United States Patent [19]

Anders

[11] **3,832,858**

[45] **Sept. 3, 1974**

[54] **PILE DRIVING**

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[73] Assignee: **Global Marine Inc.,** Los Angeles, Calif.

[22] Filed: **Jan. 15, 1973**

[21] Appl. No.: **323,826**

[52] **U.S. Cl.** **61/53.5,** 61/63, 173/24, 180/116

[51] **Int. Cl.** **E02d 7/00,** E02d 7/02, E02d 7/18

[58] **Field of Search** 61/53.5, 46.5, 63; 180/116, 117; 173/24, 23

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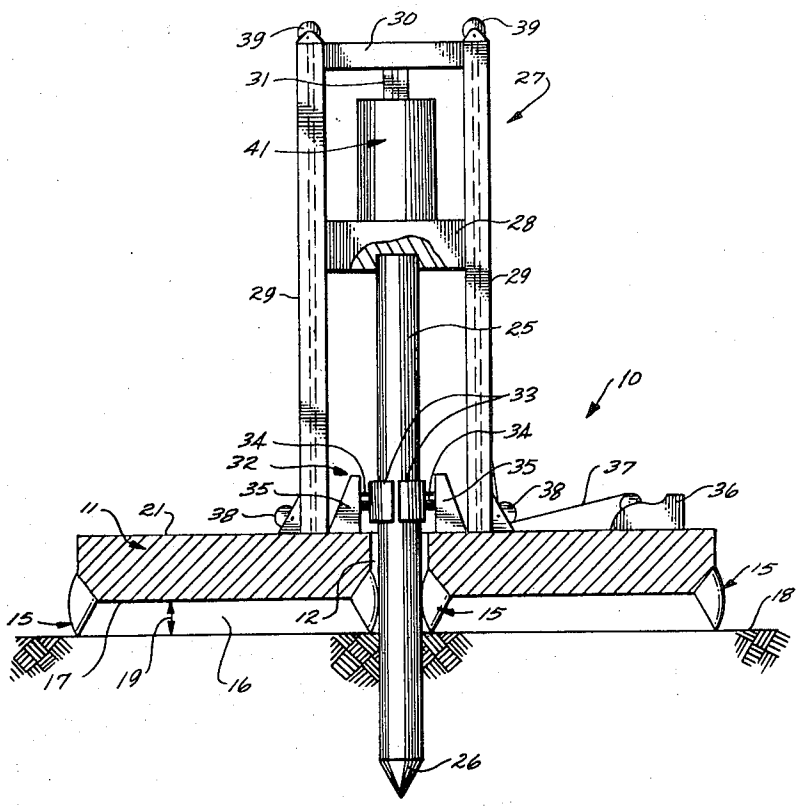
Primary Examiner—Jacob Shapiro

Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

A pile driver includes a base and selectively operable means, such as an air cushion support system, for supporting the base in an elevated position above ground. Suitable cranes are provided for disposing a pile substantially vertically of the base with the lower end of the pile in engagement with ground adjacent the base. The base carries means which are operable in the elevated position of the base for transferring at least a substantial portion of the weight of the base to the pile. A suitable hammer is carried by the base for applying impact loads to the upper end of the pile. Where an air cushion support system is used, the system may be overpowered to cause the base to oscillate vertically through a range less than the stable hover height of the base, and at least some of the energy of such oscillation is applied to the pile to drive it into the ground. Also, where an air cushion support system is used, the space under the base may be partially evacuated after the weight of the base is transferred to the pile, thereby to increase the downward steady-state preload applied by the base to the pile.

29 Claims, 16 Drawing Figures



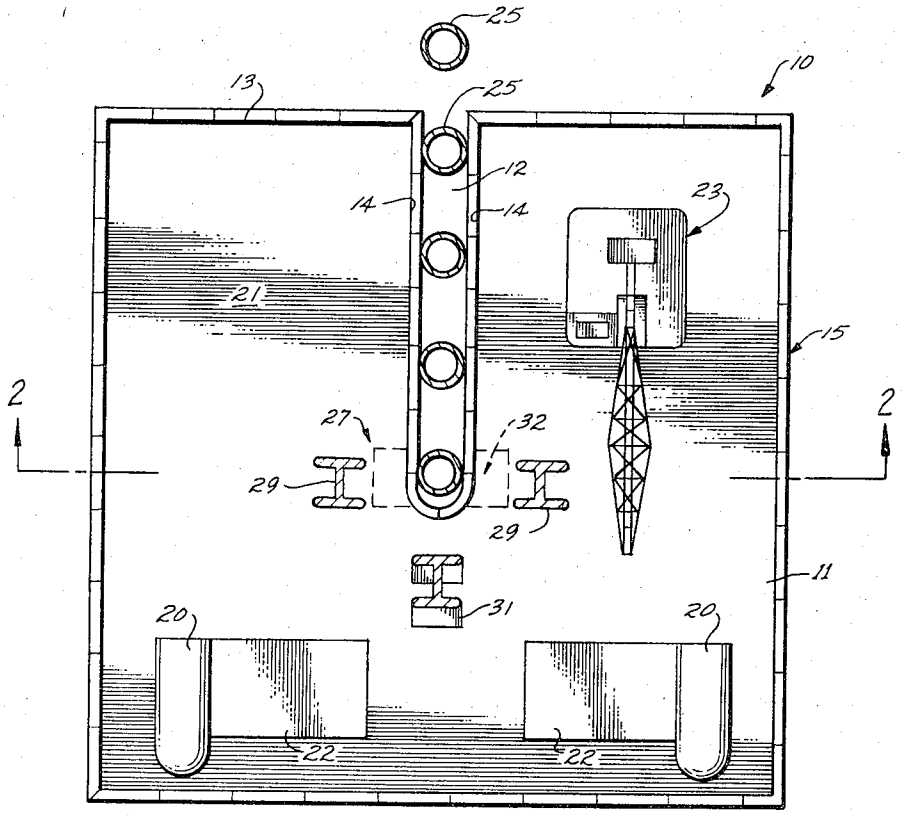


Fig. 1

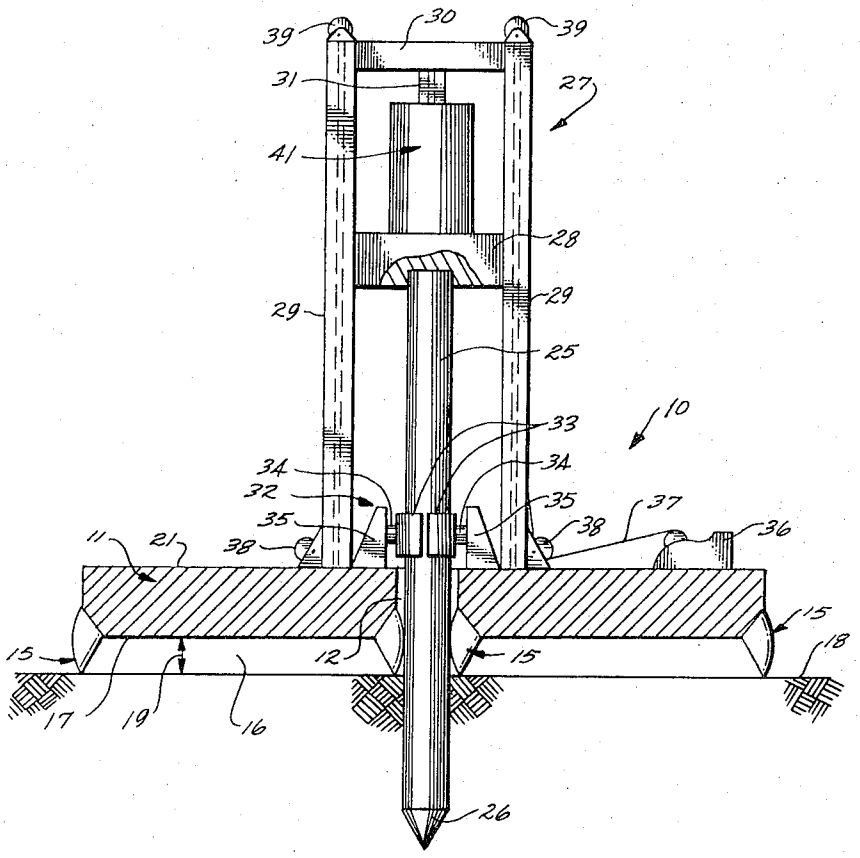

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Fig. 2

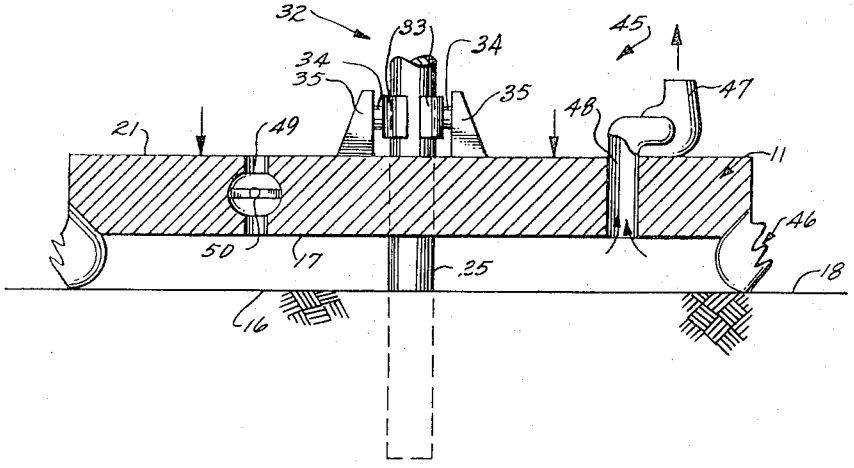

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Fig. 3

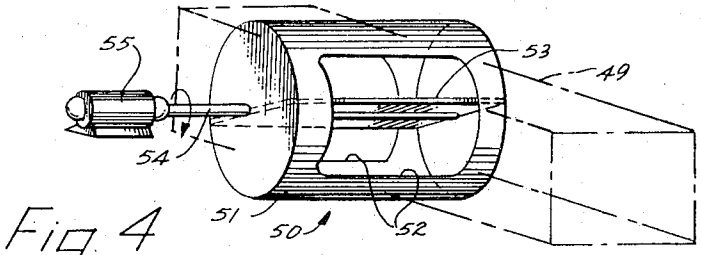


Fig. 4

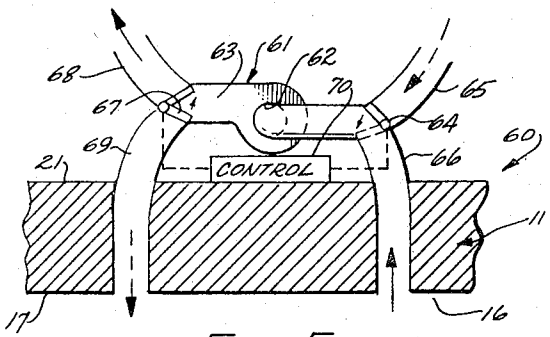


Fig. 5

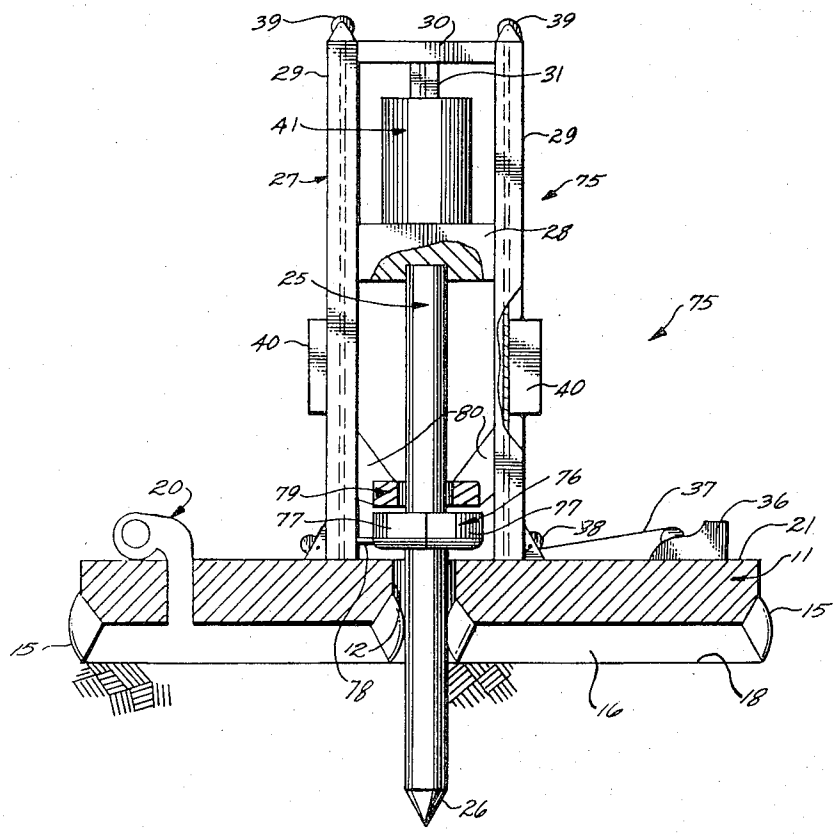


Fig. 6

FIG. 7

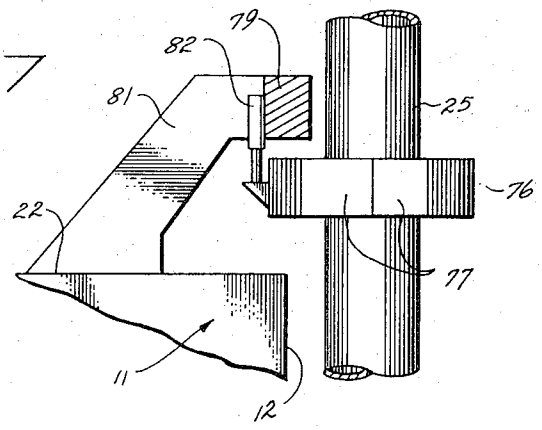


FIG. 8

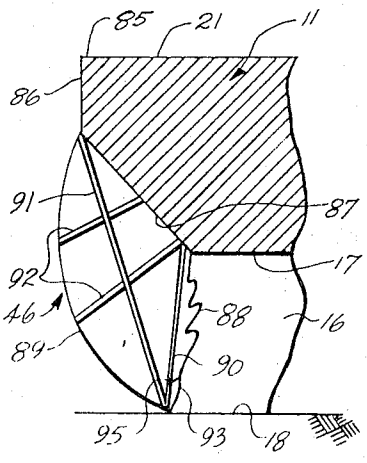
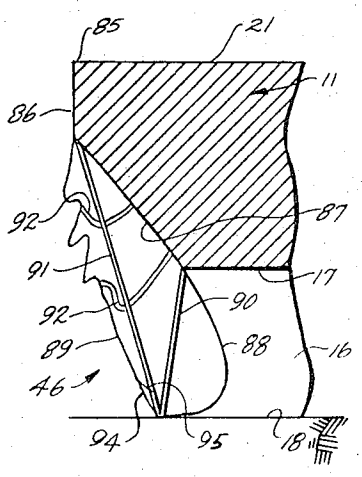


FIG. 9



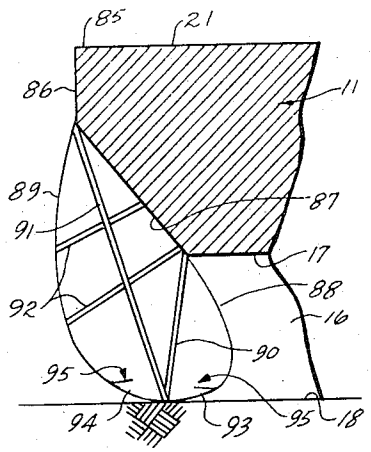


Fig_10

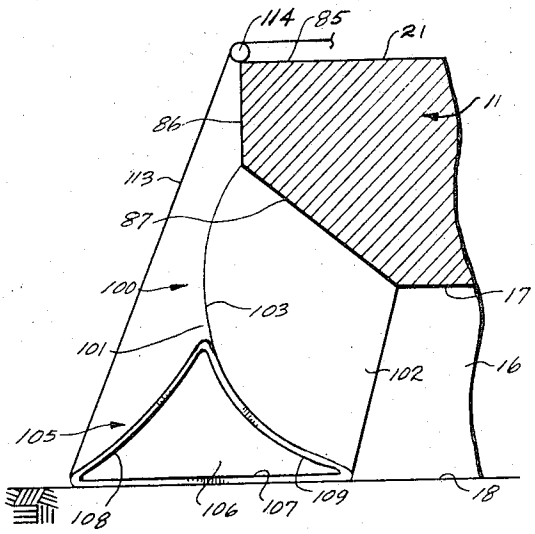


Fig_11

Fig_12

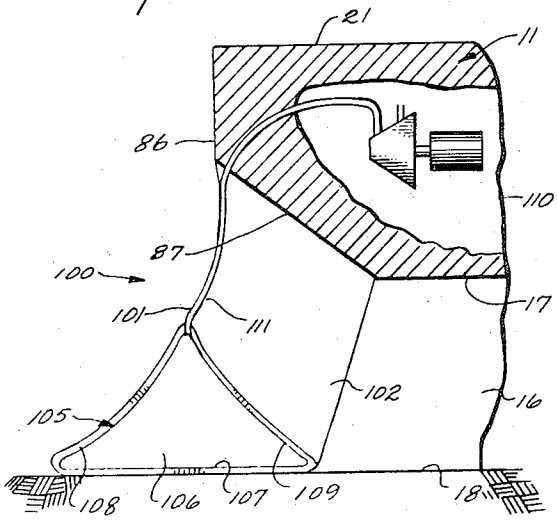


Fig_13

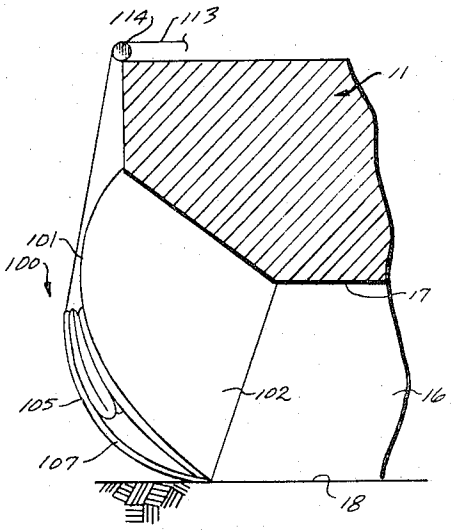


Fig. 14

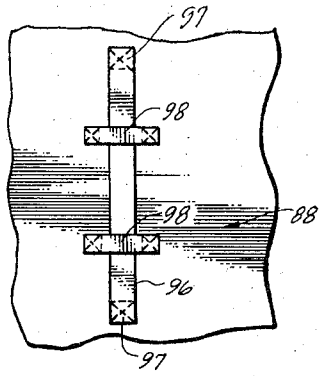


Fig. 15

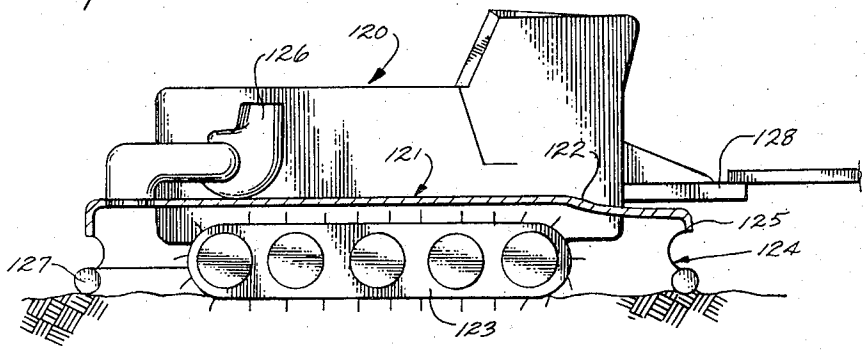
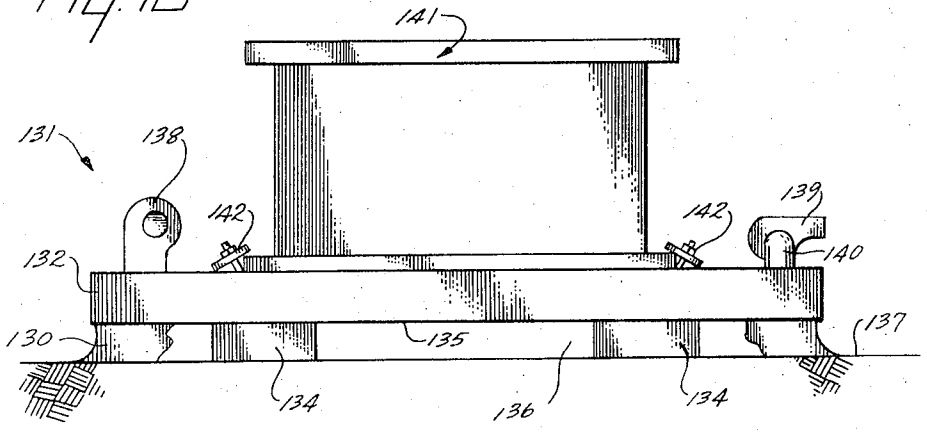


Fig. 16



PILE DRIVING

FIELD OF THE INVENTION

This invention pertains to pile driving, an more particularly to pile driving in which the pile is subjected to a steady-state or cyclic load of substantial magnitude onto which conventional pile driving techniques may be superimposed.

BACKGROUND OF THE INVENTION

REVIEW OF THE PRIOR ART

Historically, piles are driven into the ground by a hammering process in which series of separate impacts are applied to the upper end of the pile by a suitable hammer. As each impact is applied, the pile is driven into the ground by an amount which is determined by the impact energy, by the size and mass of the pile, and by the resistance of the ground to penetration by the pile. Between impacts, no downward force is applied to the pile, and the ground has an opportunity to recover and stabilize its resistance to penetration.

Those advances recently made in pile driving involve improvements in the apparatus used to apply impact loads to the pile. A notable example of such an advance is the Bodine sonic hammer in which high frequency mechanical energy is applied to the pile for transmission along the pile into the ground where it is released to partially "fluidize" the ground to a condition of reduced resistance to penetration.

Even in the case of the Bodine sonic hammer, the pile driving apparatus is conventional in that it is either a towable or self-propelled vehicle (for land operation) or barge (for marine operations). These types of pile drivers are not well suited for use in arctic areas where great need now exists for pile-supported or pile-protected structures. Such structures are needed to facilitate development of or exploration for the substantial reserves of oil or natural gas known or suspected to exist in the northern portions of Alaska and Canada, for example. Existing vehicular pile driving rigs arenot desirable in areas covered by tundra because they are heavy and are destructive of the delicate tundra which is necessary to protect the underlying permafrost. Also, the tundra is dotted with lakes and muskeg bogs which make difficult the movement of vehicular rigs. Barge-mounted pile driving rigs are not attractive economically because they can be used readily only in the short periods in which arctic waters are free of ice.

A need thus exists for an easily moved pile driver which can be used effectively and efficiently on land or on water, as appropriate. Such a pile driver is of general utility, but is of particular appeal in arctic areas. Also, a need exists for a wholly new approach to the process of driving piles.

SUMMARY OF THE INVENTION

This invention provides a novel process for placing piles in the ground. Basically, the weight (in toto or in substantial part) of the entire pile driving rig is applied to the pile, either statically or dynamically, to significantly increase the rate at which the pile is driven into the ground. The application of the rig weight to the pile is in addition to the application of serial impacts to the pile by conventional apparatus. Further, the pile driving rig itself is mounted on a buoyant ground effect (air cushion) platform. Thus, while the weight of the overall

rig may not be low, its effective footprint pressure on the ground, when supported on a cushion of air, is sufficiently low and uniform that the rig may be moved readily, as by towing, over tundra, including over muskeg bogs. For marine situations, the platform can be used in a floating state, or it can be used as its own ice-breaker in thin ice conditions, or it can be operated over thick ice to drive piles.

All of the foregoing benefits and advantages are provided by procedures and apparatus which are simple, efficient and economic.

In general terms, as to procedure, this invention provides a method for driving piles which includes providing an elevatable base. A pile to be driven is disposed substantially vertically through the base into engagement with the ground below the base into which the pile is to be driven. The base is then elevated from the ground along the pile independently of the pile and any other piles previously driven. Then, at least a portion of the weight of the base, and of all other equipment carried by it, is applied to the pile, following which other driving loads may be applied to the pile by conventional procedures, as desired.

As to apparatus, this invention provides a pile driver which includes a base and selectively operable means operable for supporting the base in an elevated position above ground and the like. The pile driver also includes means for disposing a pile substantially vertically of the base in engagement with ground adjacent the base and into which the pile is to be driven. Means are operable in the elevated position of the base for transferring substantially the entire weight of the base to a pile disposed vertically of the base.

The above mentioned and other features of this invention are more fully set forth in the following detailed description of certain presently preferred embodiments of the invention, which description is presented with reference to the accompanying drawings, wherein:

FIG. **1** is a top plan view of an air cushion pile driver;

FIG. **2** is a cross-section view taken along line **2—2** in FIG. **1**;

FIG. **3** is a cross-section view similar to that of FIG. **2** of another air cushion pile driver;

FIG. **4** is a perspective view of the valve and valve drive mechanism for the pile driver shown in FIG. **3**;

FIG. **5** is a fragmentary cross-section view of a cushion-air handling mechanism for another pile driver;

FIG. **6** is a cross-section elevation view of still another air cushion pile driver according to this invention;

FIG. **7** is a fragmentary elevation view, partially in cross-section, of a modification of a portion of the pile driver shown in FIG. **6**;

FIG. **8** is a fragmentary cross-section elevation view showing one operative state of an air cushion skirt structure useful with the pile driver shown in FIG. **3**, for example;

FIG. **9** is a view similar to that of FIG. **8** showing the air cushion skirt in another operative state thereof;

FIG. **10** is a view similar to FIGS. **8** and **9** showing the skirt structure of FIGS. **8** and **9** in a fully expanded state for purposes of illustration;

FIG. **11** is a fragmentary cross-section elevation view of one operational state of another skirt structure use-

ful with the pile driver shown in FIG. 3, for example;

FIG. 12 is a view similar to FIG. 11 showing the skirt structure of FIG. 11 in another operational state;

FIG. 13 is a cross-section elevation view similar to that of FIGS. 11 and 12 showing the skirt structure in still another operational state thereof;

FIG. 14 is a fragmentary elevation view of a portion of the skirt structure shown in FIGS. 8, 9, and 10;

FIG. 15 is an elevation view, partially in cross-section, of a tow tractor equipped with a negative pressure-sealing air skirt to enhance the drawbar pull of the tractor; and

FIG. 16 is an elevation view, partially in section, of a positioning table utilizing a positive and negative pressure-sealing air skirt.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Referring to FIGS. 1 and 2, an air cushion pile driver 10 has a floatable platform-like base 11 which is of generally U-shaped platform configuration around a slot 12 which extends from about the base center of area to an adjacent edge of the base, such as rear edge 13. In FIG. 1, base 11 is shown to be of generally square configuration, but it is within the scope of this invention that the base may be a rectangular, oval, circular or any other configuration desired. It is also possible that the opposing sides of the slot may diverge relative to each other from the inner end of the slot to that peripheral edge of the platform to which the slot opens.

An air cushion skirt assembly 15, which preferably is of the segmented type, is connected to the base along its entire periphery, including along the extent of slot 12, for enclosing a space 16 between the bottom 17 of the base and the surface of ground 18 over which the pile driver may be disposed either in use at or in transit to a desired pile driving site. The skirt assembly is adapted to seal against ground surface 18 when air at superatmospheric pressure is present in space 16 and the bottom surface of the base is either at or within the distance from ground surface 18 which is indicated by dimension 19 in FIG. 2. Distance 19 is referred to herein as the "maximum stable hover height" of the platform and is the distance between ground surface 18 and the platform bottom surface 17 when air at the appropriate superatmospheric pressure (about one to three pounds per square inch gage pressure) is supplied to space 16. Preferably, hover height 19 is on the order of 4 to 6 feet. A pair of air blowers 20, such as centrifugal blowers, are mounted to the main deck 21 of base 11, and a suitable motor or diesel engine 22 is provided in association with each blower for powering the same. The outlet opening of each blower is communicated to air cushion space 16 by suitable ducts (not shown) through the structure of base 11. A turret crane 23 is mounted to the base deck adjacent slot 12 to facilitate the handling of piles during the use of pile driver 10.

FIGS. 1 and 2 show pile driver 10 in the process of driving one of a series of tubular piles 25, each of which has a closed pointed lower end 26. The minimum width of slot 12 is defined relative to the largest pile to be driven by the pile driver so that, when skirt assembly 15 is fully expanded as a result of air being applied to air cushion space 16 from blowers 20, the opposing surfaces of the skirt assembly along the slot make no more than light grazing contact with the surfaces of a pile disposed within the slot.

A vertical framework 27 is mounted on the main deck of base 11 to span the inner end of slot 12 (see FIG. 2) and defines a vertical guide track for a pile cap member 28. The framework constrains the cap member to move only vertically up and down relative to the pile driver base. Preferably, the guide portions of the framework 27 are defined by a pair of parallel wide flange beams 29 of suitable size which are interconnected at their upper ends by a cross-member 30. Framework 27 is stabilized by a strut member 31 connected between the cross-member and main deck 21 forwardly of the inner end of pile access slot 12.

A selectively operable clamp assembly 32 (see FIG. 2) is mounted to base 11 in association with framework 27 for releasably engaging a pile 25 disposed vertically through slot 12 in line with the direction of movement of cap member 28. Clamp assembly 32 is provided for transferring all or a substantial portion of the weight of pile driver 10 to a pile in the manner described below. The clamp assembly includes a pair of shoe members 33 which are configured to mate with the exterior of pile 25 on opposite sides of the pile. Preferably, the surfaces of the shoe members which cooperate with the pile carry hardened steel friction members (not shown) for biting superficially into the material of the pile to prevent slippage of the shoe members along the pile. It will be appreciated that, in the example shown in FIGS. 1 and 2, the shoe members are semi-circularly configured; where a pile of non-tubular configuration is used, then the configuration of the shoe members is modified accordingly.

Each shoe member is mounted by a corresponding double acting ram assembly 34 to a corresponding foundation structure 35 for movement toward and away from engagement with a pile disposed, as described above, through slot 12. Preferably the shoe members are movable parallel to the main deck of the pile driver base. Considering the functions which the shoe members, ram assemblies and foundation structures are called upon to perform, it is apparent that these elements of pile driver 10 are of substantial strength, and that the foundation structures are functionally an integral part of the structure of pile driver base 11. Preferably ram assemblies 34 are hydraulic rams which are operated in response to the operation of a suitable hydraulic power mechanism which is well within the talents of the art and is therefore not illustrated.

To enable cap member 28 to be raised and lowered within framework 27, a winch 36 is mounted to base main deck 11. Cables 37 extend from the winch to the cap member and are guided by suitable pulleys 38 located adjacent the bottom of track members 29 and by additional pulleys 39 mounted to the upper ends of the track members. If desired, appropriate shock absorber mechanisms 40, see FIG. 6, may be coupled between the winch and the cap member.

Cap member 28 functions as a coupling member between the upper end of a pile being driven and a hammer mechanism 41 carried by the cap member between track members 29. The hammer mechanism may be a conventional diesel hammer or it may be a Bodine sonic hammer if desired. Preferably cross-member 30 is in yoke form so that the cross-member will not interfere with the hammer mechanism when the cap mem-

ber is elevated to near the upper ends of the track members.

The driving of a pile by pile driver **10** is commenced by placing the pile vertically through retracted clamp shoes **33** into contact with ground surface **15** while the pile driver base rests directly upon the ground. Air blowers **20** are operated to supply air at suitable superatmospheric pressure to the space within skirt assembly **15** to cause the base to rise to its hover height **19** above the ground. As the base rises to its hover height, the pile slips downwardly through the retracted shoe members. Either before or after raising the base to its hover height, cap member **28** is mated to the upper end of the pile. After the pile driver base has been elevated to its operating hover height, ram assemblies **34** are operated to securely engage clamp shoes **33** with the pile. The pressure of air within air cushion space **16** is reduced to atmospheric pressure, or to some reduced pressure between atmospheric pressure and the pressure productive of hover height **19.** In this manner, all or a substantial portion of the mass of pile driver **10** is transferred to pile **25,** and this loading of the pile is sufficient to cause the pile to be driven some distance into the ground.

If the resistance of the ground to penetration by pile **25** is sufficiently low that the platform moves into direct contact with ground surface **18,** then clamp shoes **33** are relaxed from forceful engagement with pile **25,** and air is again supplied to air cushion space **26** to again raise the platform to maximum hover height; the clamp shoes are then again re-engaged with the pile, and the pressure within air cushion space **16** is reduced to again cause all or a substantial portion of the weight of the pile driver to be transferred to the pile and to cause the pile to further penetrate the ground.

If the nature of the ground is such that the pile can be driven to the desired depth by repeating the foregoing procedures, then these procedures are repeated a sufficient number of times to accomplish the desired pile driving function; in this case the use of hammer assembly **41** is not necessary. On the other hand, if pile **25** is to be driven further into the ground than is possible by repeated practice of the load transferring procedures described above, then the pile driving effect of hammer assembly **41** is superimposed upon the pile driving effects of the above-described procedure. That is, if the maximum depth to which pile **25** can be driven in the ground is say, 30 feet, using only the deadweight of pile driver **10,** and it is desired to drive the pile to a depth of 40 feet, then the above-described procedure is continued once the pile reaches the 30-foot depth in combination with the pile driving effects of hammer assembly **41.**

During pile driving operations in which hammer assembly **41** is used, the portion of the deadweight of pile driver **10** applied to the pile provides a downwardly acting, high level preload upon the pile. This preloading of the pile greatly enhances the effectiveness of hammer assembly **41** to drive the pile.

To insure that the deadweight of pile driver **10** is applied vertically to pile **25,** it is desired that the center of mass of the pile driver, including all of the equipment carried by the pile driver, be vertically aligned with the centroid of the area enclosed by skirt assembly **15.**

If the area enclosed by skirt assembly **15** is 940 square feet (corresponding to a base of about 31 feet by 31 feet excluding the slot area) and the hover air pressure applied to air cushion space **16** is 3 psig, then pile driver **10** may weigh up to 500,000 pounds and all or a portion of this mass may be applied in the manner described above to pile **25.**

Another pile driver **45** is illustrated in FIG. **3** and is similar to pile driver **10** except that pile driver **45** includes a skirt assembly **46** which is effective to seal against both superatmospheric and subatmospheric pressures in air cushion space **16.** Also, pile driver **45** includes a blower **47** coupled by duct **48** to air cushion space **16** to provide partial evacuation of air cushion space **16.** The pile driver also includes a pressure relief duct **49** through base **11** in combination with a cyclically operable valve **50.** While a key slot similar to slot **12** is not shown in FIG. **3,** it is understood that pile driver **45** defines such a slot to permit the pile driver to be moved laterally away from a pile which extends above ground surface **18** after the same has been driven into the ground. It will also be understood that while the same is not shown in FIG. **3,** pile driver **45** includes blowers, similar to blowers **20,** for supplying air at superatmospheric pressure to air cushion space **16** by a suitable duct, a framework similar to framework **27,** and a suitable hammer assembly.

Duct **48** is connected to the section port of blower **47.** The blower is operable to withdraw air from air cushion space **16** and to discharge such air to atmosphere. Thus, the blower is effective to reduce the pressure in air cushion space **16** to a pressure below atmospheric pressure, assuming that skirt assembly **46** is effective as intended to seal against ground surface **18** when the pressure within air cushion space **16** is lower than ambient, i.e. atmospheric pressure.

FIG. **4** is an enlarged perspective view of valve **50** and duct **49.** Valve **50** includes a drum-like housing **51** which has its axis disposed perpendicular to and in intersection with the axis of duct **49.** A pair of diametrically opposed ports **52,** preferably configured to correspond with the cross-sectional configuration of duct **49,** are formed through valve housing **51.** A plate-like valve member **53** is disposed within the housing and is carried by a shaft **54** which extends axially of the housing from a drive motor **55.** The length and width of the valve plate is sufficient that it makes slidable sealing contact with the inner surfaces of housing **51.** During one full rotation of shaft **54,** valve plate **53** cooperates with the inner surfaces of the housing to produce two cycles in which the valve is changed substantially harmonically from a full-open state (in which the valve member is disposed in the plane of the axis of duct **49**) and a closed state (in which the valve member is disposed perpendicular to the axis of duct **49**).

The operational procedures useful with pile driver **45** are similar to the procedures described above for operation of pile driver **10,** except that the pressure in air cushion space **16** is reduced to a pressure below ambient pressure after the platform has been raised to its maximum stable hover height and clamped to a pile to be driven. Therefore, in pile driver **45** a downward preload force greater than the weight of the pile driver and its associated equipment is applicable to a pile. For example, if the deadweight of the pile driver and its associated equipment is 500,000 pounds and this mass can be supported at full hover height by cushion air at 3 psig, and if the pressure produced in air cushion space **16** by operation of blower **47** is 1 pound per square

inch less than ambient pressure, then the total downward force capable of being applied to a pile by pile driver **45** is 666,667 pounds, i.e. 500,000 pounds plus one-third (500,000 pounds).

It is believed that a pile can be driven considerably faster than has heretofore been possible if the pile is subjected to a static downward bias force on which cyclic downward forces are superimposed. This is precisely the type of action produced by the operation of pile driver **10** when hammer assembly **41** is used. Pile driver **45,** however, is capable of producing all of the pile driving effects of pile driver **10** with the additional effect of a downwardly acting cyclic driving load separate from those cyclic forces applied to the pile hammer assembly **41.** These additional downwardly acting pile driving loads are produced when valve **50** is operated in conjunction with pressure reducing blower **47.**

That is, assuming the exemplary dimensions and characteristics of driver **45** mentioned above, it is apparent that of the 666,667 lb. load capable of being applied by the pile driver to pile **25** when the air pressure in air cushion space **16** is 1 lb. psi less than ambient pressure, 166,667 pounds of that load is attributable to the pressure difference existing across skirt assembly **46.** This pressure difference can exist only when valve **50** is in its closed state within duct **49.** However, this pressure difference can be eliminated or significantly reduced by opening valve **50.** Therefore, when valve **50** is operated cyclically simultaneously with the operation of blower **45,** the 166,667 lb. increment of the total load capable of being applied by the pile driver to the pile is cyclically variable, with the 500,000 lb. load associated with the dead weight per se of the pile driver being constantly applied to the pile. The driving force variation associated with the pressure differential existing across the skirt assembly **46** may be found to be sufficient, in conjunction with the steady state driving force attributable to the dead weight of the pile driver, to drive pile **25** to its desired depth in the ground. If not, then hammer assembly **41** may be operated in conjunction with the cyclic driving force associated with operation of valve **50.**

Valve **50** may be operated to open and close with a frequency which corresponds to that of hammer assembly **41,** or the operative frequencies of the hammer assembly and valve **50** may be different, as desired. Where the valve and hammer assembly frequencies are the same, they may be operated either in phase or out of phase with each other. If the operative frequencies of the hammer assembly and the valve are different, then the operational frequency of the valve may be an integral number of times greater than that of the hammer assembly, or it may be a non-integral number of times different from that of the hammer assembly. The precise relationship between the operative frequencies and the phase of hammer assembly **41** relative to valve **50** will be determined by the mechanics of the soil into which the pile is being driven and how these factors may best be combined with each other to achieve the maximum rate of penetration by the pile.

FIG. **5** is a fragmentary cross-sectional view of a portion fo another pile driver **60** according to this invention. Pile driver **60** is similar to pile driver **45** except that elements **47, 48, 49** and **50** of pile driver **45** are replaced by the blower and ducting arrangement shown in FIG. **5.** That is, in pile driver **60,** the evacuating blower **47** of pile driver **45** is replaced by a pressurizing and evacuating blower **61** having a suction port **62** and a discharge **63.** The suction port of blower **61** is selectively connectible either to atmosphere or to air cushion space **16** by a valve **64** and by ducts **65** and **66,** respectively. The blower discharge is selectively connectible either to atmosphere or to air cushion space **16** by a valve **67** associated with ducts **68** and **69,** respectively. Valves **64** and **67** are operated either in tandem or separately, as desired, by a suitable control mechanism **70.** Preferably, pressurizing and evacuating blower **61** is provided in addition to pressurizing blowers **20** which are not operative to affect the pressure in air cushion space **16** after the base of pile driver **60** has been clamped to a pile in the manner described above.

Assume that blower **61** is operative to produce an air cushion space pressure of 1 pound per square inch less than ambient pressure when the suction of the blower is connected to the air cushion space via valve **64** and duct **66.** Assume also that blower **61** is operative to produce in air cushion space **16** a pressure which is 1 pound per square inch greater than ambient pressure when the blower discharge is applied to the air cushion space via valve **67** and duct **69.** Under these circumstances, it is apparent that blower **61** is effective, in response to the appropriate control of valves **64** and **67,** to produce a downwardly effective cyclic force variation (attributable to pressure differential across the skirt assembly sealing space **16**) on a pile, and that the magnitude of this variable force is twice the magnitude of the cyclic force capable of being applied to the pile by pile driver **45,** all other things being equal between the two pile drivers. That is, after the pile driver has been securely clamped to a pile following elevation of the pile driver base above ground surface **18,** and after blowers **20** have either been shut down or valved to discharge to atomoshere, blower **61** can be operated to evacuate air cushion space **16** so that the effective force applied by the pile driver (both dead weight and pressure differential force) is 666,667 pounds. On the other hand, when the discharge of blower **61** is applied to air cushion space **16** following clamping of the pile driver base to the pile, the effective downward force applied by the pile driver to the pile is 333,333 pounds; in this case, one-third of the 500,000 pound deadweight of the pile driver is supported by the air in space **16** and the remainder is carried by the pile itself. Thus, the pressure-related cyclic force applied by the pile driver to the pile, as valves **64** and **67** are cycled between the conditions shown in solid lines and in broken lines in FIG. **5,** varies between a maximum of 666,667 pounds and a minimum of 333,333 pounds, at least 333,333 pounds always being applied to the pile by the pile driver whether or not hammer assembly **41** is operated.

Preferably control mechanism **70** is arranged to operate valves **64** and **67** in tandem in such manner that, when valve **64** is disposed to close duct **55** and to place duct **66** in communication with the suction port of blower **61,** valve **67** is disposed to close duct **69** and to couple the discharge of the blower to atmosphere via duct **58.** Conversely, when valve **64** is disposed to close duct **66** and to couple the suction port of the blower to atmosphere via duct **65,** valve **67** is disposed to close duct **68** and to couple the blower discharge to air cushion space **16** via duct **69.**

It has been found that the maximum hover height capable of being attained by a given air cushion vehicle is a combination of many things, including the deadweight of the vehicle, the effective area enclosed by the air cushion sealing skirts, and the pressure of air applied to the air cushion space within the skirt assembly. Inasmuch as air is compressible, the volumetric capacity of the pressurizing blowers or compressors, as well as the pressure capable of being developed by these mechanisms, is also relevant. The volumetric capacity of the pressurizing mechanisms for the vehicle should exceed the leakage existing around the skirt assembly during air cushion mode operation of the vehicle. In this context, when the air cushion pressurizing mechanism is operated at a rate peculiar to the mass and geometry of the vehicle, the vehicle will rise to its maximum stable hover height above an adjacent ground surface. If the air pressurization mechanism is operated so that its effective volumetric capacity equals the rate at which air leaks out of the air cushion space past or through the air cushion skirt assembly, the maximum hover height will be maintained in a stable manner. However, when the pressurization mechanism is operated at a pressure and effective volumetric capacity which is significantly greater than that associated with the maximum stable hover height, the vehicle will oscillate vertically at a characteristic frequency. During such oscillation, the maximum height of the air cushion vehicle above the adjacent ground surface is the maximum stable height of the vehicle or a distance somewhat greater than the maximum stable hover height. The vertical distance through which the vehicle moves during such oscillation is less than the maximum stable hover height of the vehicle.

The vertical oscillation of an air cushion vehicle due to overpowering the air cushion support mechanism is believed to be induced as the oversupply of air at superatmospheric pressure is relieved from the air cushion space by "popping" atmosphere to around the lower portions of the air cushion skirt assembly. As this occurs, the pressure in the air cushion space is momentarily reduced below the air pressure productive of the maximum stable hover height. Accordingly, the vehicle tends to drop toward the adjacent ground surface, but in such movement the skirt assembly is brought into effective sealing contact with the ground. As this occurs, the downward movement of the vehicle is arrested by the compression of the air trapped within the air cushion space. Continued operation of the air pressurizing mechanism again raises the vehicle to the maximum stable hover height, or somewhere beyond, until the overpressure in the air cushion space is reestablished and the overpressure is again relieved by the "popping" phenomenon.

Pile driver **75**, see FIG. **6**, is arranged to be operated in the above-mentioned vertical oscillatory mode during the process of driving pile **25**, and to apply at least a portion of the kinetic and potential energy of the platform attributable to downward oscillatory movement to the pile as a dirving input to the pile. To the extent that pile driver **75** includes structural features like those described above for pile driver **10**, they are shown in FIG. **6** by the use of appropriate character numbers.

Pile driver **75** includes a clamp assembly **76** which differs from clamp assembly **32** of pile driver **10** in that it is not carried directly by the structure of base **11**. The clamp assembly includes a pair of clamp shoes **77** which are movable into and out of secure mating contact with the external configuration of pile **25**, and which preferably carries hardened teeth or the like for superficially biting into the pile to prevent slippage of the shoes along the pile. Suitable ram assemblies (not shown) are connected between shoes **77** to move them relative to each other into and out of mating engagement with a pile. A flexible connection **78** for supplying suitable control and power fluid to the clamp assembly is connected between it and base platform **11**.

A heavy annular loading member **79** is mounted to base **11** and is located above the upper extent of clamp assembly **76**. The loading member is disposed concentric to the line along which pile **25** is disposed during pile driving operation of pile driver **75**. The loading member may be mounted either directly to framework **27** by supports **80** (see FIG. **6**) or it may be carried by suitable supports **81** connected to base main deck **21** (see FIG. **7**). The distance between the underside of loading member **79** and main deck **21** is greater than the vertical extent of clamp assembly **76** and preferably is greater than the sum of a) the vertical extent of the clamp assembly and b) the range of vertical movement of the base relative to ground surface **18** during vertical oscillatory movement of the pile driver in the manner described above.

Clamp assembly **76** is coupled to pile driver **75** for movement vertically, i.e., upwardly, along a pile when the clamping shoes of the clamp assembly are relaxed from intimate mating engagement with the pile. As shown in FIG. **7**, at least a pair of pneumatic ram assemblies **82** (only one of which is shown) are coupled between loading member **79** and the outer extent of the clamp assembly. Operating air is supplied to the ram assemblies by suitable connections (not shown). Preferably ram assemblies **82** are a portion of the clamp assembly control and operating mechanism of which flexible connections **78** are a part.

Pile driver **75** may be operated to at least partially drive a pile by applying all of the deadweight of the pile driver to the pile. The pile driver is raised to its maximum stable hover height above ground surface **18**, clamp assembly **76** is moved into abutment with the lower portion of loading member **79** while the clamp shoes are relaxed, the clamp assembly is operated to securely grip the pile, and then the supply of hover air to air cushion space **16** is discontinued. This process is repeated until the pile can no longer be driven into the ground. Thereafter, the pile is further driven by operating hammer assembly **41** and by operation of the pile driver in the vertical oscillatory mode described above.

For oscillatory operation of pile driver **75**, the base is disposed at its maximum stable hover height above ground surface **18**; clamp assembly **76** is secured to the pile at a location in which the upper surface of the clamp assembly is spaced from the lower portion of loading member **79** by a distance which is less than, but more than half of, the range of vertical oscillatory movement of the pile driver. Blowers **20** are then operated to oversupply air to air cushion space **16**. As the base moves through its first downward oscillatory excursion, loading member **70** engages clamp assembly **76** while the pile driver is still moving downward, and in this way a substantial portion of the kinetic energy

of the pile driver, and its residual potential energy, are transferred to the pile via the clamping assembly.

Once the pile has been driven a distance equal to the vertical oscillatory movement of the pile driver, loading member **79** is ineffective to further supply loads to pile **25.** At this point, clamping assembly **76** is relaxed on the pile and ram assemblies **82** are operated to raise the clamp assembly along the pile to reestablish the initial spacing of the clamp assembly below loading member **79.** Preferably this repositioning of the clamp assembly on pile **25** is done during continued oscillation of pile driver **75** and during continued operation of hammer assembly **41** so that driving of the pile is not interrupted.

Because base platform **11** of pile driver **75** may not be stationary as hammer assembly **41** is operated, it is desirable that cap member **28** float within framework **27.** It may be desirable to install shock absorber mechanisms **40** in cables **37** which suspend the cap member from the upper end of the framework.

To impart maximum operational flexibility and versatility to pile driver **75,** the pile driver may include a pressurizing and evacuating system like or similar to that shown in FIG. **5.** Such a pile driver is capable of applying both static, pressure-related cyclic and oscillatory driving loads to a pile onto which conventional pile driving loads, such as are produced by operation of hammer assembly **41,** may be superimposed.

In pile driver **45** (see FIG. **3**) air cushion space **16** is bounded by skirt assembly **46** which is effective to seal against the ground surface **18** when the pressure within the air cushion space is either above or below ambient pressure, i.e., atmospheric pressure in the usual case. The structure of skirt assembly **46** is shown in greater detail in FIGS. **8, 9** and **10,** which clearly illustrate that, in the presently preferred practice of this invention, pile driver base platform **11** resembles a flat-bottom barge having sloped bilges. That is, the base has a gunwale **85** at which the flat main deck of the base intersects vertical side walls **86.** The side walls intersect the upper edge of a chine surface **87** which extends obliquely between the bottom and side surfaces of the base.

Skirt assembly **46** is composed of inner and outer flexible air-impervious sheets **88** and **89,** respectively. Sheets **88** and **89** preferably are defined by a fabric which has been impregnated with a suitable elastomer. Inner sheet **88** has its upper margin connected to base **11** at about the intersection of bottom surface **17** and chine surface **87.** Outer sheet **89** has its upper margin connected to the base at about the intersection of chine surface **87** with side wall surface **86.** The lower margins of the inner and outer sheets are interconnected at the bottom of the skirt assembly.

The desired configuration of the skirt assembly, during sealing of superatmospheric pressure in air cushion space **16,** is established by a plurality of flexible inelastic straps or tapes, a set of which are interconnected between base **11** and outer sheet **89** at each of a plurality of locations spaced around the periphery of the base. Each set of tapes include a tape **90** which is connected at one end to the base between the inner and outer sheets adjacent the connection of the inner sheet to the base; this tape is connected at its other end to the outer sheet adjacent its connection to the lower margin of the inner sheet. Another tape **91** is disposed between the inner and outer sheets, and has its upper end connected to the base adjacent the upper margin of the outer sheet and its lower end connected to the outer sheet adjacent the interconnection of the outer and inner sheets. Additional tapes **92** are disposed between the inner and outer sheets and have their inner ends connected to the base at spaced locations along chine surface **87,** and their outer ends are connected to the outer sheet at spaced locations along the extent of the outer sheet between its upper and lower margins.

In skirt assembly **46,** outer sheet **89** is effective at and adjacent its lower margin to seal against ground surface **18** when the air pressure in air cushion space **16** is above ambient pressure. Inner sheet **88** is effective at and adjacent its lower margin to seal against ground surface **18** when the pressure in air cushion space **16** is below ambient pressure. The surface of the sheet which faces toward air cushion space **16** is referred to, for the sake of convenience, as the inner surface of the sheet, whereas the surface of the sheet which faces away from the air cushion space is referred to as the outer surface of the sheet.

As shown best in FIG. **10** (which is included for the purposes of illustration and which does not represent a normal operative state of the skirt assembly), a plurality of ports **93** are formed through the inner sheet at spaced locations along the extent of the sheet about the periphery of base **11.** Ports **93** are located adjacent, but not at, the location at which the inner sheet is connected to the lower margin of the outer sheet. Similarly, a plurality of ports **94** are formed through the lower portions of the outer sheet adjacent, but not at, the interconnection of the outer sheet to the inner sheet. A check valve is carried by inner sheet **88** in association with each of ports **93** to permit air to pass through the port only from the inner to the outer surface of the sheet. A similar check valve **95** is carried by the outer sheet in association with each of ports **94** to permit air to flow through ports **94** only in the direction processing from the outer surface to the inner surface of the outer sheet. A suitable check valve may be defined of a flap of air impervious material mounted to the sheet so that it may overlay the adjacent port. The flaps are secured to the outer surface of the inner sheet, and to the inner surface of the outer sheet.

FIG. **8** shows skirt assembly **46** sealing against superatmospheric pressure in air cushion space **16;** the air pressure in the air cushion space is presented to the inner face of outer sheet **89** via inner sheet ports **93.** To facilitate effective presentation of the pressure in the air cushion space to the outer sheet, the inner sheet is self-retracted, as shown in FIG. **8,** by self-retraction devices carried by the inner sheet and described below with reference to FIG. **14.** On the other hand, when the air pressure within air cushion space **16** is less than ambient pressure, the appropriate seal of the air cushion space is provided by inner sheet **88.** Ambient air pressure is presented to the outer face of inner sheet **88** via outer sheet ports **94,** and outer sheet **89** is self-retracted (see FIG. **9**).

The self-retraction of the inner and outer sheets of skirt assembly **46** is provided by elastic retraction straps **96** secured to the sheets at spaced locations around the periphery of base **11.** Each retraction strap is disposed vertically in the skirt assembly and is secured at its opposite ends to the respective skirt sheet, as by stitching **97.** Intermediate its ends, the strap is guided through loops formed on the adjacent surface of

the skirt sheet by a plurality of transversely disposed flexible tapes secured, as by stitching, at its opposite ends to the sheet on either side of the retraction strap. When the skirt sheet is in its operative position, the retraction straps are extended. The elastic stiffness of the several retraction straps associated with each skirt sheet is sufficiently low that the skirt sheet can assume the desired configuration when the appropriate pressure differential exists across the sheet.

Skirt assembly **46** has an external configuration which resembles a conventional air cushion skirt assembly when the pressure within air cushion space **16** is greater than ambient pressure. Thus, pile driver **45** can be moved on a cushion of air from place to place over the ground surface.

Another air cushion skirt assembly **100,** suitable for use in pile driver **45,** is shown in FIGS. **11, 12** and **13.** Skirt **100** includes a principal sheet **101** which is fabricated of a flexible, air impervious material and which is connected to base **11** at its upper extent adjacent the intersection of chine surface **87** and side surface **86.** A plurality of positioning partition webs **102** are provided at regularly spaced stations along the extent of the skirt assembly around base **11.** Each partition web is connected to the base along chine surface **87** and also to the inner surface **103** of sheet **101.** Sheet **101,** adjacent its lower margin, is disposed at an acute angle to ground surface **18.**

Skirt assembly **100** also includes a sealing assembly **105** which extends along the length of the skirt and is carried by the lower portion of the principal sheet. The sealing assembly defines an inflatable inner chamber **106** which, when inflated, is of generally triangular configuration. The sealing assembly is fabricated of air impervious flexible material and includes a lower sheet **107** adapted to be engaged directly with ground surface **18.** An outer sheet **108** and an inner sheet **109** are connected at their lower edges to the opposite edges of sheet **107;** the upper edges of the inner and outer sheets are interconnected to each other and to principal sheet **101.** If desired, sheet **109** may be eliminated from sealing assembly **105** by connection of the upper margin of sheet **108** directly to principal sheet **101** at an intermediate location along the vertical extent of the principal sheet, and by connection of sheet **107** at its inner edge to the lower margin of the principal sheet.

Sealing assembly chamber **106** is connected at appropriate locations along the skirt via suitable flexible ducts **111,** to a compressor **110** disposed within base **11;** see FIG. **12.**

FIG. **11** illustrates skirt assembly **100** sealing against superatmospheric pressure within air cushion space **16.** FIG. **12** shows the skirt assembly sealing against subatmospheric pressure within the air cushion space. The seal against superatmospheric pressure is provided by inner sheet **109** being forced outwardly and downwardly relative to base **11.** A particularly effective positive seal is obtained by pressurizing chamber **106** so that the outward and downward bias applied to sheet **109** by super-atmospheric pressure within space **16** urges sheet **107** into sealing contact with ground surface **18** over an extended area circumferentially of base **11.**

On the other hand, during negative sealing conditions i.e. when the pressure in air cushion space **16** is less than atmospheric pressure, sheets **107** and **108** of sealing assembly **105** are effective to produce the desired seal against the leakage of air into space **16.** To provide the desired negative seal, chamber **106** is pressurized. Air at atmospheric pressure is effective on the outer surface of sheet **108** to bias the entire sealing assembly into engagement with ground surface **18.**

Sealing assembly **105** is used to provide the desired positive and negative seals when base **11** is at a desired operational location and is not being moved horizontally across ground surface **18.** To facilitate movement of base **11** from one pile driving site to another, sealing assembly **105** is retracted as shown in FIG. **13.** At spaced locations along the extent of the skirt assembly, corresponding ones of a plurality of cables **113** are connected to the sealing assembly at the connection between sheets **107** and **108.** Cables **113** are guided by suitable pulleys **114** to suitable winches on the base. When air at superatmospheric pressure is present in air cushion space **16,** a positive seal against ground surface **18** is provided by the lower portions of principal sheet **101,** by sheet **109,** and by the inner margins of sheet **107,** even when the sealing assembly has been retracted. Retraction of the sealing assembly is achieved by pulling in cables **13** so that the skirt assembly may function like a conventional skirt.

Skirt assembly **100** is arranged so that sheet **109** of sealing assembly **105** is either directly below or slightly outboard of chine surface **87** during use of the skirt assembly. This relative positioning of the chine surface and sheet **109** make it possible for base **11** to directly engage ground surface **18,** as when subatmospheric air pressure in air cushion space **16** is used to apply an increased static load to a pile for initial driving of the pile, without damaging pinching of the skirt assembly or the sealing assembly by the base.

It will be appreciated that both skirt assemblies **46** and **100** may be used to support base **11** over water for marine usages of the pile drivers described above.

The negative differential sealing properties of skirt assemblies **46** and **100** have utility in applications other than the pile drivers described above. For example, a negative sealing skirt assembly **124** is mounted about the periphery of a crawler tractor **120,** see FIG. **15,** for increasing the effective weight of the vehicle, to thereby increase the effective drawbar pull, without significantly increasing the actual weight of the vehicle. A mounting structure **121** is added to the vehicle to define a deck **122** around the vehicle above the endless belt crawler mechanism **123** on which the tractor body is supported. The support structure preferably extends sufficiently far outwardly, forwardly, and rearwardly on the tractor body to prevent any interference by the skirt assembly **124** with the vehicle propulsion mechanism. The support structure has a downwardly extending peripheral flange **125** to which the skirt is connected. An evacuating blower **126** is carried by the mounting structure and has its suction port connected to the interior of the skirt. The skirt assembly includes an inflatable sealing and wear tube **127** around its lower periphery for maintaining contact with an uneven ground surface. Operation of blower **126** increases the apparent deadweight of the vehicle, and thereby increases the pulling power of the tractor at drawbar **128.**

A positive and negative sealing skirt assembly **130** is a component of a workpiece transporting and positioning platform **131** (FIG. **16**) for use in a large machine shop or the like. Platform **131** includes a base **132**

which carries a plurality of support blocks **134** on its lower surface **135** within an air cushion space **136** bounded by skirt assembly **131.** The base is movable across a desired floor **137** on a cushion of air at superatmospheric pressure generated within the air cushion space by operation of a pressurizing blower **138** mounted to the base and having its discharge connected to the air cushion space. Subatmospheric pressure may be generated in air cushion space **136** by operation of an evacuating blower **139** carried by the base and having its suction port coupled to the air cushion space by a suitable duct **140.** A large workpiece **141** is held in position on the upper surface of the base by a plurality of conventional machinist's dog assemblies **142** engaged in appropriate grooves or slots in the upper surface of the base.

If a plurality of holes are to be drilled vertically in the upper portion of workpiece **141** by a large vertical boring mill, platform **131** is moved on a cushion of air across floor **137** and onto the rotary table of the boring mill while pressurizing blower **138** is operated. During such movement of the platform, base **132** is elevated sufficiently that support blocks **134** are raised above the floor. So long as the base is supported on a cushion of air, it is a simple matter to align the platform on the boring mill rotary table without the use of hoists or the like. Once the platform is properly positioned, air cushion support of the base is discontinued and the platform is settled onto the boring mill table for support thereon by blocks **134.** Evacuating blower **139** is then operated and subatmospheric pressure is generated in the air cushion space. In effect, base **132** and skirt assembly **131** function as a large suction cup to securely hold the platform in the desired position for machining of the workpiece. After the desired holes have been drilled, it is a simple matter to move the workpiece to another machining station.

Workers skilled in the art to which this invention pertains will readily appreciate that the foregoing embodiments of apparatus and procedures according to this invention have been presented by way of example rather than as an exhaustive delineation of all forms which this invention may take. Accordingly, it will be understood that the procedures and structures described above may be modified or altered without departing from the scope and spirit of this invention while still having the benefit of the advantages which this invention has provided. Therefore, the foregoing description of presently preferred embodiments and applications of this invention should not be considered as limiting the scope of the invention.

What is claimed is:

1. A pile driver comprising:

a. a base,

b. selectively operable means operable independently of any piles and the like previously driven for supporting the base in an elevated position above ground and the like,

c. means for disposing a pile substantially vertically of the base in engagement with ground adjacent the base into which the pile is to be driven, and

d. means operable in the elevated position of the base for transferring at least a substantial portion of the weight of the base to a pile disposed vertically of the base.

2. A pile driver according to claim **1** including impact means carried by the base and engageable with the upper end of a pile disposed vertically of the base.

3. A pile driver according to claim **1** including load receiving means attachable to a pile to be secure from movement longitudinally of the pile, wherein the selectively operable means is operable to cause the base to move cyclically substantially up and down within a range less than the distance between the base and ground in the elevated position of the base, and means carried by the base for cooperating with the load receiving means to transfer to the load receiving means at least a portion of the momentum of the base due to downward cyclic movement thereof.

4. A pile driver according to claim **3** including means cooperating between the base and the load receiving means for adjusting the position of the load receiving means along the pile.

5. A pile driver according to claim **4** wherein the position adjusting means is operable for maintaining the load receiving means at a location on the pile which is a selected distance from a reference location on the base when the base is at a predetermined position within its range of cyclic movement.

6. A pile driver according to claim **5** wherein the position adjusting means includes means for clamping the load receiving means to the pile, and means for operating the clamping means in synchronism to cyclic vertical motion of the base.

7. A pile driver according to claim **1** wherein the base defines an opening vertically therethrough in vertical alignment with the center of mass of the base, and wherein the means for disposing a pile is arranged to dispose the pile through said opening.

8. A pile driver according to claim **7** wherein said opening extends to and opens through a margin of the base.

9. A pile driver according to claim **7** wherein the selectively operable means includes a flexible skirt assembly carried by the base substantially peripherally thereof for enclosing a space between the base and ground and the like, and means for supplying air at superatmospheric pressure to the space.

10. A pile driver according to claim **9** wherein the skirt assembly is arranged to effectively enclose said space in the presence of air at subatmospheric pressure within the space, and means for evacuating air from the space.

11. A pile driver according to claim **10** including an air blower common to the air supplying means and the evacuating means.

12. A method for driving a pile and the like comprising the steps of:

a. providing an elevatable base,

b. disposing a pile to be driven substantially vertically through the base with the lower end of the pile in engagement with ground into which the pile is to be driven,

c. elevating the base from a lower position thereof relative to the ground and the pile independently of the pile and any other piles previously driven, and

d. applying to the pile at least a portion of the weight of the base including coupling the base to the pile at a position of the base above the lower position thereof.

13. The pile driving method according to claim 12 wherein the base is coupled to the pile when the base is at its elevated position, and further including the step of withdrawing at least a substantial portion of the support of the base following coupling of the base to the pile.

14. A pile driver comprising:
a. a base,
b. selectively operable means operable for supporting the base in an elevated position above ground and the like,
c. means for disposing a pile substantially vertically of the base in engagement with ground adjacent the base into which the pile is to be driven, and
d. means operable in the elevated position of the base for transferring substantially the entire weight of the base to a pile disposed vertically of the base.

15. A pile driver according to claim 14 wherein the weight transferring means includes clamp means carried by the base and engageable with a pile.

16. A pile driver according to claim 15 including means coupled to the base and operable in the elevated position of the base for enclosing a space between the base and ground and the like below the base, and means for generating subatmospheric pressure within the space.

17. A pile driver according to claim 16 including means for cyclically altering the pressure within the space relative to atmospheric pressure.

18. A pile driver according to claim 14 including cyclically operable impact means carried by the base for applying downward impact forces to a pile disposed vertically of the platform.

19. A pile driver according to claim 18 wherein the impact means comprises a sonic hammer.

20. A pile driver according to claim 18 wherein the impact means comprises a diesel hammer.

21. A method for driving a pile and the like comprising the steps of:
a. providing an elevatable base,
b. disposing a pile to be driven substantially vertically through the base with the lower end of the pile in engagement with ground into which the pile is to be driven,
c. elevating the base from a lowered position thereof relative to the ground and the pile by
1. enclosing a space between the base and ground below the base with a flexible skirt assembly coupled to the base, and
2. supplying air at superatmospheric pressure to the space,
d. coupling the base in the elevated position thereof to the pile, and
e. applying to the pile at least a portion of the weight of the base by withdrawing at least a substantial portion of the support of the base following coupling of the base to the pile by discontinuing the supply of air at superatmospheric pressure to the space.

22. The method according to claim 21 including withdrawing air from the space following discontinuing the supply of air to the space.

23. The method according to claim 21 including supplying air to the space at a superatmospheric pressure in excess of the pressure corresponding to the maximum stable elevated position of air cushion support of the base above ground, thereby to cause the base to heave cyclically within a range which is less than the maximum stable elevated height of the base.

24. The method according to claim 23 including applying to a pile at least a portion of the energy of the base attributable to said cyclic heaving motion of the base.

25. A pile driver comprising:
a. a base,
b. selectively operable means operable for supporting the base in an elevated position above ground and the like, said means comprising air cushion means for supporting the base on a quantity of air at superatmospheric pressure,
c. means for disposing a pile substantially vertically of the base in engagement with ground adjacent the base into which the pile is to be driven, and
d. means operable in the elevated position of the base for transferring at least a substantial portion of the weight of the base to a pile disposed vertically of the base.

26. A pile driver according to claim 25 wherein the air cushion means is operable to cause the base to move cyclically substantially vertically within a range of movement in which, at the lower limit of said range, the base is disposed above ground and the like and is supported, in the absence of other support, upon a quantity of air at superatmospheric pressure, and wherein the weight transferring means includes means for transferring to a pile at least a portion of the momentum of the base arising from downward movement of the base within said range.

27. A method for driving a pile and the like comprising the steps of:
a. providing an elevatable base,
b. disposing a pile to be driven substantially vertically through the base with the lower end of the pile in engagement with ground into which the pile is to be driven,
c. elevating the base from a lowered position thereof relative to the ground and the pile,
d. applying to the pile at least a portion of the weight of the base including coupling the base to the pile at a position of the base above the lowered position thereof, and
e. applying impact force to the upper end of the pile following application of at least a portion of the weight of the base to the pile.

28. Apparatus for penetrating a selected elongate member into an earth formation comprising a platform, driving means carried by the platform operable upon a substantially vertically disposed selected elongate member located adjacent the platform to urge the member to penetrate an earth formation below the platform, skirt means carried by the platform operable in combination with ground and the like below the platform for enclosing a space below the platform, means communicating with the space operable for generating subambient pressure within the space thereby to apply to the platform a downward force, and means cooperable between the platform and the member for transferring a substantial portion of said force to the member.

29. Apparatus according to claim 28 wherein the elongate member is a pile.

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