United States Patent [19]

Wisotsky

[11] **3,824,797**

[45] **July 23, 1974**

[54] **EVACUATED TUBE WATER HAMMER PILE DRIVING**

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[73] Assignee: **Orb, Inc.**, Marion, Ohio

[22] Filed: **June 30, 1972**

[21] Appl. No.: **267,753**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 163,422, July 16, 1971, abandoned.

[52] **U.S. Cl.** .... **61/53.5,** 173/1, 175/56, 181/.5 H

[51] **Int. Cl.** **E02d 7/10,** G01v 1/38

[58] **Field of Search** .... 61/53.5, 63, 46.5; 173/1; 181/.5 H; 114/206; 175/56

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Primary Examiner—Jacob Shapiro
Attorney, Agent, or Firm—Robert R. Priddy

[57] **ABSTRACT**

Driving long piles into submerged lands with a liquid ram or spear generated in an evacuated tube. Various drivers are enclosed. In one embodiment, the pile itself is used as at least a portion of the working chamber for generating water hammer.

34 Claims, 14 Drawing Figures

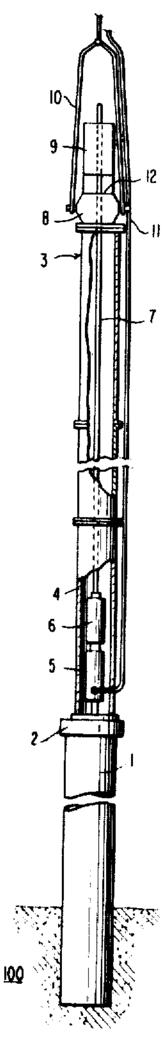


FIG.1

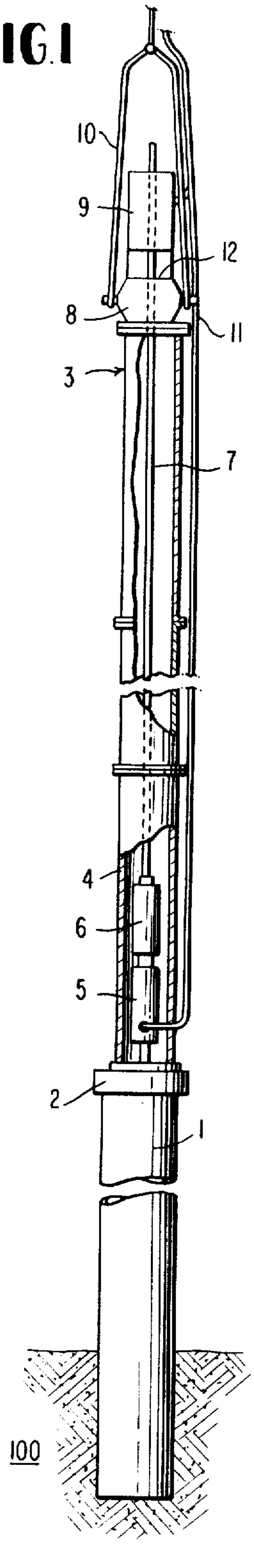


FIG.2

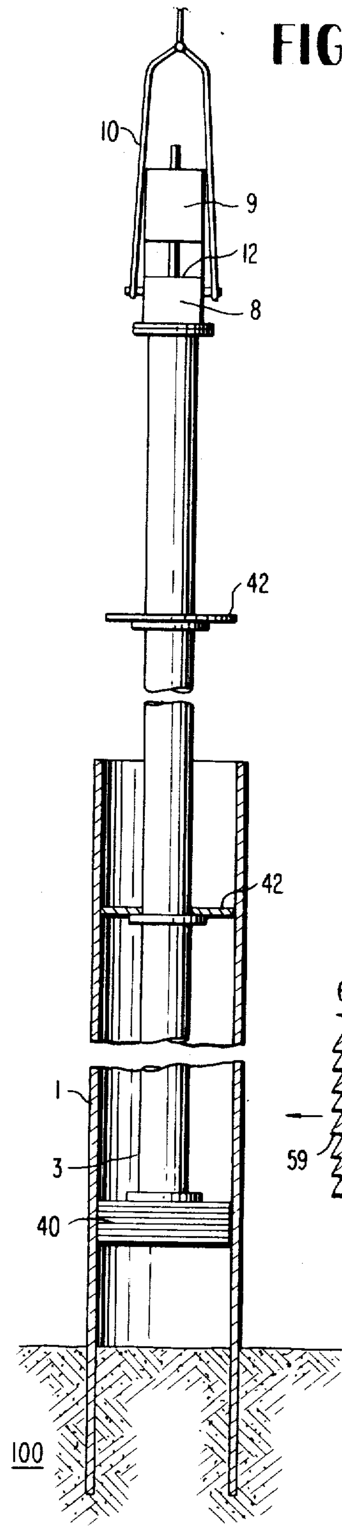


FIG.3

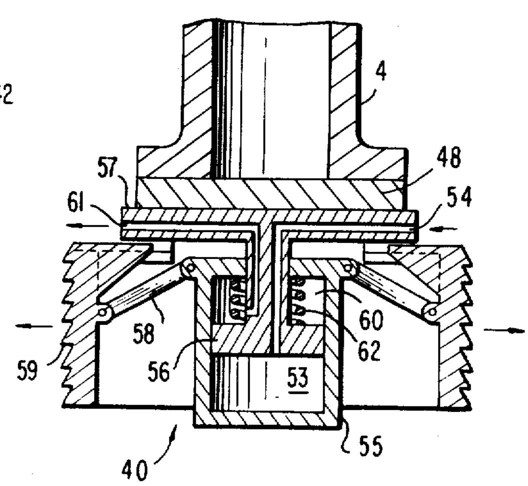
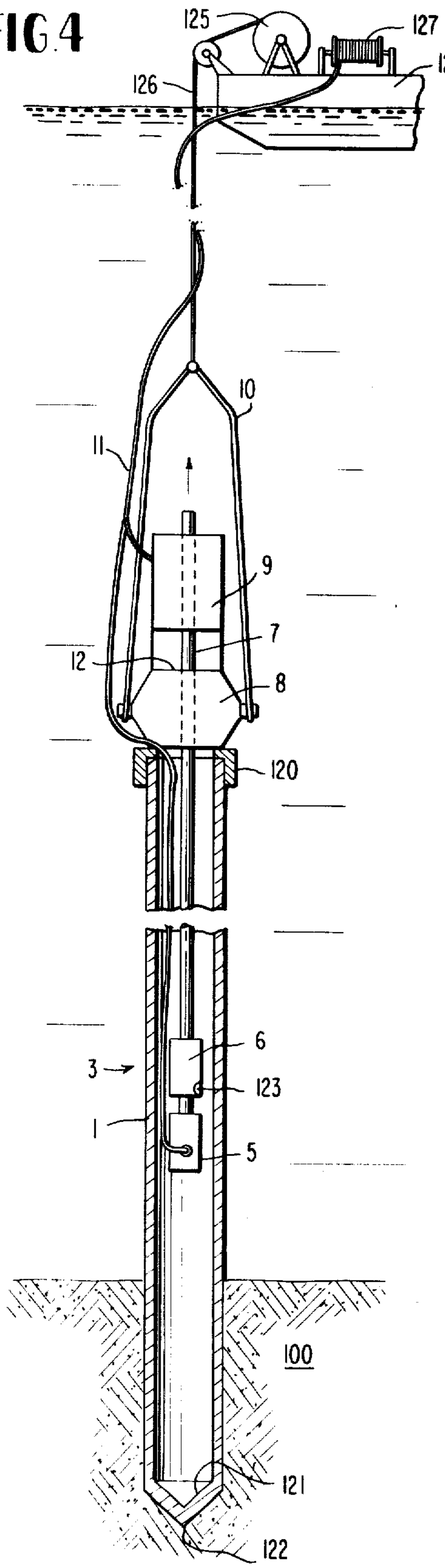


FIG. 4


125
127
124
126
10
11
9
7
12
8
120
6
3
123
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5
100
121
122

FIG. 13

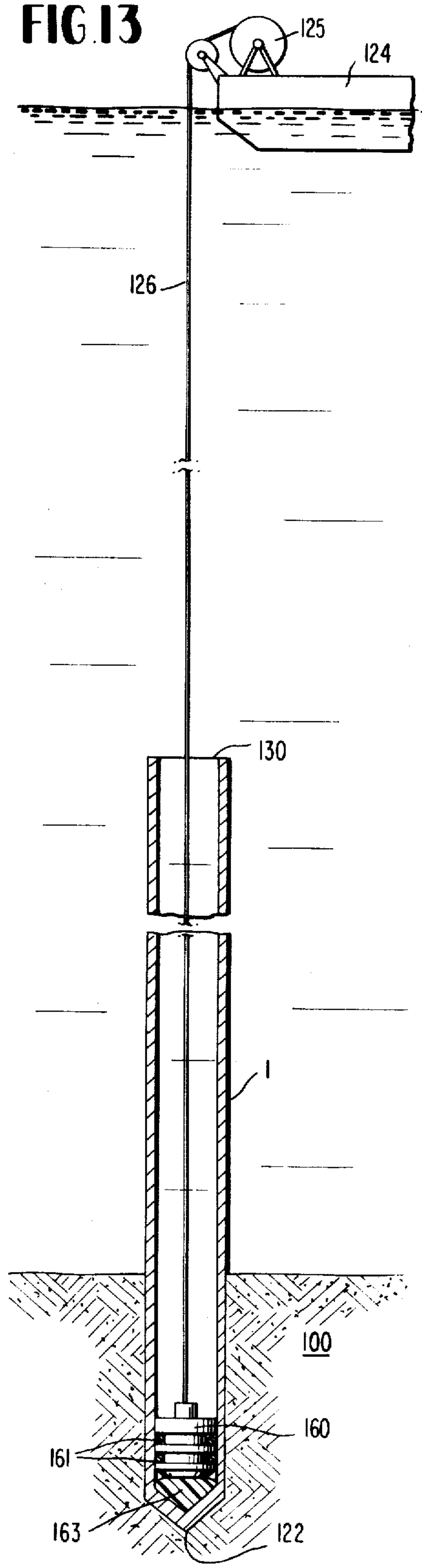
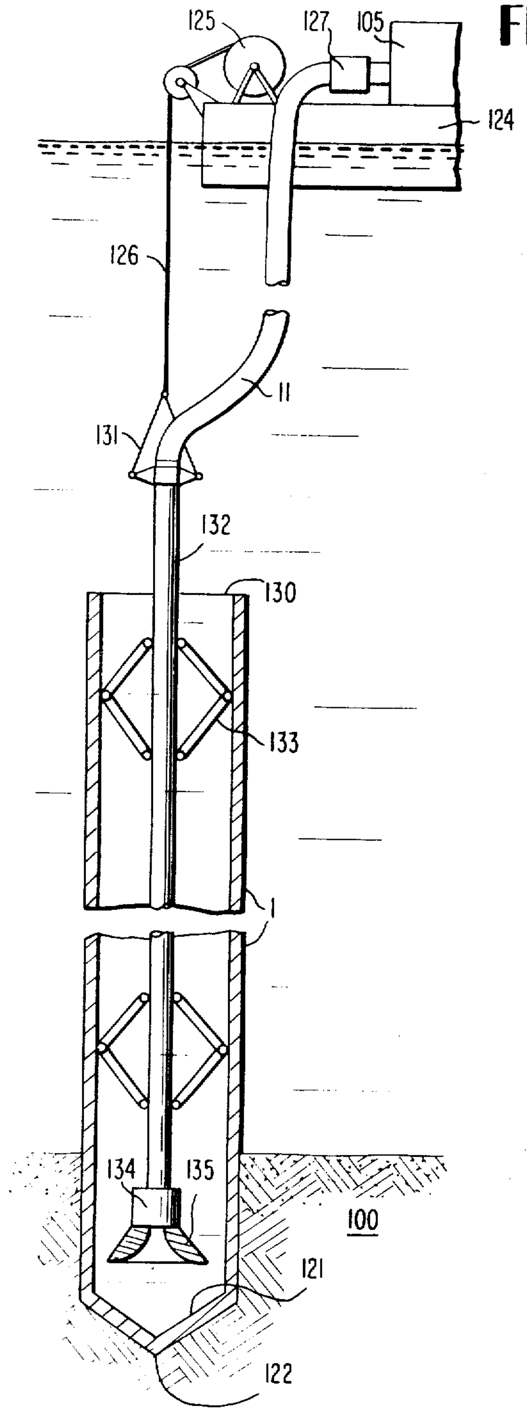

125
124
126
130
1
100
160
161
163
122

FIG 5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124
126
11
131
132
130
133
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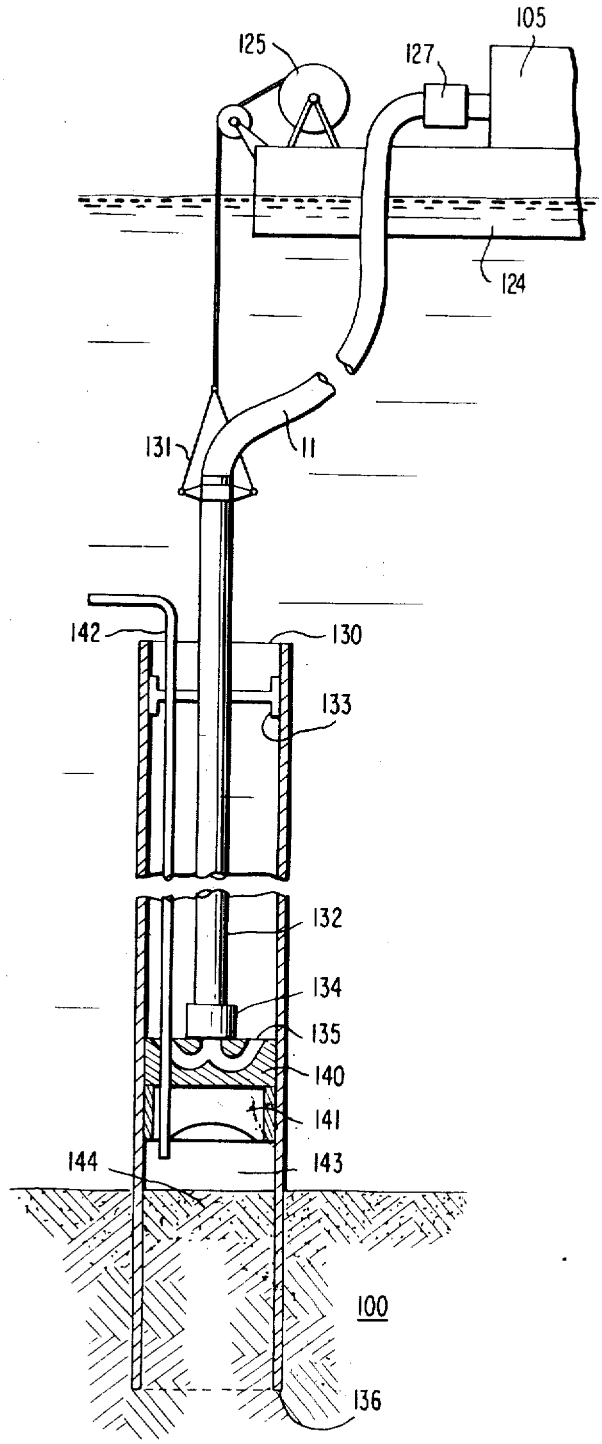
134
135
100
121
122

FIG 6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127
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131
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132
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141
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143
100
136

