# United States Patent

**Doughty**

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[54] **PILE DRIVING SYSTEM AND APPARATUS**


[72] Inventor: **Samuel Clifford Doughty,** Burlingame, Calif.

[73] Assignee: **Santa Fe International Corporation,** Santa Fe Springs, Calif.



[22] Filed: **Dec. 28, 1970**

[21] Appl. No.: **101,458**

**Related U.S. Application Data**

[62] Division of Ser. No. 756,685, Aug. 30, 1968, Pat. No. 3,604,522.

[52] **U.S. Cl.** .....**173/139,** 61/53, 138/177

[51] **Int. Cl.** .....**E02d 7/00**

[58] **Field of Search**.....173/80–89, 128–139; 175/6, 171; 61/53.5, 53; 138/177



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 863,614 | 8/1907 | Zake | 175/6 |
| 948,989 | 2/1910 | Coffey | 173/86 |
| 1,938,459 | 12/1933 | McNeilly | 173/86 |
| 2,342,253 | 2/1944 | Cooley | 173/88 |
| 2,721,055 | 10/1955 | Madson et al. | 175/293 |



*Primary Examiner*—James A. Leppink

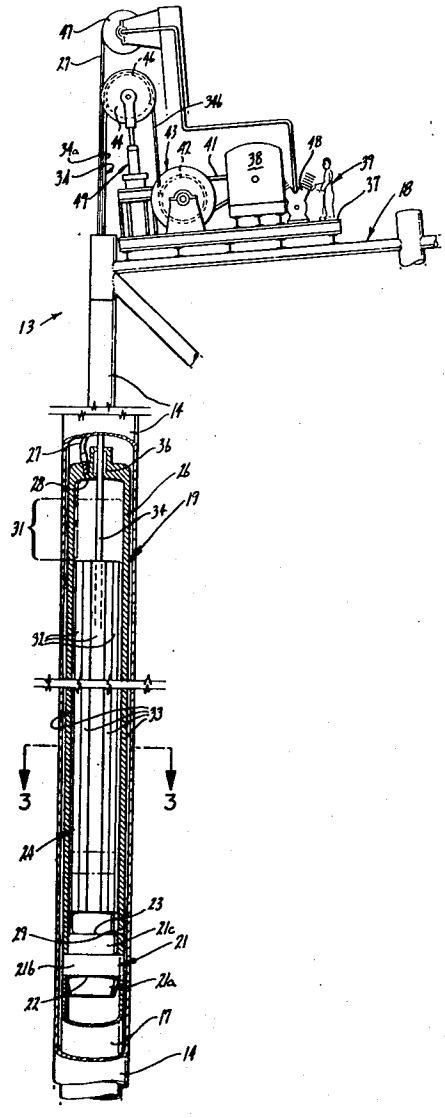
*Attorney*—Flehr, Hohbach, Test, Albritton & Herbert



[57] **ABSTRACT**

A system for driving piles by a succession of blows struck from above by a hammer element wherein a driving head assembly transfers the blows to the upper end of a hollow elongated pile. The hollow pile entraps a water column beneath the head and means are formed in the head for transmitting portions of the water column via the head in response to blows struck upon the head. A cushion of entrapped gas is disposed between the head and column of liquid to momentarily absorb reactive forces derived from the column of water.


**5 Claims, 8 Drawing Figures**



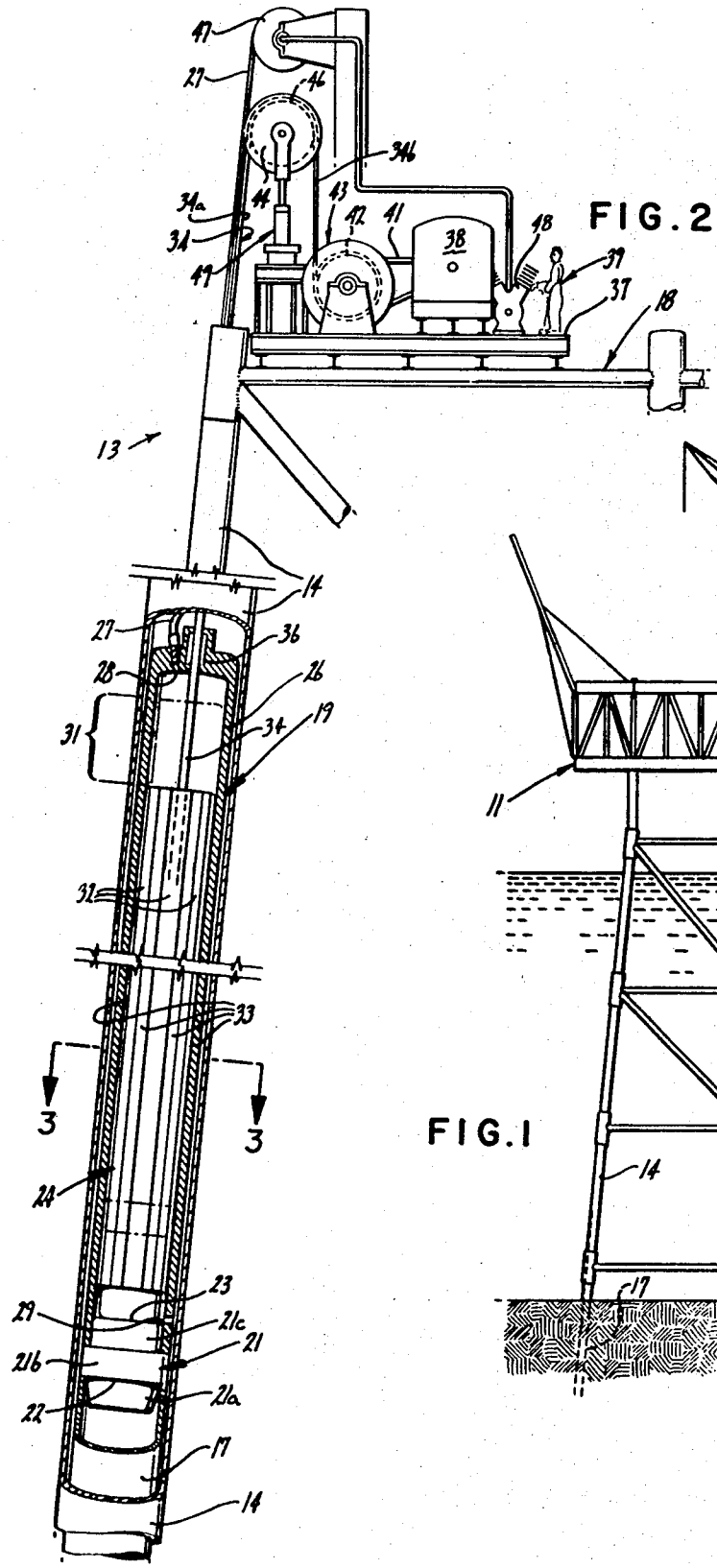



FIG. 2

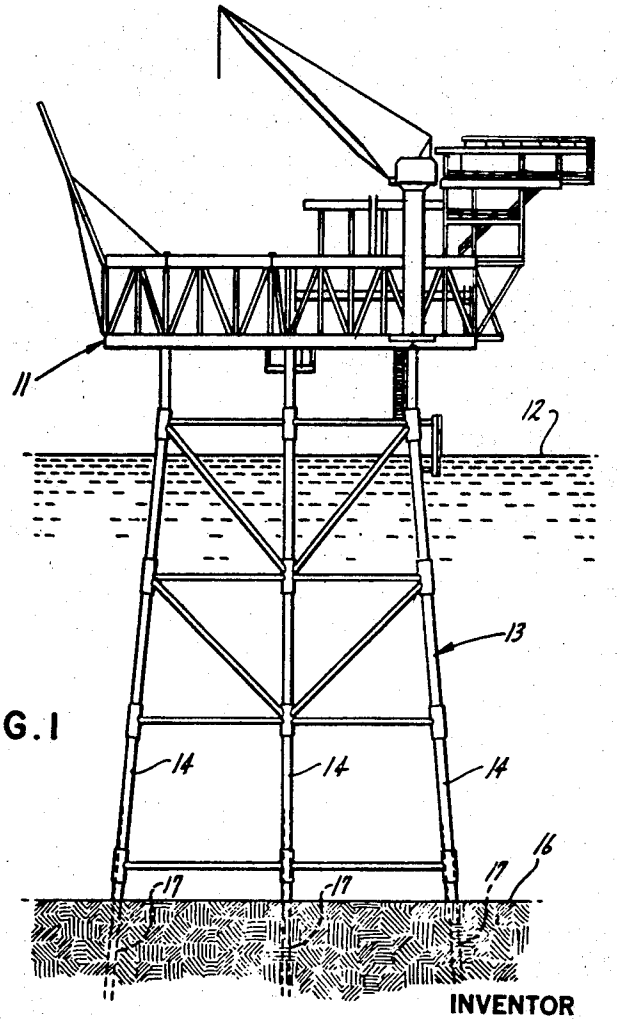



FIG. 1

INVENTOR
Samuel Clifford Doughty

Fleht, Hohbach, Test
Albritton & Herbert
ATTORNEY

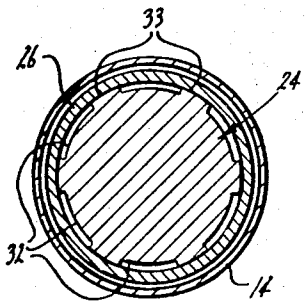



FIG. 3

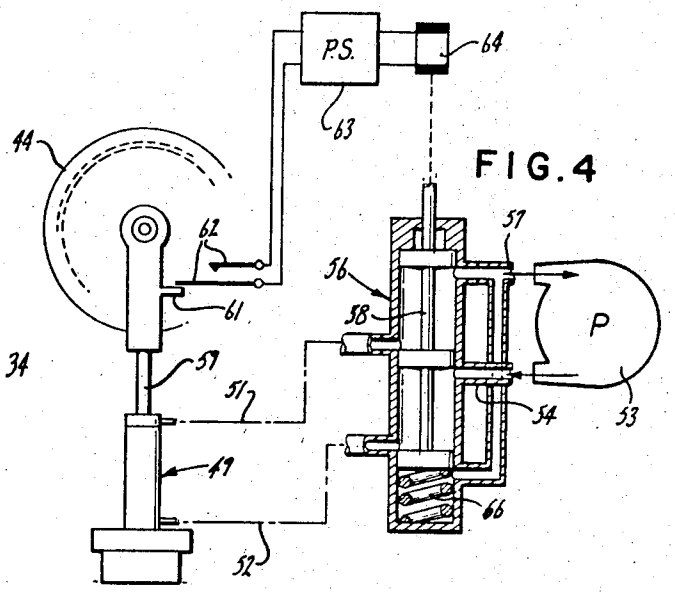



FIG. 4

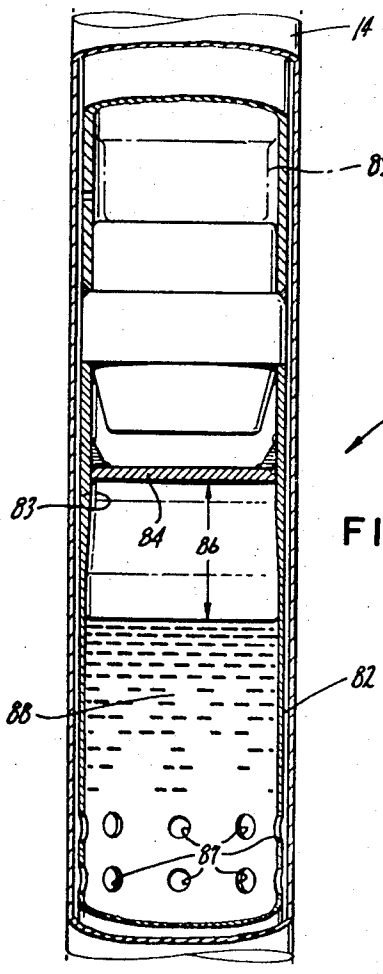



FIG. 6

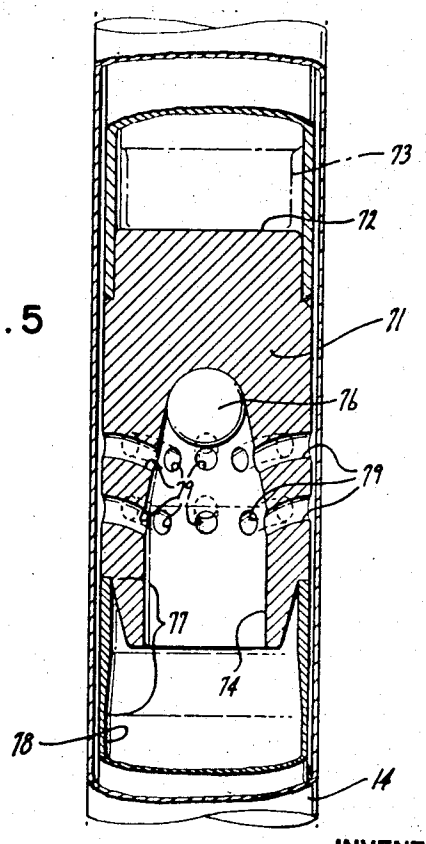



FIG. 5

INVENTOR
Samuel Clifford Doughty

Fleht, Hohbach, Test, Albritton & Herbert
ATTORNEY

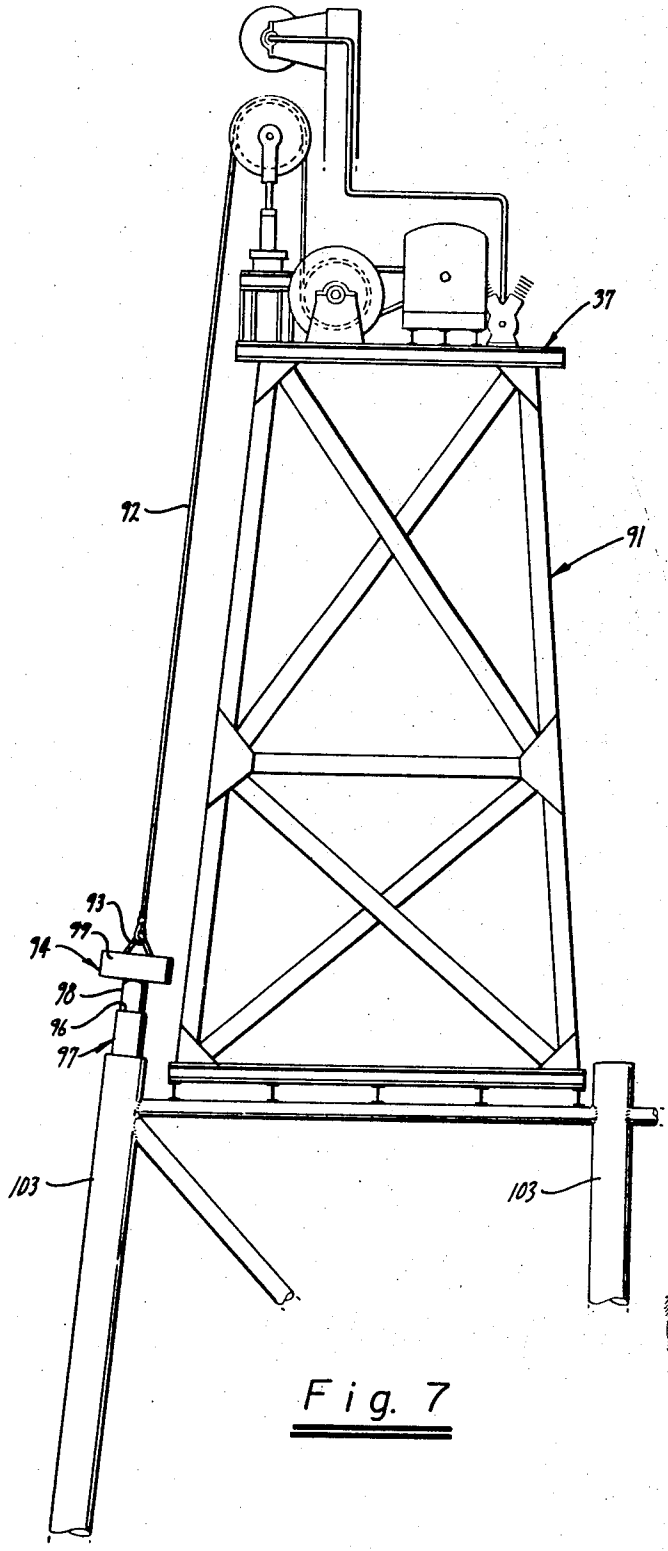
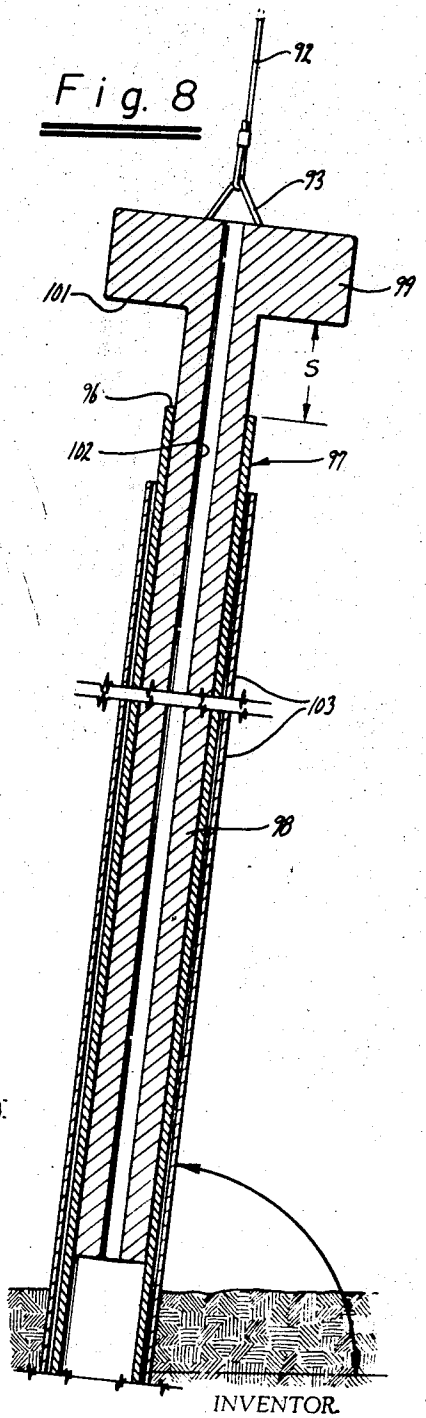



Fig. 7

Fig. 8




INVENTOR.
Samuel Clifford Doughty
Flehr, Hohbach, Test,
Albritton & Herbert
Attorneys

# PILE DRIVING SYSTEM AND APPARATUS

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a division of my application U.S. Ser. No. 756,685, filed Aug. 30, 1968, entitled "Pile Driving System and Apparatus," now U.S. Pat. No. 3,604,522 and copending herewith.

## BACKGROUND OF THE INVENTION

This invention pertains to a system for driving piles by a succession of blows struck from above by a hammer element and to apparatus for use in such systems. This invention is particularly useful in driving piles into the ocean floor under great depths of water, though not limited exclusively to such application.

In the construction of off-shore drilling platforms and other platforms located well out into the ocean, significant overturning forces of wind and sea are experienced by the platform and its supporting tower structure. Typically, in such off-shore platforms, a tower supports the platform or superstructure from the ocean floor by means of a number of elongated hollow legs extending downwardly from the superstructure. The downwardly extending legs form the so-called "-jacket" or support tower structure for the off-shore platform.

It is necessary to resist overturning forces of wind and sea as well as other overturning forces. This, in the past, has been done by means of providing elongated piles which penetrate to great depths and to which the tower can be secured by means of locating the piles coaxially of the hollow legs of the tower.

In order to drive piles coaxially of such "jacket" legs at greater and greater depths, it is becoming increasingly necessary to apply greater and greater hammering energy to the pile, preferably from the convenience of outdoor work stations rather than from submarine locations. It has been observed that losses in the transmission of energy can occur where a pile extension is disposed atop the upper end of the pile to permit the blow to be struck at such an outdoor work station above the surface of the ocean. Certain follower mechanisms have also been employed but are also believed to suffer from the same disadvantage. However, in order to employ larger and larger hammer elements or rams for striking the pile and for other reasons, and notwithstanding the inherent energy losses, it has remained preferable to drive the pile from the outdoor work station rather than to insert compressed air and steam hammers down into the leg of the tower structure for operation below the surface of the water.

Thus, while it is desirable to transmit the hammer energy substantially directly to the pile without loss of energy and by extremely massive hammer elements which can be readily operated from the outdoor work station at the top of the tower or on the platform supported by the tower, these objectives have been somewhat incompatible.

Where underwater steam and air hammers have been attempted for use at submerged locations within the tower legs, trouble has been experienced in discharging the exhaust of such devices into the air above the water since this is usually done by carrying a heavy hose downwardly through the water and coupling it to the hammer. This hose must be very strong to overcome the tendency to collapse under high external water



pressure. Other difficulties to be overcome are condensation of both live and exhaust steam when carried to great depths through cold water, whereby the hammer mechanism tends to become drowned in a pocket of water condensate which impairs its functioning.

Other difficulties in the past have stemmed from the presence of infiltrated water under high pressure finding its way into the casing so as to come between the contacting surface of the falling ram or hammer and the top of the driving block or anvil which transmits the blow to the pile. Any such intrusion of water, in view of its incompressible nature, greatly dissipates the energy of the blow of the hammer and renders it significantly less effective. Such water intrusion difficulties in the past have been countered by introducing compressed air into the casing so as to provide sufficiently high pressure to drive out the water. However, difficulties have impaired the driving efficiency of underwater hammers of this type. Furthermore, such underwater hammers have seldom been used at great depths of water, for example, at depths appreciably exceeding more than a hundred feet.

In circumstances such as the above off-shore support tower application where it is found necessary to drive piles below water level and where the piles are hollow, it has been observed that the column of water entrapped within the pile can rise to a point where the anvil element **21** acts directly against the column of water and thereby generates a compression wave, in the nature of a water hammer, capable of doing considerable damage due to the great forces developed by such wave.

## OBJECTS

It is, in general, an object of the present invention to provide an improved pile driving system and improved apparatus therefor which overcomes the foregoing and other problems.

It is another object of the invention to provide an improved pile driving apparatus wherein reactive forces derived from a column of water captured within the pile being driven are dissipated without substantial loss of energy from the pile driving blow.

These and other objects of the invention will be more clearly understood from the following detailed description of preferred embodiments when considered in conjunction with the accompanying drawings and general summary of the invention.

## SUMMARY OF THE INVENTION

In a system for driving open, hollow piles, there is provided, in general, in combination with the piles, a driving head for transmitting the blows of a hammer to an end of the pile. The driving head includes an anvil portion adapted to transmit the blows to the pile to move the pile toward a water column entrapped within the pile, and means for venting entrapped portions of the liquid of the water column from within the pile in response to the hammer blows.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an elevation schematic view showing an off-shore oil drilling platform of the type referred to above;

FIG. 2 is an enlarged elevation view (partly in further enlarged section) schematically showing a pile driving system and apparatus;

FIG. 3 is a section view taken along the line 3—3 of FIG. 2;

FIG. 4 diagrammatically shows a system for operating the actuator means for providing a drop hammer action;

FIG. 5 is an enlarged detail view, in section, of a driving head assembly according to the invention;

FIG. 6 is an enlarged detail view showing an improved pile construction according to the invention;

FIG. 7 is an elevation view showing another embodiment according to the invention; and

FIG. 8 is an enlarged section view of a detail portion of FIG. 7.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

As noted above, the pile driving system as disclosed herein may be advantageously employed in off-shore pile driving rigs of a type, for example, as shown in FIG. 1. Thus, the superstructure 11 of the rig is generally located on or above the surface of the water 12 by means of a rather tall support tower 13. In general, the support tower 13 has been referred to as a "jacket" comprised of upstanding legs 14 which are suitably braced and supported and generally angle downwardly and outwardly from the superstructure 11 at an angle to the vertical.

As they participate in the system disclosed herein, legs 14 are generally hollow tubular members forming pile guide channels. Tower 13 typically is secured to the ocean floor 16 by means of hollow piles coaxially inserted snugly into the hollow interior of legs 14 so that they may be driven downwardly into the ocean floor to great depths in order to penetrate well beyond the relatively soft upper material of the ocean floor. Piles 17 form a close sliding fit within legs 14.

The upper ends of piles 17 are typically left in place to extend upwardly above the ocean floor 16 an amount sufficient to provide the necessary stability to the rig.

A guide channel, other than legs 13, can, of course, be defined in other ways. For example, in the application of off-shore drilling circumstances, for example, so-called "skirt piles" are driven through and guided by short tubular lengths secured to the exterior portions of the "jacket." Further, annular guide rings are sometimes employed in circumstances of the above type wherein several piles are used within a single leg of the structure.

In view of the fact that the legs 14 and the piles 17 are of relatively large diameter, on the order of several feet in diameter, and in view of the exceptional length of such piles, for example on the order of several hundred feet, it is highly desirable to minimize the amount of pile extension lodged within the legs 14 consistent with safety to the tower.

Thus, where piles 17 extend the full length of legs 14, it will be readily evident that a considerable waste of expensive piles 17 has occurred in view of the fact that the uppermost portions of such piles are providing little or no supporting or stabilizing function.

In order to conquer this problem in the past, it has been suggested to employ the pile driving follower or extension, as mentioned earlier, which can be struck at its upper end in the region of the outdoor work station on platform 18 where the energy will be transmitted indirectly through the pile extension or follower to the upper end of the pile located well down in the leg. As noted, these systems have been subject to severe energy losses in providing such indirect force transmitting means.

Referring to FIG. 2, a pile driving system is shown wherein the upper end of a pile 17 is shown disposed in a hollow leg 14 of support tower 13. A driving head assembly 19 comprised generally of those components shown in the enlarged detail portion of FIG. 2 is seated in the open upper end of pile 17.

Thus, the driving head assembly comprises an anvil element 21 adapted to engage the upper end of the pile 17 in blow-transmitting relation. Anvil element 21 includes a tapered frustro-conical portion 21*a* dimensioned and adapted to fit readily into the upper end of pile 17 and to be supported by an enlarged midsection 21*b* serving to form a shoulder 22 which rests upon the upper edge of pile 17. The other end of anvil element 21 is formed to include a portion 21*c* of slightly reduced diameter and formed with a top face 23 to constitute the striking face of the anvil element 21 which directly receives the blows of a longitudinally movable ram or hammer element 24, the bottom of which can be very slightly domed.

Portion 21*c* serves to plug and seal the lower open end of an elongated hollow case 26 secured to the upper end of anvil element 21 in a manner to form an extension of anvil 21 whereby both anvil 21 and case 26 travel together in a following movement as the pile 17 penetrates into the earth. Anvil 21 and its case extension 26 fit closely within the leg 14 in sliding manner comparable to the sliding fit between pile 17 and leg 14.

Anvil element 21 may, for example, be of solid steel material or may be formed in a manner described further below relative to an additional embodiment pertaining to same.

While anvil element 21 serves to seal the lower end of case 26, the upper end of case 26 is also substantially sealed whereby the interior of case 26 is subjected to air pressure from an air hose 27 connected to pressurize case 26 through a compressed air inlet 28. At the lower end of case 26, an outlet 29 of a type serving to pass water while retaining air pressure within case 26, and of known construction, serves to evacuate any accumulated liquid from within case 26 under the air pressure from inlet 28.

Hammer element 24, as noted, moves through a stroke 31 to supply a succession of blows against the striking face 23 of anvil element 21. In order to eliminate any dissipation of the striking energy derived from the falling hammer element 24 by virtue of any accumulated cushion of air disposed between the lower end of hammer element 24 and the striking face 23, as might otherwise form at that location by virtue of the closely fitted guided relation existing between the periphery of hammer element 24 within the closed case 26, fluid passage means have been formed longitudinally of the case and hammer for transferring fluid

(such as air) therealong during movement of the hammer within the case.

Thus, as shown best in FIG. 3, fluted portions 32 form longitudinally extending peripheral indentations in the cross-section of hammer element 24 in the nature of grooves to provide sufficient clearance to transfer any entrapped air at the lower end of the falling hammer element 24 to the increasing space at the upper end of hammer element 24. In order to maintain a closely fitting guiding relation between hammer element 24 and case 26 to minimize any side movement and undesirable lateral vibration forces, longitudinally extending ribs 33 are provided. Ribs 33 formed between each adjacent pair of fluted portions 32 ride along the interior wall of case 26.

With the foregoing configuration, it becomes readily possible to employ an extraordinary massive hammer element 24 on the order, for example, of many thousands of pounds. A hammer element of such scope, if not closely contained within its guiding case can, of course, cause serious lateral impact forces acting against and damaging to the structure of the support tower 13.

Means for reciprocating hammer element 24 serves to lift it through its predetermined stroke 31 and then release the hammer element to fall freely to an advanced position where it contacts the striking face 23. Flexible cable means have been provided connected to the upper end of hammer element 24 in the form of a flexible steel cable 34 anchored in the upper end of hammer element 24 by suitable known means for embedding a cable in a solid steel material. A water-tight packing gland 36 located in the upper end of case 26 passes cable 34 outwardly thereof so that cable 34 is free to move in and out of case 26 to lift and release hammer 24.

Means for actuating the cable so as to move hammer element 24 between lowered and raised positions as well as to continuously pay out additional cable to operate the hammer at increasing depths as the pile penetrates the earth includes the structure shown at the upper end of support tower 13.

Thus, at the outdoor work station 18, a work surface or mounting platform 37 supports hoisting means which serves to pay out and retrieve both case 26 and hammer element 24 as well as to anchor or hold the upper end of cable 34. Thus, the hoisting means is in the form of an engine 38 of a suitable type readily controllable by an operator or attendant 39. Engine 38 is suitably coupled, as by means of the drive connection 41, to rotate the windlass portion 42 of a winch 43. Thus, winch 43 serves to wrap and unwrap cable 34 upon windlass 42.

A pulley 44 formed with a relatively deep sheave groove 46 engages that portion of cable 34 defined between windlass 42 and the upper end of leg 14. As windlass 42 is operated in a direction to pay out the cable 34, the air hose 27 may also be paid out accordingly so as to extend downwardly along leg 14. Air hose 27 is, therefore, conveniently carried upon a retractable hose reel 47 mounted to platform 37 so as to permit the air hose to be readily paid out along the other end of reel 47.

The upper end of air hose 27 is coupled to an air compressor 48 carried by platform 37.

Means for actuating pulley 44 to move between advanced and retracted positions so as to quickly relieve the tension in cable 34 and permit hammer element 24 to fall freely under the force of gravity includes the hydraulically operated actuator 49 (FIG. 4). Actuator 49 is a double-acting hydraulic piston operated by suitable fluid system means whereby lines 51, 52 are alternately and quickly respectively connected to pressure and exhaust lines of a hydraulic pump 53.

The system shown in FIG. 4 for alternately applying pressure and exhaust to the opposite ends of hydraulic actuator 49 is merely representative of a number of systems for providing the function of developing a great force quickly acting to raise and to lower the pulley 44 through its predetermined stroke. From the foregoing, it will be evident that, in the condition shown, the spool style control element 58 serves to couple fluid line 52 to pressure from pump 53 via line 54 while connecting fluid line 51 to exhaust fluid to the pump via line 57. It is to be further understood, of course, that suitable reservoirs and other conventional hydraulic system devices may be employed to round out the system. The system shown in FIG. 4, therefore, is merely representative of known systems for quickly and automatically reversing hydraulic drives.

Means are also provided of a conventional nature whereby as the piston rod 59 moves upwardly to a predetermined degree adequate to properly lift hammer element 24 to a point of release, the valve connections described above with respect to FIG. 4 will be quickly reversed so as to quickly hydraulically drive the piston of actuator 49 downwardly and thereby move pulley 44 rapidly out of the way of the falling cable 34 wrapped therearound. Thus, movement of a projecting finger or other protrusion 61 carried by rod 59 ultimately serves to close a pair of contacts 62 so as to close the circuit of a power supply 63 and thereby energize a solenoid 64. As solenoid 64 is energized, it will act against the urging of a spring 66 which otherwise serves to urge control element 58 to the position shown in FIG. 4.

Thus, when solenoid 64 is energized, it can serve to quickly shift control element 58 in order to reverse the hydraulic connections to actuator 49.

Having the above arrangement in mind, it is readily apparent that cable 34, as trained about pulley 44, forms first and second reaches 34*a*, 34*b* thereof. The first reach is directly coupled to move hammer element 24. Hoisting means, such as the winch 43, is coupled so as to anchor the end of the second reach 34*b*. Actuator 49 is provided with a predetermined stroke serving to move the pulley from a lower to an upper position in order to elongate the second reach 34*b* while shortening the first reach by a multiple of the stroke of actuator 49. In this manner, if the stroke of actuator 49 is on the order of two feet, the hammer element 24 will be raised a distance of four feet due to the interposition of the rising pulley 44.

Additional multiplication of the actuator stroke can, of course, be obtained by introducing additional pulleys forming additional reaches of cable 34.

Further, from the foregoing, it will be readily evident that when pulley 44 is being returned, it will have less distance to travel than will reach 34*a*, and, accordingly, pulley 44 can move to its retracted position in less time

than reach 34a and thereby more quickly relieve the strain on cable 34 to permit hammer element 24 to fall and strike its blow. It is apparent that pulley 44 only needs to be accelerated downwardly from its upper position at a rate exceeding one half the acceleration rate provided by the force of gravity (acting on the cable 34 alone). This fraction may be further proportionately reduced by introducing additional pulleys for further subdividing the cable into additional reach portions.

With reference to FIG. 5, another embodiment of the anvil element 21 serves to solve the problems of entrapped water columns as noted at the outset above whereby shock waves and water hammer effects may be created. Accordingly, an anvil element 71 includes a striking face 72 at its upper end adapted to be struck by the hammer element 73. The lower end of anvil element 71 includes a hollow recess 74 containing an inflated gas-filled bladder 76. Bladder 76 may, for example, be an inflated nylon-neoprene hollow sphere having an outside diameter on the order of one foot or greater and a sufficient capacity so that it can be inflated with air, for example, to accommodate not less than the hydrostatic head developed at the top of the submerged pile for the ultimate depth to which the pile is to be driven.

Thus, if anvil element 71 is directly engaged on the upper end of the thickened wall portion 77 of a pile 78 and the water level has risen to a point where it may make direct contact with the exterior of bladder 76, the striking blow of hammer 73 will not transmit a shock wave through the liquid medium within pile 78 in view of the fact that the compressive air within bladder 76 serves to initially absorb the shock.

The striking blow will, of course, serve to drive the pile 78 downwardly somewhat and this can serve to develop additional compression by virtue of the upwardly displaced column of water contained therein. In order to vent this water column from within pile 78, flow passages 79 of substantial diameter, for example, on the order of 4 or 5 inches, and of a sufficient number are provided so as to quickly vent the liquid. In the event that the flow passages 79 are incapable of venting the liquid quickly enough to preclude the development of a shock wave in the liquid within pile 78, it will be readily apparent that bladder 76 will absorb the momentary increase in pressure and thereby provide additional time for discharging the liquid without forming the compression wave.

Another embodiment for safeguarding against the development of a compression wave and for venting the water displaced by downward movement of the hollow pile is shown in FIG. 6.

Thus, a pile construction 81 has been provided comprised of an elongated rigid hollow member 82 adapted to be driven in an upstanding orientation by a succession of blows applied at the upper end thereof. The upper end has been prepared with a thickened wall portion 83. A closure plate 84 serves to seal the upper end of pile 81 so as to entrap a cushion of air in the region 86 when lowering pile 81 into a body of water for driving. Openings 87 are formed at a predetermined displacement beneath closure plate 84 so as to vent the column of water 88 in response to compression derived from the driving blows of the hammer element 89 as the pile moves downwardly into the earth. The cushion of air in the region 86 therefore serves to momentarily absorb the reactive forces of the column of water 88 and to permit the flow passages formed by openings 87 to vent the column.

In another embodiment of the system for driving piles, as shown in FIGS. 7 and 8, a support tower extension structure 91 supports the hoisting means and actuator structures described above at an elevation above the level of the top of the tower. An elongated cable 92 is suitably coupled to a bail 93 so as to lift and lower an improved hammer element 94, whereby a drop-hammer action can be obtained even while driving piles at a modest angle to the vertical.

Hammer element 94 is designed to strike blows upon the upper end 96 of a pile 97 and includes an elongated guide stem portion 98 movable in sliding relation coaxially within pile 97 and further includes a massive head portion 99 formed on the upper end of stem portion 98. The underside of head portion 99 projects laterally to form a shoulder 101, which moves through a predetermined stroke S, to strike the upper end 96 of pile 97 in driving the pile. A fluid passage 102 extends longitudinally of guide stem 98 for relieving or venting fluid surge during the striking movement of hammer element 94.

Thus, as in the case of driving piles deeply into the ocean floor at a slight slant, batter piles can be driven by the drop-hammer system as described above whereby the hammer is lifted and released from an outdoor work station and the hammer can strike the upper end of the pile as contained in a leg 103 or other means defining a channel in which to guide and lodge the piles 97.

As thus provided, the embodiment described lastly above provides the advantage of a drop hammer acting against the upper end of a pile being driven, while at the same time serving to permit the pile to be driven into the earth at a substantial angle to the vertical.

While the systems disclosed herein overcome the problems involved in using pile extensions and followers, it will be readily evident that the disclosed systems are not incompatible with the use of such extensions and followers. Therefore, whenever they should necessarily be required in a given construction project, the disclosed systems can be employed.

It is also apparent that the systems disclosed herein open the door to practical use of much larger hammer elements having a mass an order of magnitude greater than conventional present day systems.

I claim:

1. In a system for driving an open hollow pile by a succession of blows applied by a hammer from an end of the pile with the pile in a body of liquid subject to entrapment of a column of the liquid within the pile, a driving head disposed in blow-transferring relation to the end of the pile, said driving head including an anvil portion adapted to be struck by the hammer to move the pile toward the liquid column, and means capturing a cushion of gas between said anvil and the column of liquid to absorb reactive forces derived from the column of liquid.

2. In a system according to claim 1 wherein the last named means comprises a compliant bladder filled with a compressible gas and interposed between said head and said column in exposure to said column.

3. In a system according to claim 1 further including flow passages between the last named means and said column of liquid for venting said column of liquid therethrough in response to blows struck by the hammer.

4. A pile construction comprising an elongated, rigid, hollow member, open to receive a column of water therein, and adapted to be driven in an upstanding orientation by a succession of driving blows applied at the upper end thereof, a closure formed at the upper end of said member to entrap a cushion of air therein when lowering said member into a body of water for driving, openings formed to vent said column of water from within said member in response to compression derived from the driving blows, said cushion serving to momentarily absorb reactive forces of said column of water to permit the openings to vent said column.

5. An open, hollow pile of a type to be driven in a body of water, subject to entrapment of a column of the water within the pile, by a succession of blows applied from an end of the pile, 96 a driving head for transmitting the blows to said end of the pile, said driving head including an anvil portion for transmitting the blows to move the pile toward the water column, and means for venting entrapped portions of the liquid of the column from within the pile in response to the blows.

* * * * *

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,680,644 Dated August 1, 1972

Inventor(s) Samuel Clifford Doughty

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

Column 10, line 7, after "pile," delete "96".

Signed and sealed this 26th day of December 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents