connect the hammer frame to the leaders 48 in a slidable fashion.

[0030] The hammer 10 further comprises a drop load 11 illustrated in Figure 2 inside the approximately quadrangular outline defined by the transverse beams 46 of the hammer framework. The hammer drop load 11 is substantially quadrangular in the planar outline illustrated in Figure 2 and provided at each of its corners with two slide shoes 14 arranged perpendicularly and adapted to cooperate with respective hammer guide rails 15, one guide rail being arranged at each of the inner corners of the hammer framework. The hammer guide rails 15 are substantially in the form of angular irons, but are precision-machined parts adapted to provide a precise guidance of the drop load 11. The drop load 11 is at the side facing the rail post extension 4 provided with a bracket 17 serving a purpose which will be explained later.

[0031] Reference is now made to Figure 3, showing a vertical section through the hammer. Figure 3 shows the longitudinal beams 47 in the hammer framework 45 and the transverse beams 46 (in section), so as to illus-

trate how one set of transverse beams 46 is arranged to connect the longitudinal beams near their topmost ends, and a similar set of transverse beams 46 is arranged so as to interconnect the lowermost ends of the longitudinal beams 46. The guide rails 15 are connected to the longitudinal beams 47 at several points, so as to be firmly supported.

[0032] Figure 3 also shows how the drop load slide shoes 14 are arranged, one set of slide shoes being arranged near the lowermost end of the drop load and a second set arranged at the upper portion of the drop load, so as to provide accurate guidance of the drop load, and so as to allow a suitable length of stroke. In Figure 3, the drop load is illustrated in solid lines in a position slightly elevated above its lowermost position, and the drop load is illustrated in phantom at its topmost position.

[0033] Figure 3 further shows the slide claws 16 arranged with one pair near the uppermost, transverse beams and a second pair adjacent the lowermost, transverse beams. The two pairs of slide claws secure the guidance of the hammer along the rail post, as explained above. The direction of guidance, defined by the two pairs of slide claws 16 external to the hammer framework, is substantially parallel to the direction of guidance defined by the hammer guide rails 15 internal to the hammer framework.

[0034] Near its topmost end, the hammer framework 45 is provided with a wire pulley 21, whereby the hammer may be hoisted by the hammer wire, as explained above with reference to Figure 1.

[0035] The interfacing between the hammer and the pile 49 is generally secured by a number of components illustrated in the lower portion of Figure 3. The hammer framework is solidly mounted to a bottom plate 22 arranged adjacent the lower side of the lowermost set of transverse beams 46. The bottom plate 22 is provided with a central opening, and the drop load is provided with a central, downwardly protruding impact boss 19 sized and arranged so that it may protrude through the opening in the bottom plate 22, the lower surface of the impact boss 19 providing the drop load impact face.

[0036] Below the bottom plate 22, and rigidly connected hereto, the helmet guide 29 and the pile guide 27 are arranged. The pile guide 27 provides a downward opening sized to fit loosely about the top of the pile with the purpose of maintaining the alignment of the hammer in relation to the pile. The opening in the pile guide 27 is designed to expand downwardly in the form of a funnel with the purpose of guiding the hammer into alignment in relation to the pile when the hammer and the pile are brought together by an appropriate hoisting action.

[0037] Inside the helmet guide 29, the pile-driving element or pile cap 23 is arranged. The helmet is adapted to fit over the topmost end of the pile and provides an anvil plate 24 above the top of the pile, and serves to maintain the impact piece 28 in a position above the top of the pile and below the anvil plate 24. The anvil plate

24 may comprise a material capable of some shock absorption, such as polyethylene. The pile-driving helmet with the anvil plate and the impact piece 28 together serves to protect the pile top from destruction by the hammer blow and to modulate the blow over the hammer, so as to ensure that a maximum of force is transmitted into the pile, but with a minimum of noise and damage. The impact piece 28 is preferably a piece of wood, as a wood piece may provide appropriate dampening and transmission characteristics at a low cost, allowing the wood piece to be renewed when crushed.

[0038] The pile-driving helmet is provided with upper and lower, transversely extending flanges 25. The flanges 25 and the chamber within the helmet guide 29 are matched so that the outer edges of the flanges may slide upwardly and downwardly inside the helmet guide, the helmet thereby being guided so as to maintain its alignment and its orientation in relation to the hammer.

[0039] Between the upper helmet flange 25 and the bottom plate 22, a rubber gasket 26 is arranged, the upper flange and the bottom plate being matched so that the bottom plate 22 may be supported by the upper helmet flange 25 with the rubber gasket interposed therebetween, the rubber gasket serving to soften any impact blows therebetween.

[0040] To the righthand side of Figure 3, the hammer lifting actuator 20 is shown, the hammer actuator being a linear hydraulic ram acting between the hammer frame bracket 18 rigidly connected to a lower, transverse beam of the hammer frame and the drop load bracket 17 rigidly connected to the drop load. By extending the hydraulic actuator, the drop load may be lifted, and by contracting the hydraulic actuator again, the drop load is allowed to fall down by the force of gravity. In order to hammer down piles, the hammer and one pile are brought together by appropriate hoisting action and then lowered until the lower end of the pile is supported on or may be somewhat below the surface of ground 9 (cf. Figure 1). With the pile standing on the ground, the pile-driving helmet rests on the top of the pile, and the hammer wire 8 is slackened so that the hammer frame is resting on the pile, by the bottom plate 22 being supported on the rubber gasket 26, again supported by the upper helmet flange 25.

[0041] During the initial part of the procedure, the hammer actuator 20 is contracted, so that the drop load is supported by the pile helmet by the impact boss 19 resting on the anvil plate 24 of the pile-driving helmet. In order to produce a hammer blow to drive down the pile, the hammer actuator 20 is extended to lift the drop load 11 and then quickly contracted again. The drop load falls down by the force of gravity, until the front face of the impact boss 19 hits the anvil plate 24, transferring the impact blow through the pile-driving helmet, through the impact piece into the pile. Under the impact force of the hammer blow, the pile generally travels sharply downwardly, the degree of subsidence depending generally on the relative magnitude of the impact force, the

pile weight and the resistance against penetration of the pile tip offered by the ground or by those subsoil strata which the pile tip is penetrating. When the drop load strikes the anvil plate, the pile helmet is driven downwardly, leaving momentarily the hammer framework unsupported, so that it will fall down by its own weight until the bottom plate 22 with the interposed rubber gasket 26 comes to rest again on the upper helmet flange 25. The helmet guide 29 must be adapted to allow a sufficient stroke of downward motion by the helmet in relation to the helmet guide in order to avoid the impact blow from the drop load in being directly transferred into the helmet guide and the hammer frame, so as to avoid undue strains and wear on these components.

[0042] According to the invention, the drop load 11 is on its top surface 12 provided with a reflector plate 13 adapted to serve as a reflector for a laser beam directed onto the drop load from a position above, whereby the distance between the laser instrument and the drop load may be accurately measured. The reflector is preferably arranged so that its upper surface is perpendicular to the direction defined by the hammer guide rails. The reflector surface is, however, preferably comprises a so-called retro-reflecting material, i.e. a material having the ability to reflect optical radiation back along the direction of incidence, also in case of oblique directions of incidence, whereby the orientation of the reflector becomes less critical. If the sensitivity of the laser instrument to the reflected beam is sufficiently high in relation to the distance between the instrument and the reflector, other plane reflectors may also be used, e.g. an optically diffusive, white surface. By measuring the distance from the laser instrument to the reflector, the elevation of the reflector plate may be determined. At those instances in which the drop load and the hammer frame are both resting on the pile helmet, which is further resting on the top of the pile, there will be a well-defined relationship between the elevations of these components, and thus by measuring the elevation of the reflector plate at those instances, the elevation of the hammer frame as well as that of the pile top may be determined.

[0043] By a continuous laser measurement of the distance between the laser instrument and the reflector, the motion of the drop load may be continuously traced, and the drop load velocity may also be determined.

[0044] According to another preferred embodiment of the invention (not shown in the Figures), the hammer frame is fitted with an optical reflector plate, and the elevation of the hammer frame may be determined directly by directing the laser beam towards this reflector or alternatively by providing a separate, dedicated laser instrument oriented to trace the reflector on the hammer frame.

[0045] According to a further preferred embodiment, the hammer frame is also provided with sensors to monitor the motion of the drop load in relation to the hammer frame, preferably in the form of proximity probes mounted on the hammer frame to detect the passes of the drop

load. By arranging a pair of proximity probes vertically spaced, so that they will detect two levels during the downward passage of the drop load shortly before it hits the pile, an accurate measurement of the drop load velocity may be obtained.

[0046] According to another preferred embodiment of the invention (not shown in the drawings), the drop load is provided with an accelerometer adapted to measure the acceleration and velocity in the motion of the drop load in the vertical dimension.

[0047] Reference is now made to Figure 4, showing a schematic view of the laser instrument 30. The laser instrument essentially comprises a high-frequency section 34 with a transmitter circuit 35 driving two laser diodes to emit laser radiation. A first one of these laser diodes, the transmitting laser diode 36, emits laser radiation through a beam splitter 33 and further through an optical system adapted to focus a narrow, well-defined beam of laser radiation along the axis 32. Laser radiation reflected to return in a direction along the beam axis 32 may be received by the optical system in the receiver 38. The receiver also receives a laser signal from the second one of the emitting laser diodes, i.e. from the reference laser diode 37. The receiver 38 compares the phase of the incident, reflected signal with that of the signal from the reference laser diode and establishes the time delay therebetween.

[0048] The accuracy of the determination of the time delay is sufficient to allow an accurate determination of the distance travelled by the laser beam from the laser instrument to the reflector and back by multiplying the time delay with the velocity of light. The raw data are processed in the microcomputer 39, and the resulting data are transferred through the interface 44, which makes them available on the connector socket 43, from which a cable connects to a computer 50. The laser instrument is also provided with a display 40 to allow monitoring of the operation of the instrument, and a keyboard 41 to allow finger-touch control of the laser instrument. The instrument may also be remote-controlled by the computer 50 through the interface 44. In the preferred embodiment, the interface is a serial interface according to the standard RS232. The laser instrument used in the preferred embodiment is of the type GLE 2000 available from Sick Optic Electronics. This instrument can operate in two modes, i.e. a first mode with 40 Hz sampling frequency and a second mode with 12.5 Hz sampling frequency. The 40 Hz sampling mode allows fast tracing of moving objects, but at the cost of redundancies, implying that the distance to the object may only be determined modulus two meters. The 12.5 Hz sampling mode is slower, but less ambiguous as the result is presented as a distance modulus 131 m.

[0049] Since the instrument according to the invention is used to measure downwardly from the top of a mast of which the height in practical case is well-known and generally in the range of 6-30 m, ambiguities beyond 131 m do not present any problems. The distance may

be determined by the instrument to an accuracy of about 1 mm, and the divergence in the laser beam is so small that the diameter of the laser beam measured 20 m from the laser instrument is approximately 40 mm. The reflector used is preferably somewhat larger to allow alignment inaccuracies in the mounting or caused by bending of the mast, or perhaps by non-linearity of the rail post. In the preferred embodiment, the reflector is about 30 x 30 cm.

[0050] Reference is now made to Figure 5, showing a trace of the drop load motion. The trace in Figure 5 is produced by the computer 50 based on the data received from the laser instrument 30, these data essentially representing the distance between the laser instrument and the reflector plate measured with a sampling frequency of 40 Hz, i.e. one measurement is carried out for every 0.025 sec. The distances are expressed in mm in relation to an arbitrarily selected but fixed reference point, and the trace illustrated in Figure 5 covers a period of time of approximately 3.5 sec, during which period the hammer was operating at a rate of approximately 1 hammer stroke per sec. The letter A marks a point at which the hammer-lifting actuator commences its lifting operation, and the actuator-lifting operation effectively lasts until the point marked with B, at which the actuator quickly retracts, allowing the drop load to continue somewhat further upwardly, due to the inertia of its up-going motion, until the topmost point marked with C, whereafter it drops downwardly.

[0051] Since the level of the curve at the point A corresponds to a position at which the drop load rests on the top of the pile, the free fall of the drop load until it strikes the pile top essentially lasts until the point at which the level of the curve is equivalent to the level at the point marked with A, i.e. the difference between the levels at A and at C, respectively, marks the drop height. When the downwardly moving drop load strikes the pile top, the pile is driven a step downwardly while the drop load comes to a stop and bounces somewhat upwardly again, gradually coming to a rest, perhaps after a number of oscillations. The drop load is essentially at rest at the point marked with E, at which a new lifting action of the actuator commences. The difference between the levels at the points marked A and E, respectively, marks the subsidence of the pile during the hammer blow.

[0052] The whole action is repeated, the hammer actuator lifting the drop load from the point E to the point F, whereafter the drop load moves upwardly to the top point G and downwardly to the point marked with H. The lowermost points on the curve marked with the letters D and H mark lowermost points reached during the hammer oscillations of the reflector plate and might, in fact, also be utilized to take comparative readings with the purpose of establishing the subsidence of the pile under the hammer blow. More accurate results are, however, generally expected by taking the readings at points where the drop load has substantially come to a rest,

such as the points marked A and E, respectively.

[0053] Based on a data trace of the kind illustrated in Figure 5, the computer may count the number of hammer blows and establish for each of the hammer blows data, such as the drop height, the drop load energy and the subsidence of the pile under the hammer blow. The drop load energy may be computed from the drop height or from the drop load velocity measured by the laser instrument. For the embodiments in which the hammer comprises dedicated means for measuring drop load impact velocity, the results of the measurements are transferred to the computer, so that the computer may use them in the calculation of the drop load impact energy. These data are essential for the estimation of the load-bearing capability of the subsoil stratum at the current level of the pile tip.

[0054] Other useful data which could also be produced in the computer could be a continuous recording of the velocity of the drop load, the magnitude of the oscillations when the drop load strikes the pile top, and the dampening factor, which may be deduced from the observation of these oscillations. Hereby the computer may continually monitor the proper operation of the hammer mechanism as well as the proper function of the impact piece, and the computer may be programmed to produce suggestions for adjustments of the drop load lifting height or for the hammer operation frequency, so as to find the optimum balance between the various operation parameters, where the hammering proceeds as fast as possible while keeping the strains to the piles and to the equipment within allowable limits.

[0055] Reference is now made to Figure 6, showing a log of pile driving. The plot in Figure 6 is laid out essentially to satisfy the requirements prescribed in the above-mentioned DIN 4026 for those of the piles for which a full report (grosse Rambericht) is mandatory. The leftmost section of Figure 6 is a schematical representation of the pile with the elevations of the pile tip, the ground surface and the pile top, respectively. To the right of this schematic drawing, there is a plot of the drop height, and further to the right, there is a plot of the energy and of the cumulative energy used to drive the pile, all plots being referred to the depth below surface expressed in metres. The vertical scale extends from 0 down to 20 m below ground, and the drop height plot shows that the hammering operation has proceeded from the surface level to a level of 6 m below ground with a drop height of 20 cm, and then from the level of 6 m below ground to the final level just above the 18 m level with a drop height of 30 cm. The energy plot (the solid line) shows the energy as minimal until the 6 m level, then rising to a top point at approximately 9.5 m, and subsequently falling and rising again several times following a generally rising trend expressing increasing resistance from the ground. The cumulative energy curve (the dotted line) provides the integration of the energy curve and facilitates the reading of the accumulated values.

[0056] The actual load-bearing capability of pile foundations are generally established by controlled test-loading experiments of selected piles. Such experiments are, however, rather costly and time consuming and are, therefore, only carried out for a small number of piles. For other piles, the load-bearing capabilities may be estimated by comparing plots as those shown in Figure 6, with reference to the load-bearing capability established by test loading. The plot of Figure 6 provides rather detailed information, from which the load-bearing capability may be estimated, also for the levels actually penetrated and passed by the pile tip during the ramming.

[0057] The plot of Figure 6 may be computed and produced by the computer and may be stored in an electronic form. Other plots based essentially on the same set of data, e.g. as required by various other national regulations, may also be produced by appropriate programming of the computer.

[0058] Although the above-described embodiments of the invention comprise a hydraulically operated hammer mechanism, the invention is equally well applicable in contexts with other types of hammers, in which the drop load falls freely by the force of gravity.

[0059] The invention is believed to be particularly advantageous in connection with diesel hammers, where the invention can solve the problem of computing the actual drop-load velocity just before the impact of the hammer, a quantity which may be somewhat difficult to establish accurately with diesel-driven hammers, where the drop load is decelerated by the drive mechanism just before it hits the pile top, which makes it difficult to estimate the exact impact velocity.

[0060] Although various components have been described above in specific contexts, this presentation is not intended to exclude that these components may be useful in other contexts and may be separately patentable.

[0061] The above detailed description is only offered for exemplary purposes and not intended to limit the scope of the invention, which is defined solely by the appended patent claims.

Claims

1. A pile-driving rig adapted for hammering piles into the ground or into a similar substance and adapted for detecting the energy delivered by each blow of the hammer and for automatically recording the penetration of the pile upon each blow of the hammer, said pile rig comprising

a rail post,
a hammer means guided by said rail post to be movable in the direction along said rail post, said hammer means comprising drop load guide means, a drop load adapted for hammer-

ing piles and guided by said drop load guide means to be movable in a direction substantially parallel to said rail post, and drive means adapted for driving said drop load along said drop load guide means in an oscillating motion, means for detecting the kinetic energy of the drop load delivered in each hammer blow, means for detecting the position of the hammer means occupied momentarily while it is in contact with the pile between the hammer blows, means for comparing successively occupied positions of the hammer means and computing the travel between these position, and to deduce therefrom the penetration of the pile upon each blow of the hammer, and for automatically recording said penetration, the means for detecting the position of the hammer means comprising means rigidly connected with said rail post and adapted for remote measurement of the distance to said hammer means, and the means for detecting the position of the hammer means comprising a laser instrument attached to said rail post and an optical reflector associated with said hammer means, said laser instrument being adapted to emit a laser beam to strike said optical reflector, to detect the reflected laser beam and hereby to measure the distance between said laser instrument and said reflector.

2. The rig according to Claim 1, **characterized in that** the laser instrument is placed at a distance from said hammer means in a direction opposite to the direction towards the pile when the pile is placed in a position for pile driving, and **in that** said laser instrument is oriented to emit said laser beam in a direction substantially parallel to said rail post.

3. The rig according to Claim 2, **characterized in that** the optical reflector is associated with the drop load so that the position of said hammer means is only determined indirectly by determining the motion of the drop load.

4. a method for the recordal of the penetration of a pile due to the impact blow delivered to the pile from a pile-driving hammer, whereby the pile penetration is determined as the distance between two positions of the hammer as recorded at two instances, in both of which the hammer is contacting the pile, one instance lying before and the other instance lying after the hammer has delivered the blow, the position of the hammer being detected by a remote, non-contacting measurement,

the position of the hammer being measured in relation to the rail post guiding the hammer dur-

ing the hammering;
 the position of the hammer being determined by determining the motion of the drop load of the hammer, and
 the position of the hammer is determined by a laser measurement, whereby a laser beam being emitted by a laser instrument which is attached to the rail post, reflected at an optical reflector associated with the hammer, and the reflected laser beam being detected by the laser instrument in order to measure the distance between said laser instrument and said reflector.

5. The method according to Claim 4, **characterized in that** the laser beam is emitted from a position spaced from the hammer in a direction opposite to the direction towards the pile, and **in that** the laser beam is oriented towards the hammer in a direction approximately parallel to the rail post.
6. The method according to Claim 5, **characterized in that** the reflector is arranged on that side of the drop load which lies opposite the pile, so that the reflected laser beam may be detected from a position spaced from the hammer in a direction away from the pile.
7. The method according to Claim 6, **characterized in that** the travel of the hammer drop load is recorded by the laser measurement.
8. A method for determining the load-bearing capabilities of various underground strata, comprising hammering a pile into the ground while determining the energy associated with each of the hammer blows, as well as the penetration into the ground upon each of the hammer blows by the method according to any of the Claims 4-7, and by computing therefrom the resistance to the pile offered by the subsoil strata at the respective depths.

Patentansprüche

1. Pfahleinschlagvorrichtung, der geeignet ist, Pfähle in den Boden oder in eine ähnliche Substanz zu hämmern, und der geeignet ist, die Energie zu erkennen, die bei jedem Hammerschlag aufgewendet wird und automatisch die Eindringtiefe des Pfahls bei jedem Hammerschlag aufzuzeichnen, wobei der Pfahlurm umfasst:

eine Schienensäule,
 ein Hammermittel, das von der Schienensäule geführt wird, um in die Richtung englang der Schienensäule beweglich zu sein, wobei das Hammermittel ein Falllastführungsmittel um-

fasst, eine Falllast, die dazu geeignet ist, Pfähle einzuhämmern, und die von dem Falllastführungsmittel geführt wird, um in eine Richtung beweglich zu sein, die im wesentlichen parallel zur Schienensäule ist, und ein Antriebsmittel, das dazu geeignet ist, die Falllast englang dem Falllastführungsmittel in einer hin- und hergerichteten Bewegung anzutreiben,
 ein Mittel zur Erkennung der kinetischen Energie der Falllast, die bei jedem Hammerschlag freigesetzt wird,
 ein Mittel zur Erkennung der Position des Hammermittels, die momentan eingenommen wird, während es sich zwischen den Hammerschlägen mit dem Pfahl in Berührung befindet,
 ein Mittel zum Vergleichen der nacheinander eingenommenen Positionen des Hammermittels und Berechnen des Abstands zwischen diesen Positionen, um davon die Eindringtiefe des Pfahls bei jedem Hammerschlag abzuleiten und automatisch die Eindringtiefe aufzuzeichnen,
 ein Mittel zur Erkennung der Position des Hammermittels, das ein Mittel umfasst, das steif mit der Schienensäule verbunden und dazu geeignet ist, eine Femmessung des Abstands zum Hammermittel durchzuführen, und
 ein Mittel zur Erkennung der Position des Hammermittels, das ein Lasermessgerät umfasst, das an der Schienensäule befestigt ist, und einen optischen Reflektor, der mit dem Hammermittel in Verbindung steht, wobei das Lasermessgerät dazu geeignet ist, einen Laserstrahl auszusenden, der auf den optischen Reflektor trifft, den reflektierten Laserstrahl zu erkennen und dadurch den Abstand zwischen dem Lasermessgerät und dem Reflektor zu messen.

2. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** das Lasermessgerät in einem Abstand vom Hammermittel in einer Richtung entgegen der Richtung zum Pfahl hin angeordnet ist, wenn der Pfahl in eine Position zum Einschlagen angeordnet wird, und dass das Lasermessgerät so ausgerichtet ist, dass es den Laserstrahl in eine Richtung aussendet, die im wesentlichen parallel zur Schienensäule ist.
3. Vorrichtung nach Anspruch 2, **dadurch gekennzeichnet, dass** der optische Reflektor mit der Falllast in Verbindung steht, so dass die Position des Hammermittels nur indirekt bestimmt wird, indem die Bewegung der Falllast bestimmt wird.
4. Verfahren zur Aufzeichnung der Eindringtiefe eines Pfahls aufgrund des einwirkenden Schlags, der von einem pfahleinschlagenden Hammer auf den Pfahl ausgeübt wird; wobei die Pfahleindringtiefe als Ab-

stand zwischen zwei Positionen des Hammers bestimmt wird, wie sie an zwei Zeitpunkten aufgezeichnet werden, wobei in beiden diesen Fällen der Hammer den Pfahl berührt, wobei der eine Zeitpunkt vor und der andere Zeitpunkt nach dem Ausführen des Schlags durch den Hammer liegt, wobei

die Position des Hammers durch eine berührungslose Femmessung erkannt wird, die Position des Hammers in Relation zur Schienensäule gemessen wird, welche den Hammer während des Hämmerns führt, die Position des Hammers durch Bestimmung der Bewegung der Falllast des Hammers bestimmt wird, und die Position des Hammers von einem Lasermessgerät bestimmt wird, wobei ein Laserstrahl durch ein Lasermessgerät, das an der Schienensäule befestigt ist, von einer Position ausgesandt wird, wobei der Strahl von einem optischen Reflektor, der mit dem Hammer in Verbindung steht, reflektiert wird, und der reflektierte Laserstrahl durch das Lasermessgerät erkannt wird, um den Abstand zwischen dem Lasermessgerät und dem Reflektor zu messen.

5. Verfahren nach Anspruch 4, **dadurch gekennzeichnet, dass** der Laserstrahl von einer Position ausgesandt wird, die vom Hammer in eine Richtung beabstandet ist, welche entgegen der Richtung zum Pfahl hin liegt, und dass der Laserstrahl zum Hammer in eine Richtung hin gerichtet ist, die etwa parallel zur Schienensäule ist.
6. Verfahren nach Anspruch 5, **dadurch gekennzeichnet, dass** der Reflektor an jener Seite der Falllast angeordnet ist, die gegenüber dem Pfahl liegt, so dass der reflektierte Laserstrahl von einer Position aus erkannt werden kann, die vom Hammer in einer Richtung weg vom Pfahl beabstandet ist.
7. Verfahren nach Anspruch 6, **dadurch gekennzeichnet, dass** der Weg der Hammerfalllast vom Lasermessgerät aufgezeichnet wird.
8. Verfahren zur Bestimmung der Lasttragefähigkeiten verschiedener Untergrundschichten, umfassend das Einhämmern eines Pfahls in den Boden, während die Energie bestimmt wird, die bei den einzelnen Hammerschlägen freigesetzt wird, sowie die Eindringtiefe in den Boden bei den einzelnen Hammerschlägen durch das Verfahren nach einem der Ansprüche 4-7, und durch Berechnung des Widerstandes, auf den der Pfahl in den Unterbodenschichten in den entsprechenden Tiefen trifft, auf dieser Grundlage.

Revendications

1. Engin de battage de pieux adapté pour enfoncer des pieux dans le sol ou dans une substance similaire et adapté pour détecter l'énergie délivrée par chaque coup de mouton et pour enregistrer automatiquement la pénétration du pieu à chaque coup de mouton, ledit engin de battage comprenant
 - un montant à rail
 - des moyens de mouton guidés par ledit montant à rail afin d'être mobiles dans la direction suivant ledit montant à rail, lesdits moyens de mouton comprenant des moyens de guidage de charge de battage, une charge de battage adaptée pour enfoncer des pieux et guidée par lesdits moyens de guidage de charge de battage pour être mobile dans une direction sensiblement parallèle audit montant à rail, et des moyens d'entraînement adaptés pour entraîner ladite charge de battage le long desdits moyens de guidage de charge de battage selon un mouvement oscillant,
 - des moyens pour détecter l'énergie cinétique de la charge de battage délivrée à chaque coup de mouton,
 - des moyens pour détecter la position des moyens de mouton occupée momentanément pendant qu'ils sont en contact avec le pieu entre les coups de mouton,
 - des moyens pour comparer les positions successivement occupées des moyens de mouton et pour calculer le déplacement entre ces positions et pour en déduire la pénétration du pieu à chaque coup de mouton et enregistrer automatiquement ladite pénétration,
 - des moyens pour détecter la position des moyens de mouton comprennent des moyens reliés de manière rigide avec ledit montant à rail et adaptés pour mesurer à distance la distance le séparant desdits moyens de mouton, et
 - des moyens pour détecter la position des moyens de mouton comprennent un instrument à laser fixé audit montant à rail et un réflecteur optique associé auxdits moyens de mouton, ledit instrument à laser étant adapté pour émettre un faisceau laser destiné à heurter ledit réflecteur optique, pour détecter le faisceau laser réfléchi et ainsi mesurer la distance entre ledit instrument à laser et ledit réflecteur.
2. Engin selon la revendication 1, **caractérisé en ce que** l'instrument à laser est placé à une certaine distance desdits moyens de mouton dans une direction opposée à la direction du pieu lorsque le pieu est situé dans une position permettant le battage du pieu, et **en ce que** ledit instrument à laser est orien-

té de manière à émettre ledit faisceau laser dans une direction sensiblement parallèle audit montant à rail.

3. Engin selon la revendication 2, **caractérisé en ce que** le réflecteur optique est associé à la charge de battage de telle sorte que la position desdits moyens de mouton n'est déterminée qu'indirectement en déterminant le mouvement de la charge de battage. 5
10

4. Procédé pour enregistrer la pénétration d'un pieu suite à un coup porté au pieu au moyen d'un mouton de battage de pieux, de telle sorte que la pénétration du pieu soit déterminée comme étant la distance entre deux positions du mouton telles qu'enregistrées en deux occurrences à chacune desquelles le mouton entre en contact avec le pieu, une occurrence étant étudiée avant et l'autre occurrence après que le mouton eut porté le coup, la position du mouton étant détectée par une mesure à distance sans contact, 15
20

la position du mouton étant mesurée par rapport au montant à rail guidant le mouton pendant l'opération de battage, 25

la position du mouton étant déterminée en déterminant le mouvement de la charge de battage du mouton, et

la position du mouton est déterminée par une mesure au laser, de telle sorte qu'un faisceau laser soit émis par un instrument à laser qui est attaché au montant à rail, réfléchi au niveau réflecteur optique associé au mouton, et le faisceau laser réfléchi étant détecté par l'instrument à laser afin de mesurer la distance entre ledit instrument à laser et ledit réflecteur. 30
35

5. Procédé selon la revendication 4, **caractérisé en ce que** le faisceau laser est émis depuis une position espacée du mouton dans une direction opposée à la direction du pieu, et **en ce que** le faisceau laser est orienté vers le mouton dans une direction approximativement parallèle au montant à rail. 40
45

6. Procédé selon la revendication 5, **caractérisé en ce que** le réflecteur est agencé du côté de la charge de battage situé à l'opposé du pieu, de telle sorte que le faisceau laser réfléchi puisse être détecté depuis une position à distance du mouton dans une direction opposée au pieu. 50

7. Procédé selon la revendication 6, **caractérisé en ce que** le déplacement de la charge de battage du mouton est enregistré par la mesure au laser. 55

8. Procédé pour déterminer la force portante de diverses strates souterraines, comprenant les étapes

consistant à enfoncer un pieu dans le sol tout en déterminant l'énergie associée à chacun des coups de mouton, ainsi que la pénétration dans le sol à chacun des coups de mouton au moyen du procédé selon l'une quelconque des revendications 4 à 7 et à calculer à partir de cela la résistance au pieu offerte par les strates souterraines à des profondeurs respectives.

Fig. 1

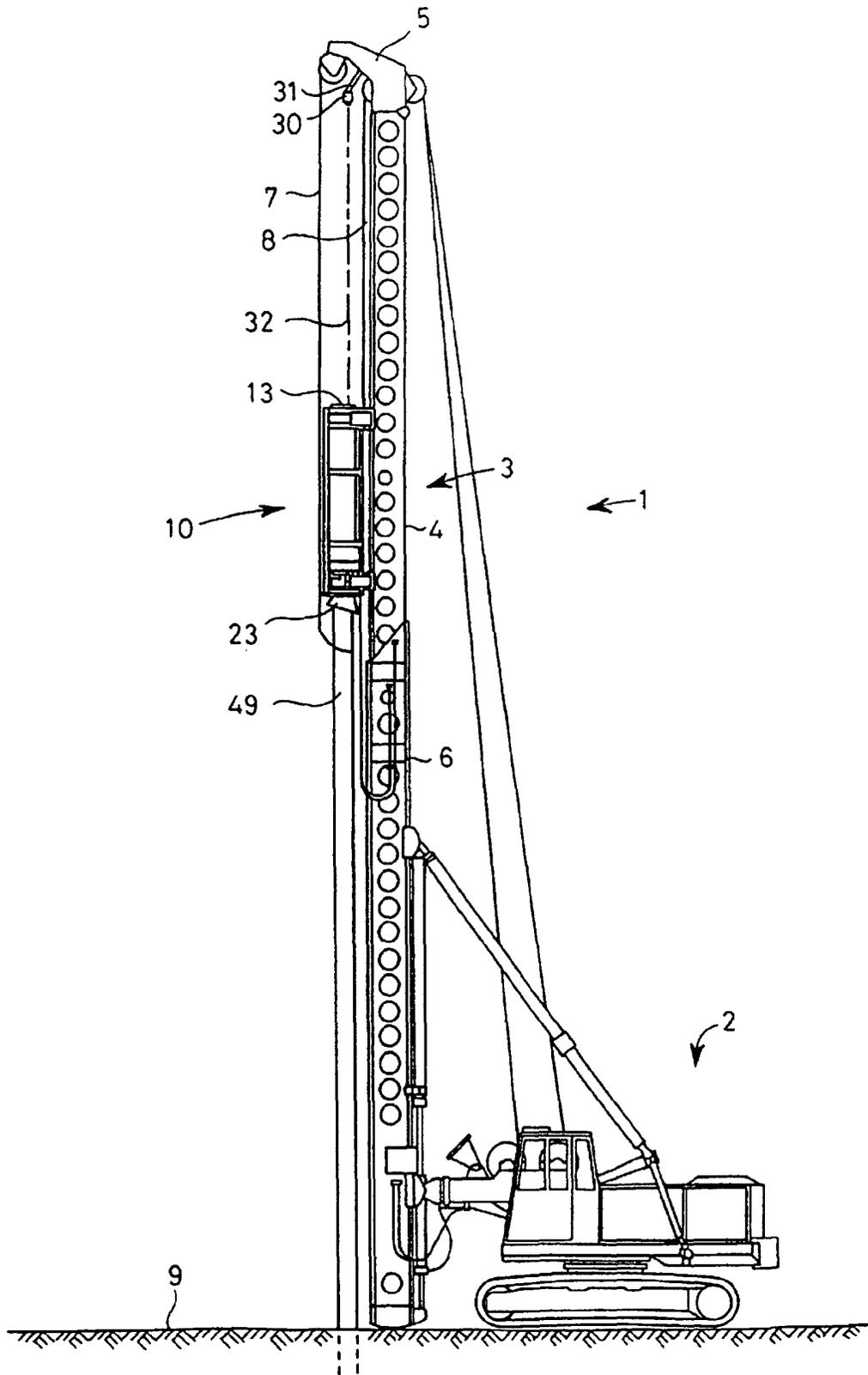


Fig . 2

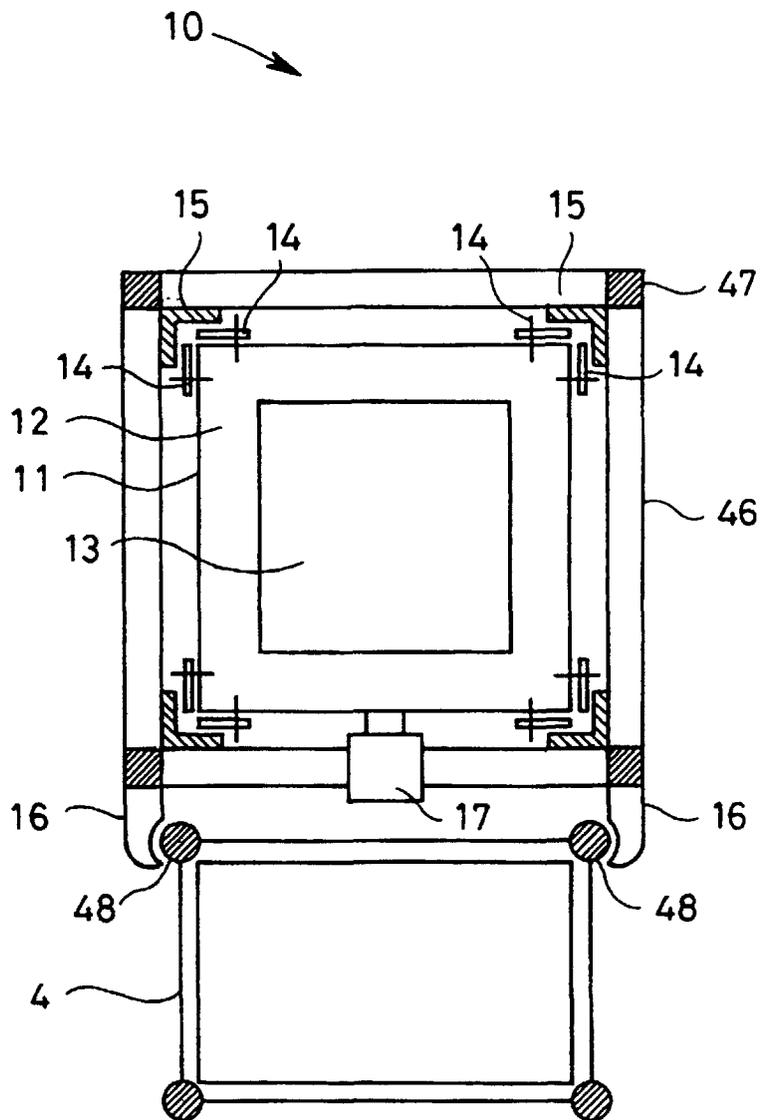
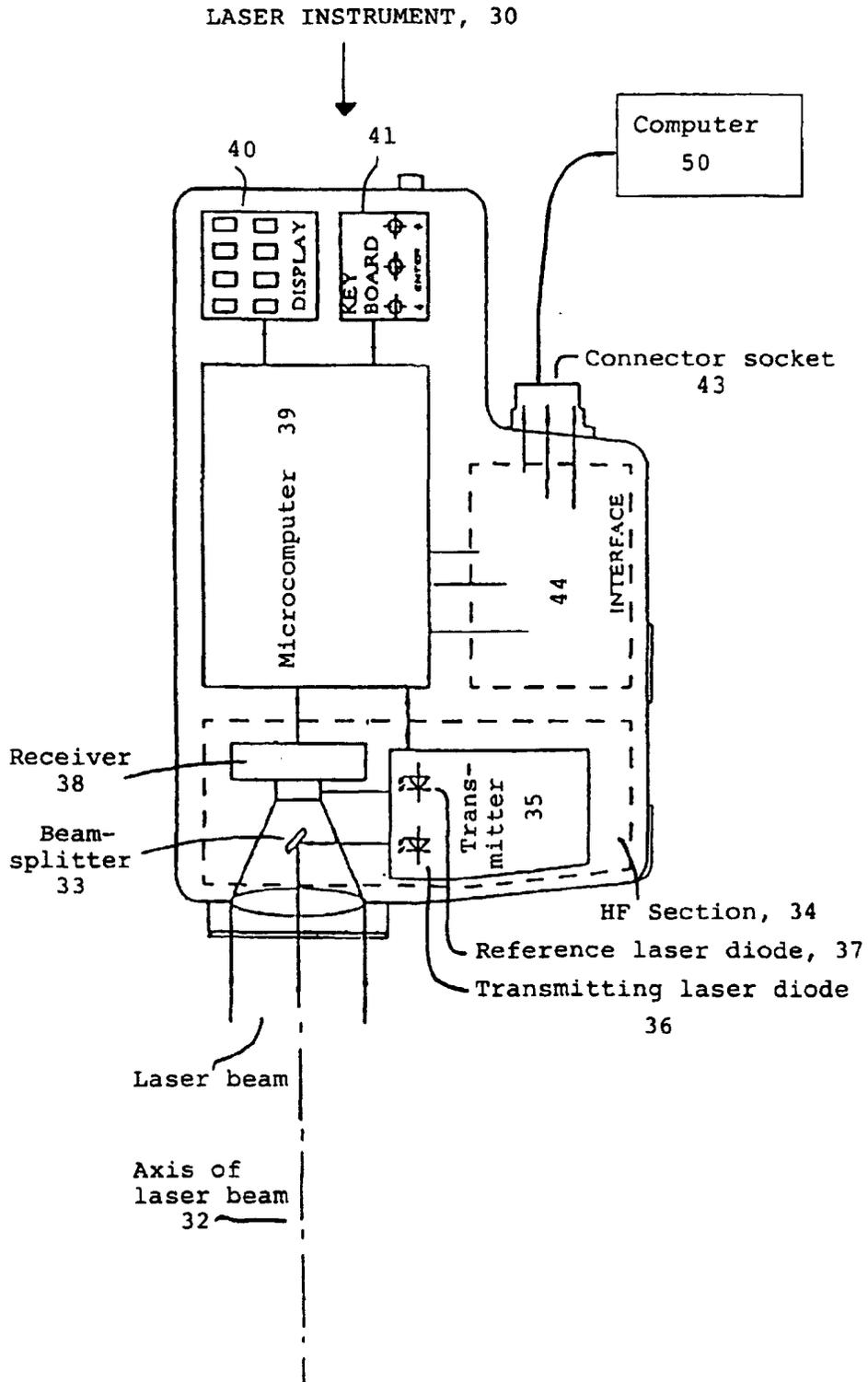


Fig. 4



TRACE OF DROP LOAD MOTION

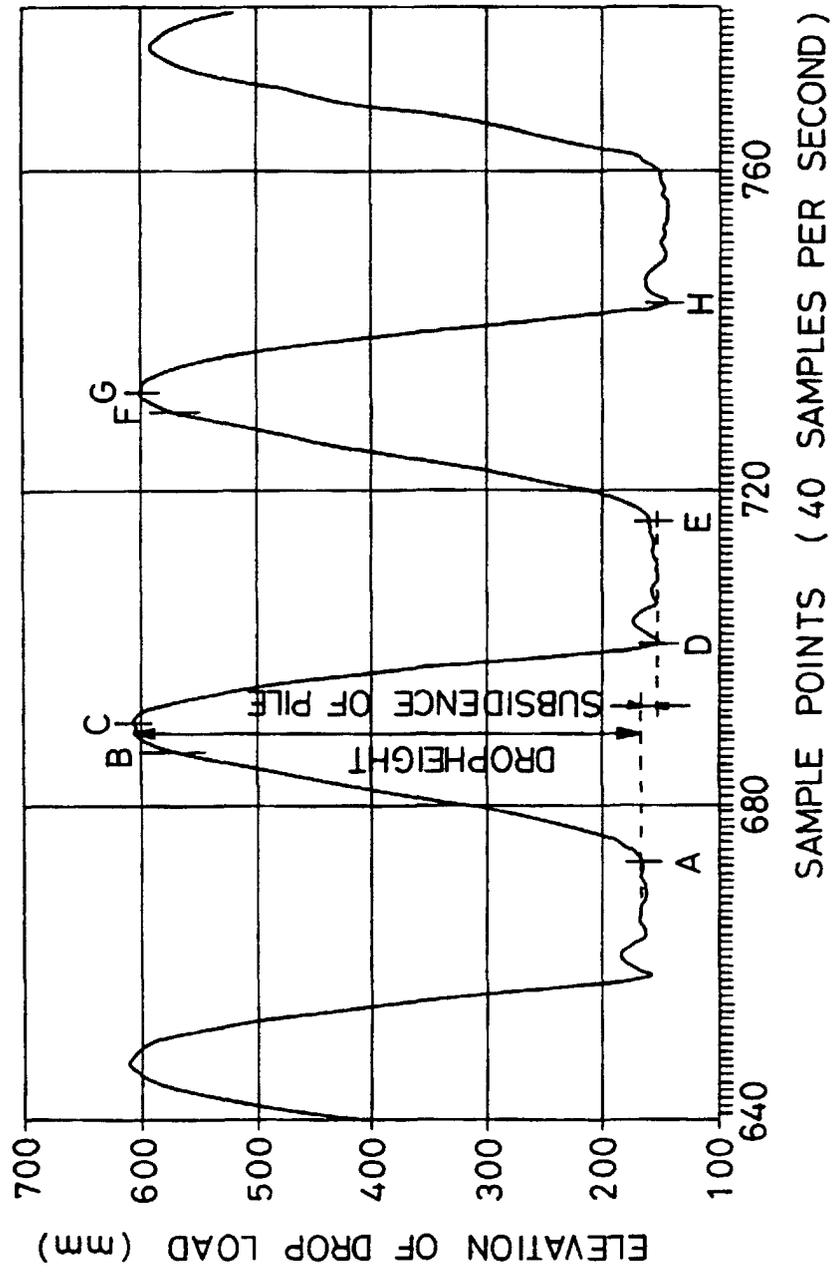


Fig. 5

Fig. 6

LOG OF PILE DRIVING