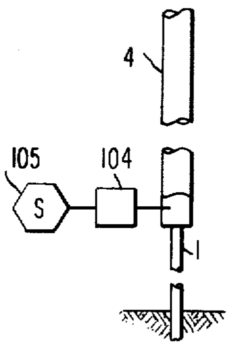


FIG.7

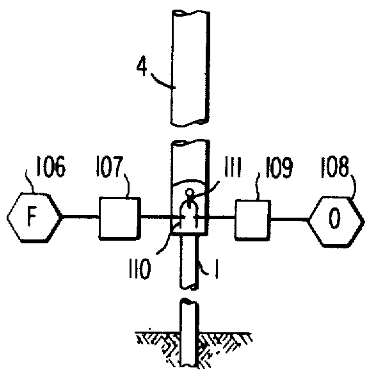


FIG.8

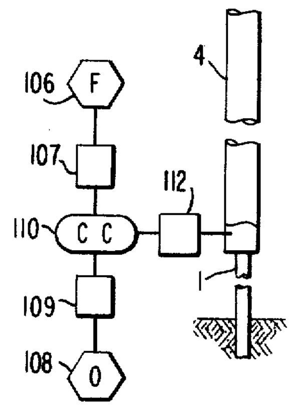


FIG.9

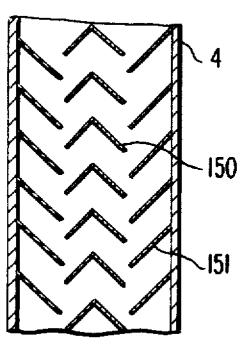


FIG.10

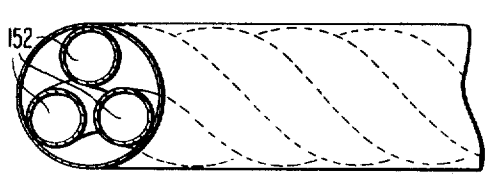


FIG.11

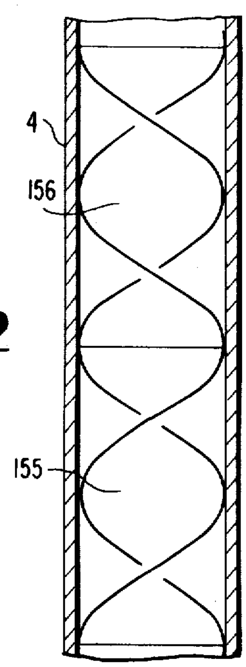
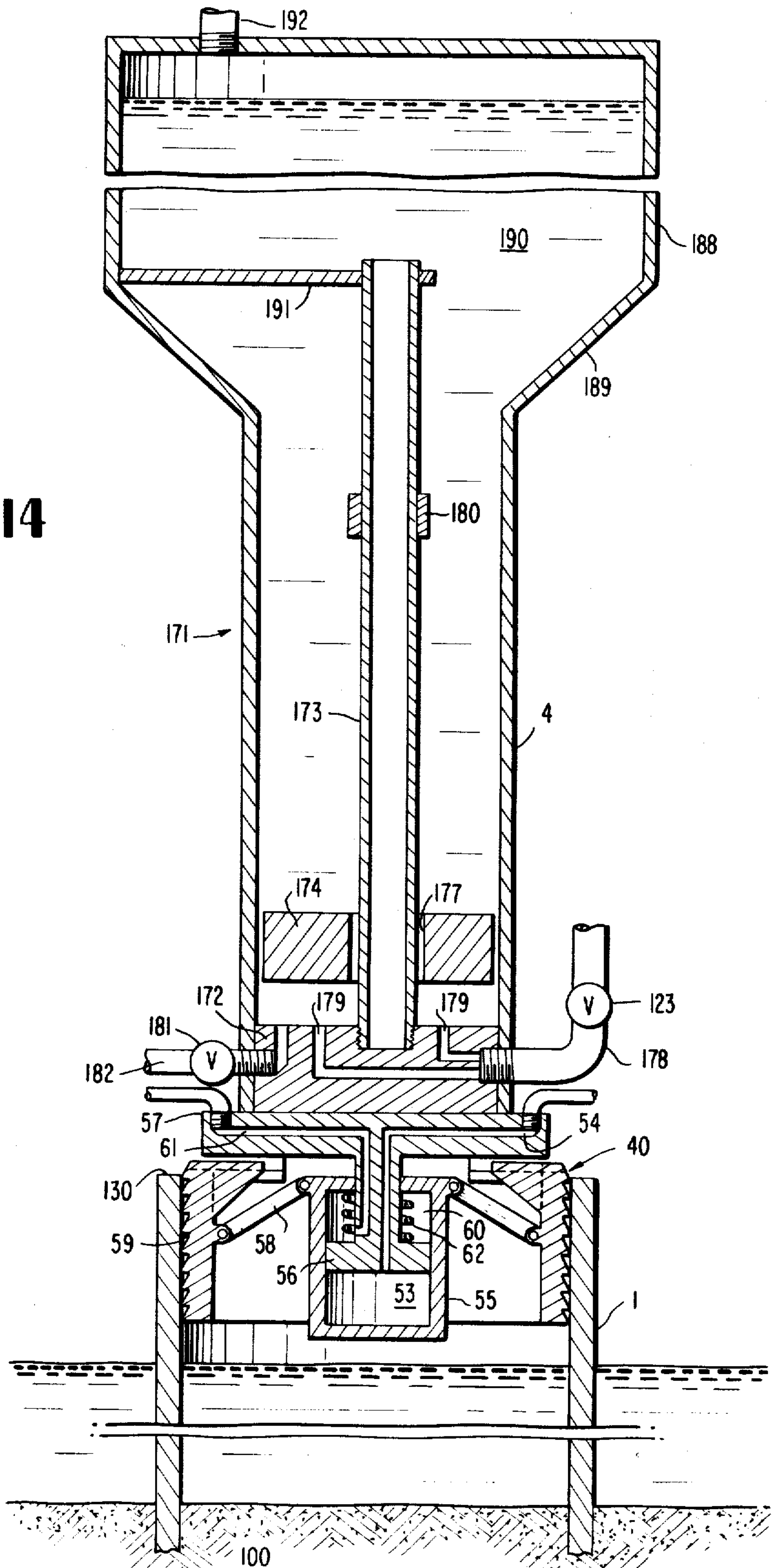


FIG.12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191
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180
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173
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174
177
172
179
179
181
V
123
V
182
178
57
54
61
40
130
60
59
58
62
56
53
55
1
100

FIG.14

EVACUATED TUBE WATER HAMMER PILE DRIVING

CROSS-REFERENCE

This is a continuation-in-part of an abandoned prior copending application Ser. No. 163,422, filed July 16, 1971, and now abandoned, the disclosure of which is hereby incorporated by reference.

BACKGROUND

The kinetic energy output of a pile driver is the product of its driving mass and its velocity at the instant of impact with a pile. The emplacement of piles in the ground by pile driving is accomplished by transmitting the kinetic energy of a hammer or other driving mass to a pile in sufficient quantity to cover nonproductive energy consuming factors such as impact stresses, radiation, reflection and ground quake, and to overcome the friction, elasticity and inertial impedence components of the pile and ground.

Increasingly larger land-based and offshore structures are constructed year after year. Larger structures demand longer and more massive piles for their foundations, more deeply embedded in the ground. This requirement is particularly severe in the case of large offshore installations such as ship terminals, and oil drilling, production and storage facilities. Without suitable foundations, such structures weighing tens of thousands of tons can be readily dislodged and toppled by heavy storms, large vessels bumping, earthquakes, ice floes, often with catastrophic loss of life, damage to the environment and loss of invested capital. Thus, to provide adequate load-bearing and to prevent pull-out, requirements exist for driving piles hundreds of feet long, several feet in diameter, weighing hundreds of tons, and for continuing the driving to depths of soil penetration where driving resistance is severe.

A complex series of relationships pertaining to pile and soil characteristics, driving environment, economics and materials governs the design of a pile driver. However, generally speaking, the advent of piles of greater mass and conditions productive of more severe driving resistance require drivers of increasing kinetic energy output. In the absence of adequate driving energy, that which is available is consumed largely or completely by the aforementioned nonproductive energy consuming factors, leaving little or no energy to drive the pile. Under such conditions, some help is obtained by palliatives such as drilling a pilot hole, water jetting or grouting into an over-size hole, but these measures normally reduce load-bearing capacity. Thus, as each new generation of more massive piles and more severe driving conditions arises, drivers of greater energy output must be designed.

The kinetic energy output of an existing hammer can be increased by increasing either its mass or its impact velocity. The latter alternative is unattractive for a number of reasons.

First, there is the matter of the efficiency with which the hammer transfers energy to the pile. In a complete inelastic collision between a hammer and pile, the kinetic energy remaining after impact for overcoming the nonproductive factors and driving the pile is in proportion to the ratio of the hammer mass divided by the total mass of hammer plus pile. An increase in pile mass

without a corresponding increase in hammer mass results in a reduction of driving efficiency.

Also, higher hammer velocities are more predisposed to produce high local impact stresses. When the latter exceed the yield point of the pile material, kinetic energy is wasted and efficiency reduced.

For these and other reasons, manufacturers discourage the use of a pile driver in which the hammer's mass is less than one-fourth that of the pile, and a mass ratio of one-half is generally recommended for land-based operations.

This presents a dilemma in off-shore pile driving. The largest steam hammer pile drivers currently in use in off-shore/marine work are limited, practically, by safety considerations relative to their handling in stormy weather, to weights on the order of 60 tons (hammer mass about 30 tons). Consequently, they usually are inadequate to drive the larger piles due to mass-mismatch.

For instance, with a 200-ton pile, the energy transfer efficiency of a 30-ton hammer would be 100 percent $\times$ 30/(30 + 200) or about 13 percent. Moreover, even this relatively small amount of energy transferred to the pile is not altogether effective in driving for other reasons stated below.

The picture is further complicated by the fact that the energy in a pile is effective to penetrate the soil only if there is a proper impedance match between the force-time-displacement characteristics of the driver and corresponding parametric thresholds of the soil. The available alternatives for varying the force-time-displacement characteristics of a steam hammer are limited, and this presents practical problems as the tip and sides of a pile often pass through strata of widely varying characteristics as the pile penetrates the earth.

Thus, under the severest conditions, pile driving is an arduous, time consuming and expensive task which sometimes ends in failure to achieve design load-bearing capacity or depth. Also, the inability to drive large piles to sufficient depths often necessitates driving a larger number of smaller piles, so that as many as eight or 16 piles may be required for the foundation of a single log of a multi-leg offshore structure.

Bearing in mind the storm-weather safety considerations mentioned above, it is of interest that at least one pile driver manufacturer has proposed for offshore operations a pile driver, nominally rated at almost 500,000 ft. lb., weighing on the order of 230 tons, equivalent to the weight of several locomotives. Lifting this gigantic mass and adequately securing it during storm conditions present major challenges. Nevertheless, the fact that at least some of those active in the art seem ready to accept these formidable challenges suggests the severity of the problems and limitations with which the pile driving art is now struggling.

SUMMARY OF THE INVENTION

The method of the present invention is carried out in a long, massive pile which is, or is intended to be, part of the foundation for a large offshore structure. The pile has its tip embedded in the subsoil of a body of water. An evacuatable enclosure with sidewalls and a lower barrier is effectively coupled with the tip of the pile for transmitting driving forces exerted upon said barrier to said tip. The method comprises: evacuating at least a portion of said enclosure, by removing water and at least a portion of any gases or vapors which may be present in the evacuated portion and evacuating sufficiently to provide space for acceleration and deceleration of a mass of water adequate to produce the necessary force and energy for driving said pile; accelerating along the axis of said pile a mass of water which moves substantially independent of said pile; suddenly decelerating said mass against said barrier, thereby converting hydraulic kinetic energy to a water hammer driving pulse for driving said pile into said sub-soil and repetitively evacuating, accelerating, decelerating and driving as aforesaid. Using this method, it is possible to generate powerful mechanical impulses whose force-time characteristics can be tailored over a wide range of values to better match the driving requirements of various pile and soil conditions. Other advantages will be discussed along with certain preferred embodiments of the invention as illustrated in the accompanying drawings and text.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical elevation, foreshortened and partially broken out, showing an evacuated tube water hammer driver in which the evacuatable enclosure is a tube other than the pile itself.

FIG. 2 is a schematic diagram of a driven similar to that shown in FIG. 1, but provided with a pipe coupler and alignment means for securing the driver within a pile.

FIG. 3 is a sectional view of a coupler for the FIG. 2 driver.

FIG. 4 is a schematic diagram in which the evacuatable enclosure is defined at least in part by the walls of the pile, the motor-pump combination, water hammer valve and control means being similar to that described in FIG. 1.

FIGS. 5 and 6 are schematic diagrams of steam-reset water hammer pile drivers in which the evacuatable enclosure is defined at least in part by the walls of the pile.

FIGS. 7 through 9 are schematic diagrams of condensable vapor reset pile drivers in which the evacuatable enclosure is a tube separate from but coupled to the pile, and in which various different kinds of condensable vapors are employed.

FIGS. 10 through 12 are schematic diagrams of means insertable in the evacuatable enclosures of the previously described water hammers for varying the water hammer impulse.

FIGS. 13 and 14 are schematic diagrams of free-piston evacuatable enclosure water hammers in which the pistons are reset by mechanical and fluid pressure means respectively.

DESCRIPTION OF PREFERRED EMBODIMENTS

In accordance with the invention, the enclosure walls can be at least partly or wholly, defined by a tube separate from the pile being driven, as disclosed by FIGS. 1–3, 7–9 and 14 hereof. FIG. 1 represents a configuration of a pile **1** driven underwater into the ground **100** by a top-mounted hammer. The pile **1** is securely fastened to the hammer **3** by a coupling means **2**. This coupling **2** may take the form of simply bolted flanges or a more sophisticated mechanical clamping arrangement similar to the scroll- or pneumatically-operated machine tool lathe chucks which are well-known and will not be described further. The pile hammer **3** in the present case includes hammer tube **4**, made of flanged sections of heavy-walled tubing bolted together and contains a shock-mounted electric motor **5** – hydraulic pump **6** combination near its bottom. (The motor-pump positions may be interchanged.) The pump **6** evacuates the water out of the hammer tube **4** through a center-mounted pipe **7** discharging vertically out its top. The pump **6** axially supports the discharge pipe **7** or, in other configurations, vice versa. On the top-most section of the water hammer tube **4** is mounted the fast-opening water control valve **8** and its pneumatically operated actuator **9**. When open, valve **8** freely admits water from the surrounding body of water through the valve body and its inlet **12** into hammer tube **4**. A wire rope sling **10** supports the entire assembly from the surface and also conveys the power and control harness **11** thereto.

The design of the water control valve **8** may be such that rapid opening thereof is aided by the force generated by the ambient hydrostatic head acting on the valve. In order to prevent the inrushing water from exerting any drag forces on the pump **6** and motor **5** assembly, the liquid level is controlled to prevent the draw-down of water to the pump level. The casings of the pump, motor and discharge pipe should be made strong enough to withstand the resulting water hammer pressure. When required, the motor-pump-discharge pipe assembly can be made free-floating and mechanically shock-isolated axially from the water hammer tube by a lower compression spring (not shown) which supports the static air weight of the motor-pump-pipe assembly and an upper compression spring (not shown) which helps the gravity return of the pump assembly to its normal mid-position. A hydraulic type shock absorber (not shown) can be used to provide viscous damping to reduce oscillations. Further shock resistance can be provided by making the motor pump critical components neutrally buoyant in their respective liquid by means of low density construction materials and high density liquids incorporated in their respective frames. Motor conductors and control cables pass from the surface to the motor **5** and valve **8** through the water-tight power and control harness **11**.

When the pile is of sufficient length and diameter, and also to facilitate the handling of long assemblies, the hammer tube **4** may be located internally within the pile as shown in FIG. **2**, using any internal coupling, such as that (**40**) shown in FIG. **3**. This permits incremental upward repositioning of the hammer as the pile **1** is driven into the bottom **100**. It also permits coupling of the driver to the pile at a position which is closer to the sub-soil **100** than the top of the pile, giving an improved driving action. Concentricity alignment rings **42** may be secured to each water hammer tube flange joint as shown in FIG. **2**.

To secure the hammer within the pile high pressure fluid is fed into the lower cylindrical cavity **53** of the pile coupled **40** through port **54**, FIG. **3**. This flow causes the cylinder frame **55** to move downward over the piston **56**. The piston shaft is secured to the base **57** that is bolted to the bottom flange **48** of the water hammer tube **4**. When the cylinder frame **55** moves downward it creates a toggle action in the multiplicity of links **58**. The resultant mechanical advantage varies as the cotangent of the angle between the link and the radial normal. Consequently, hard-tooth shoes **59** slide radially outward in T slot guides in the base **57** and bite into the pile walls. Simultaneously, the fluid in the upper cylindrical cavity **60** is exhausted through port **61.** A four-way electrically controlled valve (not shown) can be used to control the influx and efflux of the pressurized fluid, which may be hydraulic or air. To release the pile coupled, the influx and efflux ports on the piston base are interchanged by control valve action. The compression spring **62** in the upper cylinder **60** retracts the entire mechanism when the air pressure is off. This pile coupler also can be used in the end-drive configuration.

In accordance with the invention, the enclosure walls can be at least partly, or wholly, defined by the walls of the pile being driven, as disclosed by FIGS. **4** through **6**, and **13**, hereof. FIG. **4** represents a configuration of a pile **1** driven underwater into the ground **100** with the aid of a module which includes parts similar to the pile driver of FIG. **1**, and which therefore bear like reference numerals.

Extending axially through the control valve **8** and actuator **9** is a discharge pipe **7** which communicates with and supports a pump **6** by the pump discharge outlet. The pump in turn supports an electric drive motor **5.** The valve **8**, actuator **9**, pipe **7**, pump **6**, motor **5**, and cap **120** to which they are secured constitute a unitary module which can be mated temporarily, during driving, with each of a series of piles.

Cap **120** is in water-tight sealing engagement with the pile mouth **1** and may be provided if desired, with means for remote-controlled release, e.g., a latch and trip-wire (not shown) to the surface, for releasing the module from the pile when driving has been completed. A wire rope sling **10** is provided for lowering and lifting the module onto and off of the piles, and also conveys the power and control cable harness **11** thereto. The module is serviced by a barge **124** having a winch **125** and cable **126** for lifting and lowering the module and a drum **127** for paying out and winding up the power and control cable harness **11.**

When the module is mated to a pile, the pile performs the function of the hammer tube of the FIG. **1** embodiment, and the operation is the same. In this case, the evacuatable enclosure is defined by the cylindrical walls of the pile **1** and the inner surface **121** of the pile tip **122.** The enclosure is coupled with the tip through the wall material of the pile.

During the operation of the device, water is evacuated from that portion of the enclosure which is at or above the level of pump inlet **123** and discharged through the discharge pipe **7.** Upon opening of the fast acting valve **8**, water is drawn through valve inlet **12** and is accelerated inwardly along the axis of the pile by the ambient hydrostatic head. Because the valve is provided with a large opening, the mass of water moving along the axis of the pile substantially fills the cross-section of the evacuated portion of the enclosure. The water is unrestrained and therefore continues moving substantially independent of the pile until it is suddenly decelerated against the barrier provided by the inner surface **121** of the pile tip, the water being substantially at its theoretical bulk modulus when decelerated. In this connection, it should be noted that the mass of water can be decelerated against the barrier either directly or "per se" (if provision were made for completely emptying the pile before admitting the water) or indirectly, such as by contacting the water accumulated in the lower portion of the pile. As a result of such deceleration at the water's theoretical bulk modulus, the hydraulic kinetic energy is converted to a powerful water hammer driving pulse for driving the pile into the sub-soil.

The pile hammer **3** can be freely modified, as desired. For instance, the motor **5** and/or pump **6** may be located outside hammer tube **4** or pile **1** provided the pump inlet is in communication with the interior of the tube at a position spaced along the tube axis from water control valve **8.** Hammers can be employed which have water control valves at both ends and controls which would permit driving along the tube axis in either direction. Configurations may be fabricated for horizontal driving.

Different kinds of valves also may be used. Such others include spring-loaded, hydraulically — and electromagnetically — actuated linear and rotary shear varieties; metal, plastic and elastomeric pinch-off forms, free jet and fluidic submerged jet and pressure-switched groups; and, change-of-state valving techniques. Specific models are identified as spool and gridiron, sliding and rotary shear valves; conventional globe, gate, plug, ball, balanced/eccentric-pivoted poppet and butterfly, and flapper valves; resilient sleeve hydraulically, pneumatically, and mechanically squeezed pinch valves; jet pipes; electroviscous and magnetoviscous forms.

Any other design of evacuatable water-hammer driver may be used in the present invention. Included are those in which evacuation of the water is accomplished by condensable vapors or gas injected into or generated within the chamber. In such cases, a water control valve is not essential to start the flow of liquid in the hammer tube. These are illustrated in FIGS. **5–9**, which also show that the enclosure walls may or may not be at least partly defined by the walls of the pile itself.

IN FIG. **5**, a barge **124** is anchored above the pile **1**, having a tip **122** embedded in the subsoil **100** and an upper end **130** which is submerged and in open communication with the ambient sea water surrounding it. On the barge is a steam generator **105**, control valve **127** for metering steam flow through the insulated steam hose **11**, a winch **125**, and a cable **126.** The steam hose extends downwardly to the pile, along with cable **126**, which by an appropriate sling **131** supports and retrieves an insulated rigid steam pipe **132** prepositioned inside the pile by surface-released latching spiders **133.** The latching mechanism (not shown), and spiders must be strong enough to withstand the bottom of the steam pipe **132** terminates in a steam check valve **134** fitted with steam nozzle **135** open downward. Thus, when the valve **127** opens for a predetermined interval to emit a burst of high pressure steam (which of necessity must be of substantially higher pressure than the hydrostatic head) an expanding steam bubble is produced which forces upwardly that water which is present in the pipe above the level of the steam nozzle **135.**

Preferably, the volume of the steam burst is regulated to just evacuate the pile **1** of water. The steam is preferably of superheat quality and released in sufficient quantity to just evacuate the pile **1** of water. The efflux upward momentum generates a corresponding down thrust. It also causes a sudden vapor condensation when the tube pressure is driven negative The attendant evacuation by change of the physical state of the steam results in reversing the water flow to generate the downdriving water hammer impulse to the pile **1**. If a non-condensable gas like air were used to the exclusion of steam, a spring-like compliance would be imparted to the water, severely reducing the power of the hammer blow. A Helmholtz type of damped oscillation is then generated, whose frequency depends on the volume of entrapped air, hydrostatic head, and mass of water in the tube.

FIG. **6** represents a similar arrangement which operates in the same manner. However, in this case, the pile **1** has an open-ended tip **136**, and the barrier **140** is a remote-controlled incrementally-moved gripper assembly (similar in construction and operation to FIGS. **3** and **2**, respectively). Said assembly secures check valve **134** terminating steam pipe **132** feeding steam nozzle **135** (of folded horn construction) which exhausts upwards. As the pile is driven downward the water which is entrapped in cavity **143** between the barrier **140** and soil plug **144** exhausts out through drain pipe **142**. The gas-filled compliant balloon **141**, precharged to ambient pressure, absorbs the momentary volumetric increments of the water displaced during driving. The hydraulic tightness of the water barrier **140** is not critical when leakage absorbed by the compliance **141** subtracts only an insignificant amount from the total dynamic pressure.

FIG. **7** discloses a condensable vapor reset driver in which the evacuatable tube is defined by a tube **4** other than the pile **1** itself. The tube **4** is coupled, to the pile, for instance, by a coupler (not shown) similar to that in FIG. **3**. The controls for the coupler, the steam generator **105** and control valve **104** may be mounted on a surface barge (not shown) and may pass to the pile in any desired manner, such as for instance as disclosed in FIG. **5**. In the operation of this embodiment, the steam control valve **104** is open momentarily to meter the proper amount of steam from generator **105** to the interior of the pile. The operation is the same as the FIG. **5** embodiment.

FIG. **8** represents an arrangement similar to FIG. **7**, utilizing a two-phase combustible mixture consisting of a pressurized fuel such as hydrogen, or a hydrocarbon as kerosene or alcohol, in container **106**, a fuel-metering valve **107**, a pressurized oxidizer such as oxygen in container **108**, and its corresponding metering valve **109**. The fuel combustion chamber **110** is located within the water hammer tube **4**. The component **111** represents either the external ignition source, such as a spark plug, or proprietary catalyst for the monopropellent type rocket fuels such as hydrogen peroxide or hydrazine. For hypergolic (spontaneous combustion upon mixing) type propellants the igniter **111** may be eliminated. On the other hand, liquid (water)borne particles of solid type propellants or explosives may be metered via the valve **107**, caught in the screened combustion chamber, and fired off by means of the igniter **111**. The products of combustion are used to expel the water as previously discussed. These combustion products will be condensable, or at least partly so, due to their water vapor content.

Similarly, FIG. **9** also represents the use of socalled rocket fuels wherein the combustion chamber **110** is external to the water hammer tube **4**. The combustion products' metering valve **112** controls the water evacuation cycle and also acts as a check valve against the water hammer pressure. The remaining parts are similar to those shown in FIG. **8**.

Practically, the principal limitation on the generation of larger values of water hammer within a single pipe may be the circumferential tensile or hoop stress. As will be shown, the generation of water hammer at a 1,000 ft. depth in a 2-foot diameter steel pipe requires a wall thickness of 2.34 inches in order to keep the stress down to 69,000 psi While this is not an excessive working stress for modern alloy steels, it still exceeds structural grade ratings. Since the invention is normally used in limited access or restricted environments, a low safety factor can be employed. To avoid the use of excessively massive pipe walls, reinforcement in the form of filament winding or an axial series of external or internal spaced reinforcing rings is recommended. The distributed spring mass configuration of the latter also reduces the transonic velocity of wave propagation along the pipe. Two advantages follow, namely, reduction of hoop stress and increase of impulse duration. The use of pipe wall materials with a lower elastic modulus like aluminum or resinated fiberglass achieves a reduction in water hammer pressure by lowering the transonic velocity. For these to be fully effective under water, additional acoustic pressure release material like cork may be applied at the ambient water interface in order to preclude acoustic loading. Another method of reducing wall stresses, by slowing down the axial velocity, is to use a series of truncated cone baffles **150** and **151** as illustrated in FIG. **10** or to spiral the water in the tube by uni-directionally twisted or alternately twisted bundles of smaller diameter tubes or baffles. Thus, the water hammer tube **4** of any of the preceding embodiments may be provided with a plurality of twisted tubes **152** within the tube **4** and extending axially of at least a portion of the tube which defines the evacuatable enclosure. Where the tube **4** includes a discharge pipe **7** or other equipment along its axis, the spiral tubes **152** may be arranged around or above them. Similarly, baffles **155** and **156** of varying rotation may be used, as disclosed in FIG. **12**. The longer travel path provided by these various means proportionally creates a longer pulse.

Where the water hammer device is provided with a valve to start the water flow, the water hammer intensity can be reduced by retarding the rate at which the valve goes from full closed to full open position.

Thus, for a given driving application (assuming a given depth, pile mass and soil conditions) it is possible to tailor the force-time characteristics of the water hammer impulses by a suitable selection of the length and diameters of th water hammer tube, and the reinforcement and material of construction thereof. Also, one may employ the acoustic pressure release material, baffles and valve opening rate as discussed above. Thus, it will be seen that the method has far more flexibility than is provided by the conventional steam hammer.

When the water hammer tube is provided with a unidirectional helix, a component of mechanical torque and rotation can be generated by the checked angular momentum of the falling mass of water. This can increase the penetrating power of the pile driver in certain soils. The "screw" vs. the "nail" action also improves a friction pile's load bearing capacity, especially when the "lead" or helix angle is optimized for the soil conditions.

FIG. 13 discloses one example of that class of evacuatable tube water hammer drivers which include one or more "free" pistons. In the present context, a free piston is one which, during at least a portion of its movement between the extreme limits of its travel, is not directly coupled to or is at least substantially independent of, the pile. Configurations are possible in which the free piston, provided with means to raise it in the evacuatable chamber, can replace the pump-motor combination. In the preferred mode of operation, the piston will replace both the pump-motor combination and the water control valve.

In FIG. 13 a barge **134** is anchored over a pile **1** having its tip **122** embedded in sub-soil **100**. The pile's open mouth **130** is submerged. From a winch **125** on the barge descends a cable **126** through pile mouth **130** to a piston **160.** The latter fits closely enough within the pile walls to at least partially and preferably substantially completely bar the entry of water into the space below the piston as it is raised, the need for or desireability of packing **161** being determined in part by the speed at which the piston is to be raised and lowered.

Operation of this embodiment simply involves repetitively and alternately raising the piston **160** with winch **125** and dropping the piston, which may, if desired come to rest against a cushion block **163.** Raising of the piston evacuates an enclosure defined by the pile tip and side walls. Quick release of the piston and rapid descent thereof through the pile accelerates a mass of water above the piston. This mass is suddenly decelerated by indirect contact through the rigid piston with the barrier provided by th cushion block **163** when the piston strikes the latter. This, in turn, generates the water hammer impulse which drives the pile.

To minimize drag and inertia forces which would retard the fall of piston **160,** a clutch may be used to disengage the winch reel from its drive motor during the fall of the piston. For large piston loads a multi-sheaved block and tackle, mounted on the top of the hammer tube, may be employed. The main hook made in the form of a bull gear may be disengaged from the piston by rotation, pivoting around a bushed holding pin. The required mechanical power may be provided by a small electric or hydraulic motor-driven pinion. A small rope which follows the piston down its stoke may act as a guide for reengaging the lifting hook. Other quick make-break configurations are the commerically available wireline overshot latching clips for removing downhole core barrels from diamond bits left inside petroleum wells.

A guided long rack and motor-driven pinion means may also be used to raise the piston. A high pressure-angle stubby gear tooth profile facilitates the easy disengagement of the pinion from the rack by a guick-acting cam or hydraulic piston means. The rack can ride down with the piston and the pinion assembly remain fixed at the top of the hammer tube.

Similarly, another piston-raising means may employ a split nut fastened to hydraulically or cam-actuated chuck jaws to engage and quickly disengage a long, threaded screw fastened to the piston. The nut is rotated by a motor driven pinion meshing with a bull gear made integral with the chuck, all mounted in top of the water hammer tube.

Another method would use a hydraulically-actuated cylinder to lift the piston. A hydraulic chuck, on the end of the cylinder rod, latches and disengages the piston.

For shorter and faster piston hammer strokes a tube-mounted electric or hydraulic motor-driven cam is used to provide a relatively slow lift and free drop to the piston.

Instead of packing or piston rings, a rolling diaphragm type seal may be used to keep the water out of the interior of the water hammer tube. A suitably-shaped fillet at the bottom of the stroke supports the elastomeric-impregnated fabric against the high-amplitude water hammer pressure pulse.

In the above-described embodiments, the water hammer tube has been entirely submerged in the water in which it is operating, the preferred mode of carrying out the invention. This makes use of the hydrostatic head available in the water to power the driving impulse. Also, the submerged-operation feature of the invention offers the possibility of easier handling during storm conditions. However, in other cases, especially shallow water applications, the water hammer tube may be at least partially above the surface of the water. Whether the evacuatable enclosure is defined by a tube separate from the pile, or by the pile itself, the water for generating the water hammer pulses may be provided by an upward extension of the pile or the tube, which is filled with water, or by a reservoir located above the hammer tube as shown in FIG. **14.**

IN FIG. **14** is shown a pile **1** partially embedded in sub-soil **100** and having its upper end **130** protruding above the water's surface. A driver **171** is releasably secured in the top of the pile by a coupler **40** similar to that disclosed in FIG. **3,** like parts of the respective couplers being identified in the drawings by the same reference numerals. To the base **57** of the coupler is secured the base **172** of the driver.

Extending upwardly from the base **172** is an upright, elongated water hammer tube **4.** A reservoir **188** is supported by the tube **4** and connected thereto by flared walls **189** to promote smooth flow of water **190** between the tubes and reservoir. The reservoir may be pressurized if desired by forcing in gas or vapor through inlet **192.** A central column **173** is suitably secured to the base **172** and extends upwardly and coaxially with the water hammer tube **4** and thence at least part way into reservoir **188,** where it may be supported by a three-legged spider **191** secured to the reservoir walls, only one leg of which is shown in the drawing.

Piston **174** is mounted for vertical or axial reciprocation on column **173** between base **172** and stop **180** secured toward the upper end of the column. Both the piston and base **172** are reinforced to withstand the mechanical shock associated with water hammer pressures. The piston itself may of course contribute some driving momentum during operation, but normally, during driving, the mass of the piston is less, and usually substantially less than half, the mass of the fluid (water) which is above it or which enters the tube 4 during the down stroke.

The piston has a central aperture **177** of slightly greater diameter than the outside of column **173,** and has an outer diameter slightly less than that of the inner diameter of the water hammer tube **4.** Suitable seals may be provided if desired in the clearances between the piston on the one hand and the pile and column on the other. However, when operating with a small pressure differential across the piston, e.g., 1 atmosphere or less, leakage of water and steam past the piston will be minimal. Thus, it is possible to fabricate the apparatus in a way which provides a close but essentially drag-free relationship between the piston and the other parts. Also, making the piston neutrally buoyant relative to water may reduce the pressure differential and discourage leakage.

Connected to a suitable steam supply (not shown) is a steam conduit **178** with control valve **123.** Conduit **178** feeds passages in base **172** terminating in steam outlets **179.** When the control valve **123** is opened to emit a burst of steam from the outlets **179** at a pressure greater than the ambient water pressure above piston **174,** it will be forced upwardly in tube **4.** When the piston retains sufficient upward momentum after control valve **123** closes, the resultant further expansion of the space beneath the piston can super-cool the steam and condense it, thus evacuating the space beneath the piston. Where, because of insufficient momentum or other reasons, there is not sufficient auto-cooling of the steam, cool water may be sprayed into the space beneath the piston by water conduits and spray nozzles (not shown) fitted into the central column and/or base, or into the side walls of tube **4.**

In order to keep the evacuatable enclosure free of steam condensate, and possibly of cooling water where such is used, the base **172** may be fitted with a drain pipe **182** and valve **181.** Valve **181,** like steam valve **123,** will normally be opened during the raising of piston **174** and closed on the down stroke.

In certain apparatus, e.g., that having a cam-actuated free piston, it may be found desirable to adjust the actuation of the valve to maintain the hydraulic pulse repetition rate at an operational resonance of the system. This can be accomplished by placing sensors on the driver and/or pile and/or ground and automatically actuating the valve in response to signals from the sensors.

Although water is used as an example, the working fluid is not necessarily limited thereto. In a closed system, any liquid may be used.

EXAMPLE

When working with water hammer tubes of about 50 feet and longer, one can obtain driving pulses which are approximately two or more times as long as with the large steam hammer described in the comparison example, Longer pulses are obtained with a hammer tube of 100 feet in length. This may be illustrated with a water hammer tube of 24 inch diameter schedule **160** (2.343 inch wall) steel pipe 100 feet long and weighing 54,209 pounds. Ancillary equipment includes a pump to evacuate the tube at some convenient rate, a watertight cap at one end of the tube, and a fast acting valve at the other end.

After the pipe is evacuated and the control valve is suddenly opened, the water entrance velocity "$U_{1,000}$" at the 1,000 ft. depth "h" is

$$U_{1000} = \sqrt{2gh} = \sqrt{[2 \times 32.2 \text{ ft./sec}^2(1{,}000 + 34)\text{ft.}]} = 259 \text{ ft./sec.}$$

The external, upward force on the capped bottom end of the pipe due to the difference between the ambient pressure and internal vacuum is

$$F_v = \rho g h S_t = 64 \text{ lbs./ft.}^3 \times 1{,}034 \text{ ft.} \times 2.03 \text{ ft.}^2 = 134{,}500 \text{ lbs.}$$

The weight of the evacuated water and resultant buoyancy is

$$F_W = \rho g S_t L = 64 \text{ lbs./ft.}^3 \times 2.03 \text{ ft.}^2 \times 100 \text{ ft.} = 13{,}000 \text{ lbs.}$$

The transonic velocity in the pipe is

$$v = \frac{c}{\sqrt{1 + \dfrac{BD}{ET}}} = \frac{4890 \text{ ft./sec.}}{\sqrt{1 + \dfrac{3.3 \times 10^5 \text{ p.s.i.} \times 19.3 \text{ in.}}{29 \times 10^6 \text{ p.s.i.} \times 2.34 \text{ in.}}}} = 4670 \text{ ft./sec.}$$

The water hammer pressure is

$$p_{WH} = \rho v U = 1.99 \text{ slugs/ft}^3 \times 4{,}679 \text{ ft/sec} \times 259 \text{ ft/sec} = 16{,}700 \text{ psi.}$$

The corresponding simple tensile hoop stress in the pipe walls is

$$s = pD/2t = (16{,}700 \text{ psi} \times 19.3 \text{ in})/(2 \times 2.34 \text{ in}) = 69{,}000 \text{ psi.}$$

The water hammer impulse force is

$$F_{WH} = p_{WH} S_t = 16{,}700 \text{ psi} \times 293 \text{ in.}^2 = 4{,}900{,}000 \text{ lbs.}$$

The time duration of the impulse force on the capped end is

$$T_{WH} = 2L/v = (2 \times 100 \text{ ft.})/4{,}670 \text{ ft/sec} = 0.0428 \text{ sec.}$$

The hydraulic momentum of the incoming water, just before impact, is

$$(MU)_H = \rho S_t L U = 1.99 \text{ slugs/ft}^3 \times 2.03 \text{ ft}^2 \times 100 \text{ ft} \times 259 \text{ ft/sec}$$
$$= 104{,}500 \text{ slug-ft./sec} = 104{,}500 \text{ lb-sec.}$$

The hydraulic kinetic energy of the incoming water is

$$KE_H = \tfrac{1}{2} \times 13{,}000 \text{ lbs.}/32.2 \text{ ft/sec}^2 \times (259 \text{ ft/sec})^2$$
$$= 13.5 \times 10^6 \text{ ft.lbs.} = 18.3 \text{ Mega Joules}$$

The incoming hydraulic power is

$$W_H = \pi/8\rho\, D^2 U^2 = \pi/8 \times 1.99 \text{ slugs/ft.}^3 \times (1.61 \text{ ft})^2 \times (259 \text{ ft/sec})^3$$
$$= 35 \times 10^6 \text{ ft.lbs./sec} = 47.5 \text{ Megawatts}$$

As a check, the work required to evacuate the pipe against the ambient hydrostatic head, or the potential energy of its cavity is

$$PE_H = \text{ambient pressure} \times \text{pipe volume} = \rho\, g\, h\, S_t\, L$$
$$= 64 \text{ lbs/ft}^3 \times 1{,}034 \text{ ft} \times 203.5 \text{ ft}^3 = 13.5 \times 10^6 \text{ ft.lbs.}$$

The water hammer power is

$$W_{WH} = \pi/8\rho\, D^2 U^2 v = \pi/8\,(1.99 \text{ slugs/ft}^3)\,(1.61 \text{ ft})^2\,(259 \text{ ft/sec})^2(4{,}670 \text{ ft/sec})$$
$$= 631 \times 10^6 \text{ft.lbs./sec.} = 855 \text{ Megawatts}$$

COMPARISON

An example of the contemporary state-of-the art is referenced for comparison. One of the largest, commercial single-acting steam/air hammers for land-based or offshore piledriving is the 060 size rated at 180,000 ft.lbs. The practical underwater operational limit is 200 ft. The striking energy, obtained by a 60,000 lb: weight free-dropping 3 ft., is 1/75th of the water hammer value from the two foot pipe example. At the theoretical terminal velocity of $U_{SH} = \sqrt{2gh} = \sqrt{2 \times 32.2 \text{ ft/sec}^2 \times 3 \text{ ft}} = 13.9$ ft/sec, its momentum, $(MU)_{SH} = 60{,}000$ lbs/32.2 ft/sec² × 13.9 ft/sec = 25,900 lb.sec. or one-fourth of that acquired by the water hammer example. The principal feature of the water hammer, however, is in the relatively long time duration of the impulse force. In order to improve on this desirable characteristic, the steel piledriving hammer uses an expendable wooden or resinated-fabric cushion block insert between the ram and the pile to diminish the impact shock. Wave propagation theory, using computerized solutions of finite difference equations, has been applied to a math model describing system behavior of "What happens when (the) hammer hits (the) pile," *Eng. News Record*, 5 Sept. 1957, Edw. A. Smith; also, refer to E.A.L. Smith, "Pile-Driving Analysis by the Wave Equation," J. Soil Mechanics and Foundations Div., Proc. ASME, Aug. 1960. A further investigation, correlating piledriving characteristics with its load bearing capacity, (Forehand and Reese, "Pile-Driving Analysis Using the Wave Equation," Princeton Univ., M.S. Engineering Thesis, 1963), discloses that the impulse duration, defined as "the time the velocity remains positive," is of the order of 10 milliseconds for the steel hammer blow or one-fourth of that in the water hammer example. If so, then the 30 ton steel hammer impulse force is

$$F_S = 25{,}900 \text{ lb.sec.}/0.01 \text{ sec} = 2{,}600{,}000 \text{ lbs.}$$

or roughly one-half of the water force. The mechanical power transfer rate of the steel hammer is, roughly, $W_S = 180{,}000$ ft. lbs./0.01 sec. = 24.4 M W, or 1/35 of the water hammer power. If the impulse duration of the steel hammer blow is shorter, the force obviously increases in inverse proportion, but then a new difficulty arises in establishing compression, and displacement, simultaneously along the entire length of a long pipe. For example, in a steel pile 200 ft. long, even with an undamped (unclamped) sound velocity of 16,600 ft/sec. in steel, it takes 12 milliseconds for the impulse to reach the tip. With concrete piles, this trouble is further aggravated because sound velocity in concrete is one-third slower. Some contemporary offshore foundation designs call for loads up to 2,000 tons from piles 200–600 ft. long, 3–8 ft. in dia., weighing 100–200 tons, in up to 1,000 ft. of water. Without supplementary techniques involving pre-drilling or jetting such piles are practically undrivable by the steam-air hammer even when spliced to extend to the surface.

From the foregoing, it may be seen that the invention provides many advantages. It makes feasible a large increase in driving capability. And this can be done using a smaller mass ratio (driving mass versus pile) than has heretofore been thought advisable in steam hammer operations. That is, larger impulses can be generated using a driving mass which is less than one-fourth that of the pile. This, in turn, makes it possible to drive piles without the use of palliatives such as pilot hole drilling, water jetting and grouting into an oversized hole, which measures can reduce pile load-bearing capacity.

The pressure-time characteristics of the water hammer impulse can be tailored over a wide range of values to match corresponding requirements of the pile and soil. Thus, driving impedance can be better matched to that of the earth than when operating with for instance a steel hammer.

Under the longer impulses which can be generated by a water ram or spear having a length to diameter ratio of 10 or more, long piles, e.g., L/D   15, move more nearly as a unit, e.g., their driving action is more like that of a nail, rather than a worm, in which one part moves ahead while other parts are held back. Thus, a greater fraction of the driving energy is usefully expended in overcoming displacement skin friction, to advance the pile, rather than being tied up in the rubber-like ground "quake." With the long pulses which may be provided with water hammer if desired, unwanted standing wave conditions in the pile can be prevented more effectively. The invention renders unnecessary the use of a cushion block, as sometimes required with a steel hammer, thereby eliminating the inelastic collision energy loss associated therewith.

Certain important advantages are associated with the convenient manner in which the invention may be applied under water. With the driver submerged, it may be handled with greater safety and ease during storm conditions. Coupling of the driver to the pile at a point below its top end helps to reduce losses of driving energy attributable to the mechanical compliance of the pile. Submerged operation provides inherent capacity for generating larger pulses as submergence increases, and particularly a depths greater than 200 feet where hydrostatic back pressure aggravates the venting problem of the air operated hammer, where thermal line losses preclude the steam driven hammer and where conventional vibratory driving requires such a relatively large back-mass for preload and such low frequencies that reaction forces necessary for driving become ineffective without excessively large excursions. Handling is facilitated because the driving mass can be drained from the apparatus when it is being transported and lifted above the surface.

Moreover, water hammer operation makes it convenient to twist the pile as it is driven downward, such as by including helical baffles in the water hammer tube which impart a twisting motion thereto. In some cases, especially where the "lead" or helix angle is optimized for the soil conditions, this can improve the pile's load bearing capacity.

In view of the foregoing, it is apparent that the present invention is a broad one, and that many changes may be made in the foregoing embodiments without departing from the spirit of the invention.

What is claimed is:

1. In the driving of piles underwater, wherein the pile has its tip embedded in the subsoil of a body of water and an evacuatable enclosure with side walls and a lower barrier is effectively coupled with the tip of the pile for transmitting driving forces exerted upon said barrier to said tip, the method which comprises: evacuating at least a portion of said enclosure, by removing water and at least a portion of any gases or any vapors which may be present in the evacuated portion and evacuating sufficiently to provide space for acceleration and deceleration of a mass of water adequate to produce the necessary force and energy for driving said pile; accelerating along the axis of said pile a mass of water which moves substantially independent of said pile in said evacuated portion of said enclosure; suddenly decelerating said mass against said barrier, thereby converting hydraulic kinetic energy to a water hammer driving pulse for driving said pile into said subsoil; and repetitively evacuating, accelerating, decelerating and driving as aforesaid.

2. A method in accordance with claim **1** wherein said evacuatable enclosure is beneath the surface of said body of water, and the mass of water accelerated along the axis of said pile is accelerated under the influence of the hydrostatic head in said body of water.

3. A method in accordance with claim **1** wherein said evacuatable enclosure is in communication with a reservoir, and the mass of water accelerated along the axis of said pile is accelerated under the influence of a hydrostatic head in said reservoir.

4. A method in accordance with claim **3** wherein said reservoir is pressurized with gas or vapor.

5. A method in accordance with claim **1** wherein said enclosure is within said pile.

6. A method in accordance with claim **1** wherein the walls of said enclosure are defined at least in part by the walls of said pile.

7. A method in accordance with claim **1** wherein the driving force is applied to said pile through a coupling which is below the top of the pile.

8. A method in accordance with claim **7** wherein the coupling is closer to the subsoil of said body of water than to the top of said pile.

9. A method in accordance with claim **1** wherein the enclosure is evacuated by pumping.

10. A method in accordance with claim **1** wherein said enclosure is evacuated with a condensable vapor.

11. A method in accordance with claim **10** wherein said condensable vapor is condensed, and the acceleration of said mass of water is commenced, by spraying cool water into the condensable vapor.

12. A method in accordance with claim **1** wherein said enclosure is evacuated with combustion gases that are at least partially condensable.

13. A method in accordance with claim **1** wherein said enclosure is evacuated by forcing the water away from the barrier with piston means.

14. A method in accordance with claim **13** wherein said piston means is moved by pressure exerted thereon by condensable vapor, and said condensable vapor is then condensed to commence the acceleration of said mass of water along the axis of said pile.

15. A method in accordance with claim **1** wherein the acceleration of said mass of water along the axis of said pile is commenced by the rapid opening of valve means communicating between said enclosure and a source of water under pressure.

16. A method in accordance with claim **15** wherein said valve is retained closed during evacuation of said enclosure and opens in response to the water reaching a predetermined level in the evacuation of said enclosure.

17. A method in accordance with claim **15** wherein a hydrostatic head in said source of water is applied to said valve for assisting in the rapid opening thereof.

18. A method in accordance with claim **15** wherein the water hammer intensity is controlled by controlling the rate at which said valve is opened.

19. A method in accordance with claim **1** wherein said pile is driven in either direction by valves at both ends of said enclosure and by controls for driving along the tube axis in either direction.

20. A method in accordance with claim **1** including selectively retarding the axial velocity of said mass of water for varying the pressure and time characteristics of the water hammer driving pulse to compensate for varying strata and driving conditions.

21. A method in accordance with claim **20** wherein said axial velocity is retarded by retarding the opening of a valve which commences the acceleration of said mass of water.

22. A method in accordance with claim **20** wherein said axial velocity is retarded by baffle means in said enclosure.

23. A method in accordance with claim **20** wherein said axial velocity is retarded by imparting a twisting motion to the mass of water which moves along the axis of said enclosure.

24. A method in accordance with claim **1** wherein the mass of water accelerating along the axis of said enclosure substantially fills the cross section of said enclosure.

25. A method in accordance with claim **1** wherein the water decelerated against said barrier has substantially theoretical bulk density on impact.

26. A method in accordance with claim **1** wherein the mass of water decelerated against said barrier has less than one-fourth the mass of said pile.

27. A method in accordance with claim **1** wherein said pile has a length to diameter ratio of equal to or greater than 15, said pile is submerged in water 200 feet deep or deeper, said evacuatable enclosure is beneath the surface of said body of water, and the mass of water accelerated along the axis of said pile is accelerated under the influence of the hydrostatic head in said body of water.

28. In the dirving of piles underwater, wherein a pile having a length to diameter ratio of equal to or greater than 15 has its tip embedded in the subsoil of a body of water 200 feet deep or deeper and an evacuatable enclosure with side walls and a lower barrier is effectively coupled with the tip of the pile for transmitting driving forces exerted upon said barrier to said tip, the method which comprises: evacuating at least a portion of said enclosure, by removing water and at least a portion of any gases or any vapors which may be present in the evacuated portion and evacuating sufficiently to provide space for acceleration and deceleration of a mass of water adequate to produce the necessary force and energy for driving said pile; accelerating along the axis of said pile a mass of water which moves substantially independent of said pile in said evacuated portion of said enclosure; selectively retarding the axial velocity of said water mass for varying the pressure and time characteristics of a water hammer driving pulse to be generated by impact of said mass against said barrier; suddenly decelerating said mass against said barrier, thereby converting hydraulic kinetic energy to said water hammer driving pulse for driving said pile into said subsoil; and repetitively evacuating, accelerating, decelerating and driving as aforesaid.

29. A method in accordance with claim **28** wherein said axial velocity is retarded by retarding the opening of a valve which commences the acceleration of said mass of water.

30. A method in accordance with claim 28 wherein said axial velocity is retarded by baffle means in said enclosure.

31. A method in accordance with claim 28 wherein said axial velocity is retarded by imparting a twisting motion to the mass of water which moves along the access of said enclosure.

32. In the driving of piles underwater, wherein a pile having a length to diameter ratio of greater than or equal to 15, a diameter of three feet or larger and a length of 200 feet or longer has its tip embedded in the subsoil of, and is completely submerged in, a body of water at least about 200 feet deep, and has an evacuatable enclosure beneath the surface of said body of water with side walls and a lower barrier effectively coupled with the tip of the pile for transmitting driving forces exerted upon said barrier to said tip, the method which comprises: evacuating at least a portion of said enclosure, by removing water and at least a portion of any gases or any vapors which may be present in the evacuated portion and evacuating sufficiently to provide space for acceleration and deceleration of a mass of water adequate to produce the necessary force and energy for driving said pile; accelerating along the axis of said pile under the influence of the hydrostatic head in said body of water a water ram or spear having a length to diameter ratio of 10 or more which moves substantially independent of said pile in said evacuated portion of said enclosure; suddenly decelerating said mass against said barrier, said water being at substantially theoretical bulk density on impact, thereby converting hydraulic kinetic energy to a water hammer driving pulse for driving said pile into said subsoil; and repetitively evacuating, accelerating, decelerating and driving as aforesaid.

33. A method in accordance with claim 32 in which the evacuated portion of said enclosure is 50 feet in length or longer.

34. In the driving of piles underwater, wherein the pile has its tip embedded in a subsoil of a body of water and an evacuatable enclosure with side walls and a lower barrier is effectively coupled with the tip of the pile for transmitting driving forces exerted upon said barrier to said tip, the method which comprises: evacuating at least a portion of said enclosure, by removing liquid and at least a portion of any gases or any vapors which may be present in the evacuated portion and evacuating sufficiently to provide space for acceleration and deceleration of a mass of the liquid adequate to produce the necessary force and energy for driving said pile; accelerating along the axis of said pile a mass of said liquid which moves substantially independently of said pile in said evacuated portion of said enclosure; suddenly decelerating said mass against said barrier, thereby converting hydraulic kinetic energy to a liquid hammer driving pulse for driving said pile into said subsoil; and repetitively evacuating, accelerating, decelerating and driving as aforesaid.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,824,797 Dated November 5, 1974

Inventor(s) Serge S. Wisotsky

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

b) lines 12 and 13, delete "the product" and insert -- a function --; and

c) line 52, change the "," after "hole" to --; --.

d) Column 2, line 44, delete "log" and insert --leg--.

e) Column 3, line 26, delete "driven" and insert --driver--.

f) Column 4, line 57, after "pile" insert --, --; and

g) line 59, delete "coupled" and insert --coupler--.

h) Column 5, line 7, delete "coupled" and insert --coupler--.

i) Column 6, line 51, after "the" insert --water impact forces, and yet not unduly impede its flow. The --.

j) Column 7, line 18, after "downward" insert --, --.

k) Column 8, line 41, delete "varying" and insert --alternating --.

l) Column 9, line 46, delete "stoke" and insert --stroke --,

m) line 55, delete "quick-" and insert --quick- --;

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,824,797 Dated November 5, 1974

Inventor(s) Serge S. Wisotsky

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

n) line 58, delete "main" and insert -- mains--.

o) Column 11, line 51, delete "," and insert --.--;

p) line 53, delete "160" in bold face type and insert --160-- in normal face type; and

q) lines 62 to 65, delete

"
$$U_{1000} = \sqrt{2\ gh} = \sqrt{[2 \times 32.2\ ft/sec^2\ (1,000 + 34)\ ft.] = 259\ ft./sec.}$$
"

and insert

$$-- U_{1000} = \sqrt{2\ gh} = \sqrt{[2 \times 32.2\ ft./sec^2\ (1,000 + 34)\ ft.]}$$
$$= 259\ ft./sec/ \quad --$$

r) Column 12, line 48, delete "U^2" and insert --U^3 --.

s) Column 14, line 9, after"L/D" insert -- $\geqslant$ --; and

t) line 32, delete "a" and insert -- at --.

u) Column 16, line 39, delete "dirving" and insert --driving--.

v) Column 17, lines 6 and 7, delete "access" and insert --

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,824,797 Dated November 5, 1974

Inventor(s) Serge S. Wisotsky

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

axis --.

Signed and sealed this 11th day of March 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks