PROCESS AND SYSTEM FOR INCREASING LOAD-BEARING CAPACITY OF SOIL

Inventor: Stephen V. Chelminski, West Redding, Conn.


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UNITED STATES PATENTS
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Primary Examiner—Jacob Shapiro
Attorney, Agent, or Firm—Bryan, Parmelee, Johnson & Bollinger

ABSTRACT

Improved air gun energy source adapted to be submersible in water, sand, gravel, soil, marshland, concrete slurry or the like for repeatedly suddenly discharging pressurized air into the surrounding material including means providing a flushing venting of pressurized air from the operating cylinder into the release cylinder during the time when the operating piston is unseated from its stop to prevent the entry of grit into the release cylinder when the discharge port is opened by the release piston. The flushing venting air flow is shown passing around the release piston.

8 Claims, 11 Drawing Figures
PROCESS AND SYSTEM FOR INCREASING LOAD-BEARING CAPACITY OF SOIL

This application is a division of application Ser. No. 131,919, filed Apr. 7, 1971, and which issued as U.S. Pat. No. 3,707,848 on Jan. 2, 1973.

The present invention relates to an improved air gun energy source submersible in water, sand, gravel, soil, marshland, concrete slurry and the like.

In many areas of the world, the construction of buildings and other structures must be carried out in places where the soil is not firm enough to support the weight of the intended structure. For instance, marshland or coastal land where the ground is soft are examples of locations where this problem is often encountered.

In many of these locations having unfirm soil conditions, it is sufficient to drive piles down into the ground beneath the place where the structure is to be erected. The pile is driven down until the cumulative force along the length of the inserted pile is sufficient to enable it to support the load of the structure. Alternatively, the piles may be driven down until they hit a layer of earth, or of rock, which in itself is firm enough to support the intended structure, providing that enough of the piles can be driven down until they reach engagement with such a firm layer.

There are, however, a number of places or conditions where piles alone are not suitable to support the intended structure and, therefore, it is necessary to improve the load-bearing ability of the soil beneath the site where the structure is to be built.

In use of the invention, in one of its aspects, a densely compacted column of granular material, for example, such as sand or gravel, is produced extending down into the soil to the desired depth. A number of these densely compacted granular material columns are produced beneath the site for the intended construction project. These columns serve to stabilize the soil, and they provide a load-bearing capability for supporting the structure to be built.

For producing each column of compacted granular material, a long hollow tubular member, such as a hollow steel pipe having a diameter, for example, from about six inches up to about five feet, is positioned in the soil so that the lower end of the hollow member is approximately at the depth at which the lower end of the load-bearing granular material column is to be located. Then, the granular material is fed down through the hollow member toward its lower end, and pressurized air is abruptly released near the lower end of the hollow member to produce a powerful impulse which can be repeated as often as desired by the operator. These repeated powerful impulses of the abruptly released pressurized air impel the granular material outwardly from the lower end of the hollow member into the surrounding region in the soil.

When sufficient granular material has been distributed and compacted in this first region, the hollow member is withdrawn an increment and the steps are repeated to produce a column of compacted granular material of the desired height extending from the first region upwardly toward the surface of the earth.

A plurality of these columns of compacted granular material are produced by this process, and they collectively provide a greatly enhanced load-bearing capability for the site involved.

In use of the present invention, in another of its aspects, granular material is compacted at the lower end of the desired load-bearing column, in the soil, and then poured concrete is impelled outwardly by the repeated impulses of abruptly released pressurized air from an air gun in a region immediately above the compacted granular material to create a mass of concrete resting upon the compacted granular material. After sufficient poured concrete has been distributed to provide a footing, the lower end of the hollow member may be left inserted down into the poured concrete, so as to create a hollow pile embedded in a concrete footing. If desired, the interior of the hollow member can also be filled with poured concrete to any desired depth so as to create a steel encased solid concrete pile.

In accordance with the present invention, in yet another of its aspects, a system is provided in which a novel air gun energy source adapted to be operated while inserted into the soil is connected to the lower end of a long string of piping. This string of piping has a smaller diameter than the hollow member such that the string can be inserted down into the hollow member to form a removable inner pipe assembly. The hose line to supply highly pressurized air and the electrical "firing" line for the air gun extend down to the air gun through the bore of the inner pipe assembly. The air gun is "fired" repeatedly as desired to produce powerful impulses for distributing and compacting granular material, poured concrete and the like. In addition, the powerful impulses from the air gun can be used to advantage to facilitate the initial insertion of the hollow member in the soil. This insertion is accomplished by flowing water down through the hollow member and repeatedly firing the air gun to impel outwardly the soil, thus removing the soil from below the lower end while compacting the soil in a generally cylindrical region spaced around the outside of the hollow member. By virtue of this radial compaction effect, the soil is enhanced in its ability to provide lateral support for the load-bearing column to be produced.

Columns of more coarsely granular material may be produced in the soil to enable the ground water to percolate up out of the soil to the surface through these columns. The ground water is released by the intense impulses created by the repeated firing of the air gun. By virtue of the compaction of the surrounding soil, the load-bearing ability of the surrounding soil is increased.

The various objects, aspects and advantages of the improved submersible air gun energy source for producing load-bearing columns in the soil of the present invention will, in part, be pointed out and, in part, will become more fully understood from a consideration of the following detailed specification when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is an elevational view illustrating the process and system using the present invention for producing
loadbearing columns in the soil. A portion of FIG. 1 is shown in cross section. For clarity of illustration, that part of FIG. 1 which is directly associated with the soil is shown greatly enlarged as compared with the crane and associated equipment which is located above ground level. The hollow member is shown in its initial position in FIG. 1, and a removable inner pipe assembly is shown positioned within the hollow member, with an air gun located at the lower end of the inner pipe assembly for generating powerful impulses by abruptly releasing pressurized air from the air gun.

FIG. 2 is similar to FIG. 1, but it shows an intermediate stage in the sequence of steps, with the load-bearing column having been partially produced, and with the hollow member having been raised to a position substantially above its initial position. Also, FIG. 2 shows more details of the automatic loader and conveyor mechanism for continuously introducing the granular material into the upper end of the hollow member; FIG. 3 is an illustration generally similar to FIG. 1, but FIG. 3 shows a composite load-bearing column being produced in which the lower end is compacted granular material, and poured concrete is being impelled outwardly and compacted immediately above the bed of granular material; FIG. 4 is similar to FIG. 3 and shows a later stage in the production of a composite load-bearing column. The removable interior pipe assembly with the air gun at its lower end has been removed from the hollow member, and the hollow member has been filled with concrete, so as to reinforce the hollow member, forming an encased solid concrete column; FIG. 5 shows the adapter assembly and loading unit at the upper end of the hollow member in which the granular material and/or poured concrete can be introduced and also showing the upper end of the removable interior pipe assembly; FIG. 6 shows the inner pipe assembly on enlarged scale. Portions of FIG. 6 are in section to show the electrical control cable and the high-pressure hose and their connections for supplying the pressurized air to the air gun at the lower end of the inner pipe assembly; FIG. 7 is a top plan view of the upper end of the inner pipe assembly, this view being taken along the plane 7—7 in FIG. 6, looking downwardly; FIG. 8 is a longitudinal sectional view of the air gun and lower end of the inner pipe assembly; FIG. 9 is a cross section taken along the line 9—9 in FIG. 8; FIG. 10 is a cross section similar to FIG. 9 showing a modified embodiment; and FIG. 11 is a cross section similar to FIGS. 9 and 10 showing another embodiment.

As shown in FIG. 1 of the drawings, when it is desired to increase the support capability of the soil 18 by producing a load-bearing column of granular material, such as shown dotted at 20, a hollow tubular member 22 is inserted down into the soil. This hollow member 22 is usually a length of steel pipe having a diameter, for example, from about six inches up to about five feet. The hollow member 22 may have any desired length from about 10 feet up to more than 100 feet, depending upon the conditions and characteristics of the soil 18 and depending upon the weight and size of structure intended to be supported by the column 20 and by other similar nearby columns (not shown) to be produced in the soil 18.

Removably positioned within this hollow member 22 is an inner pipe assembly 24, having an air gun energy source 30 secured to its lower end, as shown in greater detail in FIG. 6. The inner pipe assembly 24 includes a lower pipe section 26-L, an upper pipe section 26-U, and between these two pipe sections 26-L and 26-U is an intermediate pipe section 26-I having a length such that the total length of the entire assembly 24 is commensurate with the desired length of the hollow member 22. The lower and intermediate pipe sections 26-L and 26-I are releasably coupled together by a lower pipe coupling 27, which is threaded onto the lower and intermediate pipe sections and is permanently welded to the lower section by a weld at 31. Similarly, the upper pipe section 26-U and intermediate section 26-I are coupled together by an upper pipe coupling 28, which is threaded onto both the upper and intermediate pipe sections and is permanently welded to the upper one by a weld at 32. In this way, the inner pipe assembly 24 can conveniently be disassembled by unscrewing the intermediate pipe 26-I to be replaced by a shorter or longer pipe section as required by the particular job site.

To the lower end of the inner pipe assembly 24 is secured a novel soil-submergence air gun 30 which is supplied with pressurized air through a high pressure hose line 34 (FIG. 6) and is controlled by electrical signals through wires located within an insulated electrical cable 36 extending within the pipe sections 26.

As an alternative to firing the air gun in response to an electrical signal, it can be arranged to be automatically self-firing, for example, to fire every so many seconds. Electrical firing apparatus for an air gun and also arrangements for making the air gun automatically self-firing at intervals are disclosed in U.S. Pat. No. 3,739,273 which issued Apr. 23, 1968.

A convenient manner of inserting the hollow member 22 into the soil 18 is to pump a jetting flow of water downwardly through the annular space 38 (FIG. 1) surrounding the inner pipe assembly 24. This flow of water is provided by a pump 40 (FIG. 1) driven by an engine 42 with an in-take line 44 extending from the pump 40 over to a suitable nearby source of water, shown as a body of water 46. The water is drawn into the line 44 through a strainer 47 to prevent sand and grit from entering the pump 40. A control valve 48 can be used, if desired, to regulate the flow through a jetting water supply line 49 connected into the head adapter unit 50 (FIG. 5) which is attached to the upper end of the hollow member 22.

In order to produce a forceful downward flow of water in the annular space 38 (FIG. 1), is indicated by the flow arrows 51 in FIG. 5, the upper end of the head adapter unit 50 is temporarily shut off by a manually operable valve mechanism 52 containing a plurality of large ports 54 which can be closed by means of a movable disc 53 which can be turned relative to a fixed disc 55, so that ports in both discs align or not. The movable disc is operated by a control handle 56. With the ports 54 closed, the water being supplied through the line 49 is forced down through the annular space 38, so as to issue with a jetting action from the lower end 58 (FIG. 1) of the hollow member 22. In this way the jetting water action in the vicinity of the lower end 58 dis-
lodges and erodes the soil, so as to aid in inserting the hollow member 22 down into the earth. As the emplacement of the hollow member 22 is being carried out, it is sometimes advantageous to “fire” the air gun 30 from time to time. The result of firing the air gun 30 is that pressurized air is abruptly released in all directions simultaneously through its multiple discharge ports 60 (FIG. 6) serving to forcefully impel the soil away from the lower end 58, thus enhancing the ability of the entire assembly to penetrate down into the earth. Also, the radial compaction of the surrounding soil enhances its load-bearing ability.

Among the advantages of using the water jetting action aided by repeated firing of the air gun 30 to emplace the hollow member 22 into the earth, is that the method utilizes components of the same system of equipment which will be used to produce the load-bearing column 20.

An alternative way in which the hollow member 22 can be positioned into the earth is to drive it down by a pile driver, with the inner pipe assembly 24 having been removed before the hollow member 22 is driven down. Then after the hollow member 22 is in place, a water jet pipe (not shown) is pushed down through the interior of the hollow member 22 to flush out any soil material within the member 22. Then, this water jet pipe is removed, and thereafter, the inner pipe assembly 24 is lowered into position within the hollow member 22. The spacing struts 64 (FIG. 1) near its lower end serve to keep the inner pipe assembly 24 centrally positioned, in concentric relationship within the hollow member 22. As shown in FIG. 5, there are radial struts 65 which interconnect the upper pipe section 26-U to the head adapter unit 50. There are multiple large set screws 62 which releasably secure the unit 50 to the upper end of the hollow member 22 after the inner pipe assembly has been lowered into position.

In order to raise or lower the hollow member 22 or the inner pipe assembly 24, an operating and control vehicle 66 is provided having a crane mechanism 68 with a lifting cable 69 attached to a sling chain 70 (FIG. 5) secured to the upper end of the head adapter unit 50. A similar sling chain 71 (FIG. 5) is secured to a connector assembly 72 at the upper end of the inner pipe assembly 44.

The vehicle 66 also includes a high pressure air supply 74 including multiple stage air compressor and a suitable tank or receiver for storing the compressed air produced. This compressed air may be stored at any suitable pressure from approximately 500 to approximately 3,000 pounds per square inch, depending upon the desired operating pressure for the air gun 30. At the output from the high pressure air source 74 is an adjustable pressure-regulating valve (not shown) and a shut-off valve 76 connected to the high pressure hose line 34. Also, contained on the vehicle 66 is an electrical control circuit (not shown) which produces the signal that is sent through the cable 36 (FIG. 6) whenever it is desired to fire the air gun 30. There is a solenoid operated valve 78 (FIG. 6) mounted upon the air gun 30 and connected to the electrical cable 36 which is actuated by the electrical firing signal and serves to trigger the firing of the air gun.

This solenoid valve 78 is described in detail and claimed in the copending patent application of Anthony J. Delano and myself, Ser. No. 855,667, filed Sept. 5, 1969.

After the hollow member 22 and inner pipe assembly 24 are positioned as far down in the soil 18 as desired, it is sometimes desirable to create a cavity about the lower end 58 because this cavity is sometimes helpful to facilitate the initial stages of introduction of the granular material into the soil. Such a cavity may be initially generated in the soil in the region surrounding the lower end 58 by providing a flow 51 (FIG. 5) of water down through the annular space 38 with the large ports 54 closed and by repeatedly firing the air gun 30 while the water flow is occurring. These interacting steps compact the soil in the region of the bottom end 58 and create a cavity by flushing out the loose, light-weight and fine material there.

The steps which are carried out when it is desired to produce the load-bearing column 20 of granular material are as follows:

In order to start producing this load-bearing column 20, the water flow 51 is stopped, the firing of the air gun 30 is stopped, and the large ports 54 are opened. The desired granular material 82 is now fed into the hopper funnel 80 (FIG. 5) on the head adapter unit, so as to feed down through the ports 54 and down through the annular space 38 into the region near the lower end 58 of the hollow member 22.

The firing of the air gun 30 is now carried out repeatedly to forcefully impel the granular material 82 outwardly and distribute it in the initial region 84 at the lower end of the desired column 20, as shown in FIG. 1, while compacting it and the soil 18 about the region 84 being filled by the granular material 82.

The granular material 82 is now fed as needed into the hopper funnel 80 (FIG. 5) by means of a conveyor belt 86 (FIG. 2) having a sequence of upstanding slats 87 at spaced intervals along the belt 86 to prevent the material 82 from sliding back down. The belt 86 is supported by a plurality of rollers 88 mounted upon a boom truss 90. The upper end of this truss 90 is removably pivotally connected at 91 to the head adapter unit 50. Its lower end is removably pivotally connected at 92 to the chassis of a loader cart 94 (FIG. 2) having a large hopper 95 with an outlet 96 which continuously supplies the granular material 82 to the conveyor belt 86. The desired type of granular material 82, such as sand, gravel, crushed stone, small rocks, or the like, is dumped into the hopper 95. The loader cart 94 has wheels so that when the hollow member is withdrawn by increments from the earth, as shown in FIG. 2, and the truss 90 and conveyor 86 incline upwardly, the cart 94 rolls over toward the member 22 a distance to accommodate the changing inclination of the truss 90 and conveyor 86.

The repeated firing of the air gun 30 serves to distribute and compact the granular material 82 and the surrounding soil 18 in the initial region 84, as discussed above. The annular space 38 is now full of the granular material, advantageously providing a dense heavy weight in the nature of a "hydrostatic" head bearing down upon the material in the region 84 being compacted. The repeated firing of the air gun 30 shakes the hollow member 22, and causes the material 82 in the annular space 38 to shake and to slump and to continue to feed downwardly. Water can be fed into the annular space 38 from the supply line 49, if desired, to facilitate...
the downward feeding of the material in the annular space 38.

After suitable amount of the granular material has been compacted into the initial region 84, the hollow member 22 is withdrawn an increment of distance, for example, such as from one to four feet to reposition the lower end 58 a short distance above its initial position, which was as shown in FIG. 1.

An advantageous way to determine when a suitable amount of the granular material 82 has been compacted into the initial region 84 is to observe the rate at which the material 82 has been feeding down through the hopper funnel 80. When this feed rate has slowed to an insignificant amount, it means that the initial region 84 has become so fully loaded and compacted with the granular material 82 that it is refusing to accept any more. Accordingly, the hollow member 22 and the inner pipe assembly 24 with the air gun 30 are now raised the increment distance discussed above to reposition its lower end 58.

The repeated firing of the air gun 30 abruptly releasing powerful impulses of high pressure air in its repositioned location impels additional granular material outwardly into a second region 98 indicated dotted in FIG. 1 surrounding the re-positioned end 58, so that this additional material 82 is adjacent to and above the material in the initial region 84.

When sufficient granular material has been distributed and compacted into this second region 98, the hollow member 22, inner pipe assembly 24, and air gun 30 are raised another increment of distance and the steps are repeated, as above described, to produce the load-bearing column 20.

FIG. 2 shows an intermediate stage in the process in which the column 20 is approximately one-half completed.

It is to be noted that the repeated forceful impulses produced by the repeated firing of the air gun 30 are capable of impelling the granular material 82 outwardly so as to produce a load-bearing column 20 which is advantageously at least three times the diameter of the hollow member 22. In the illustrative embodiment shown in FIGS. 1 and 2, the column 30 is more than four times the diameter of the hollow member 22.

Among the advantages of being able to create such relatively large diameter columns 20 is that they have greater load-bearing strength, and fewer of them are required to be produced in the soil to support a given structure, thus saving greatly in time and labor.

In the process shown in FIGS. 3 and 4, a composite column 20A in the soil is created including a base B of compacted granular material, a footing F of concrete and a pipe pile P which is reinforced by filling it with concrete. The compacted granular material 82 forming the base B in the initial region 84 is produced by the sequence of steps as described above.

When sufficient granular material has been introduced into the base B, the feed of granular material 82 is stopped. The hollow member 22, inner pipe assembly 24, and air gun 30 are raised an increment of distance to reposition the lower end 58, and concrete is not introduced into the hopper funnel 80. This concrete can be fed by the substantially horizontal conveyor belt 86 (FIG. 3) if desired or it can be pumped through a hose (not shown) into the hopper funnel 80, or can be fed directly from a concrete mixture supply truck via a chute into the hopper funnel.

The air gun 30 is repeatedly fired during the feeding of the concrete to form the footing F. In this way the concrete is impelled outwardly and compacted into a footing F in a region 98 immediately above the material 82 in the base B.

If it is desired to enlarge the depth of the footing F, the components 22, 24 and 30 are simultaneously raised another increment of distance and additional concrete is fed down while the air gun 30 is repeatedly fired.

After sufficient concrete has been introduced into the footing F, the inner pipe assembly 24, with the air gun 30, and the head adapter 50, are removed to leave the hollow member alone, as shown in FIG. 4. The lower end 58 of this member extends down into the footing F to provide a strong pipe pile member 22.

If it is desired to reinforce this pipe pile member 22, then as shown in FIG. 4, it is filled with concrete to form a steel encased solid concrete pile. Reinforcing rods may also be used.

The concrete 100 is shown being poured down a chute 101 from a concrete mixture supply truck 102.

As shown in FIG. 6, the inner pipe assembly 24 includes a mounting section 103 welded to the lower end of the lower pipe section 26-L. The air gun 30 has a mounting flange 104 which is removably fastened by machine screws 105 to this mounting section 103.

At the upper end of the upper pipe section 26-U, the outer pipe section 106 is secured another mounting section 106 to which a split retainer 108, 109 (FIG. 7) of the connection assembly 72 is removably secured by machine screws 110.

The high pressure air hose line 34 and the electrical cable 36 extend through channels in the split retainer 108, 109. As shown in FIGS. 6 and 7, stiff flexible protective sleeves 111 and 112 surround the hose 34 and cable 36, respectively, in the region where they pass through the split retainer 108, 109. The two halves 108 and 109 of the split retainer are held clamped firmly about these sleeves 111 and 112 by means of clamp screws 114. A support ring 116 is secured to the split retainer 108, 109 by means of machine screws 117, and the sling chain 71 is attached to this ring 116.

Thus, the length of the inner pipe assembly can be changed by disassembling the connector assembly 72 including the split retainer 108, 109 so as to be able to remove the hose 34 and cable 36 from within the pipe sections 26-U and 26-L. Then, a longer or shorter intermediate pipe section 26-L can be inserted as mentioned above, and the components of the inner pipe assembly 24 can be reassembled in readiness for use.

From the foregoing description, it will be appreciated that the air gun 30 is being operated in an extremely hostile and abrasive environment, for it is surrounded by water, soil, mud, granular material, such as sand or gravel, a concrete slurry, and the like. In order to enable the air gun 30 to operate advantageously and to continue reliable operations for thousands of "shots" without failure under these difficult circumstances, it incorporates certain novel improvements over the air guns disclosed in U.S. Pat. No. 3,379,273, mentioned above. Before discussing these improvements, as shown in FIGS. 8, 9, 10 and 11, which are claimed herein, it may be helpful to the reader to review briefly the operation of the air gun 30, as shown.
Wen the shuttle 120 (FIG. 8) is in its normal position prior to "firing" the lower lip 122 of the skirt 124 on the pressurized air releasing piston 126 is in sealing engagement with a movable seal ring 128 so as to hold a charge of pressurized air in a charge chamber 130. A plurality of seal springs 132 held in a retainer 133 urge the movable seal ring 128 against the rim 122. Thus, the pressurized air is held against going out through the ports 60.

A releasing cylinder sleeve 134 defines a release cylinder 135 and surrounds the release piston 126. The sleeve 134 has ports 136 aligned with the ports 60 in the air gun body 138. A seal between the movable seal ring 128 and the cylinder sleeve 134 is provided by an O-ring 140. A retainer 142 holds the O-ring 140 and also holds another O-ring 144 providing a seal between the cylinder sleeve 134 and the body 138.

In preparation for firing, air under pressure is introduced through a hose line connection fitting 146 from the hose line 34 shown in FIGS. 6 and through a passage 148 in the upper housing 149 into an operating cylinder 150 lined with an operating cylinder sleeve 152. The pressurized air enters the chamber 130 by flowing down through a constriction 153 and through an axial passage 154 in the hollow piston shaft 156, which interconnects the release piston 126 with an operating piston 158. The operating piston 158 is sealed to the hollow piston shaft 156 by an O-ring 160 and is held by a nut 162.

As the pressurized air flow into the cylinder 150, the constriction 153 briefly maintains the pressure in cylinder 150 above the pressure in the chamber 130, assuring that the rim of the operating piston 158 remains firmly seated against a firing seal O-ring 164. The seal 164 is held by a retainer and shuttle stop member 166 which also holds a shaft gland 168 in an annular socket 170. Another retainer annulus 172 retains the shaft gland 168 in the socket 170. The stop member 166 has a raised stop surface 167 which engages the lower face of the piston 158.

After the chamber 130 is filled to the desired pressure, the air gun 30 is ready to be fired. This may be accomplished by making the air gun self-firing, as explained above, in which case the solenoid valve 78 and firing cable 36 can be omitted. The firing passages 173, 174, 175, 176 also can be omitted when the air gun is made self-firing. To make the air gun self-firing, the effective area of the air releasing piston 126 exposed to the pressurized air in chamber 130 is made greater than that of the operating piston 158 exposed to the pressurized air in cylinder 150. Accordingly, when the pressure in chamber 130 has risen up substantially to that in cylinder 150, the seal between the ring 164 and the operating piston 158 becomes opened to allow the high pressure air in chamber 150 to communicate with the lower face of piston 158, and the shuttle 120 is accelerated away from the seal 164 and from seal ring 128 and abruptly opens the ports 60 to suddenly release the pressurized air providing a powerful impulse. The by-pass passages 180 in the cylinder sleeve 152 allow free communication for air to pass from chamber 150 into the space beneath the travelling piston 158. The time intervals between "shots" when the air gun is self-firing is controlled by the constriction 153. The greater the constrictive effect, i.e. the smaller the diameter of the passage 153, the longer the interval between shots, and vice versa.

Alternatively, the valve 78 can be used. When it is activated by an electrical signal through the cable 136, the pressurized air passes through firing passages 173, 174, 175 and 176 and into an annular firing chamber 178 on the opposite side of the operating piston 158 from the operating cylinder 150. The application of pressure to the chamber 178 tends to equalize pressure exerted on opposite faces of the piston 158 to allow the shuttle 120 to accelerate away from the seal 164 and seal ring 128, thus suddenly opening the ports 60 to abruptly release the pressurized air from the chamber 130. The passage 176 and the annular firing chamber 178 are formed in the retainer and stop member 166. There are by-pass passages 180 formed by cut outs in the operating cylinder sleeve 152 which serve to aid in equalizing the pressure on opposite faces of the operating piston 158 after it has begun accelerating away from the firing seal 164.

After firing, the air remaining trapped in the operating cylinder 150 above the by-pass passages 180 is compressed by the fast-travelling operating piston 158 thus serving to decelerate the shuttle 120 and then to return it to its initial position.

With respect to the novel improvements incorporated in the air gun 30 for operation when embedded in soil under the difficult environmental conditions, as described above, these improvements are included regardless of whether the air gun is made self firing or not.

To prevent any fine grit from working past the peripheral piston portion 182 so as to enter the release cylinder 135, there is an advantageous pneumatic flushing venting action which has been provided in the air gun 30. This flushing venting action is provided by the small clearance passage 186 (FIGS. 8 and 9) provided between the shaft gland 168 and the hollow shuttle shaft 156. The inside diameter (I.D.) of the gland 168 is several thousandths of an inch larger than the outside diameter (O.D.) of the shaft 156. Also, the I.D. of the retainer and stop member 166 and of the annulus 172 are correspondingly larger than the O.D. of the shaft 156.

Thus, as soon as the operating piston 158 has accelerated away from the stop surface 167, the pressurized air in the firing chamber 178 and in the cylinder 150 beneath the piston 158 rushes over the raised stop surface 167. Some of the pressurized air rushes down through the vent passage 186 and into the release cylinder. The result is to pressurize the release cylinder 135 so that there is a continuous bleeding 188 of pressurized air down along the outside surface of the enlarged peripheral portion 182 of the release piston 126 and out through the ports 60, during the time while the shuttle 120 is in motion upward and continuing until it has been returned down into position against the seal 164. This continuous air bleed 188 is a barrier to prevent the entry of any grit into the release cylinder 135 during shuttle motion. If any fine grit should find its way into the release cylinder 135, the air bleed 188 would soon flush out the grit.

The bleed 188 becomes very rapid when the release piston 126 is travelling up toward the retainer annulus 172 during firing of the air gun, which travel causes compression of the air trapped in the release cylinder 135.

Another advantage of the vent passage 186 is that it allows the escape of pressurized air from beneath the
operating piston 158 as it is moving back toward the seal 164. This venting assists in assuring a rapid reseating of the operating piston 158 against the firing seal 164.

FIG. 10 shows an alternative embodiment of the vent passage. Instead of an annular vent passage 186, as shown in FIG. 9, there are a plurality of axially extending vent channels 186A formed in the inside surface of the shaft gland 168.

FIG. 11 shows a further embodiment of the vent passage. A plurality of vent passages 186B are drilled down through the retainer and stop member 166 and down through the gland 168 and also down through the retainer annulus 172. These vent passages 186B are located so that they extend down within the raised stop surface 167. Thus, air cannot vent from the region beneath the piston 158 down through the passages 186B until after the piston 158 has accelerated away from the stop surface 167. Thus, the venting action does not reduce the pressure in the firing chamber 178 at the moment of actuation of the solenoid valve 78 to fire the air gun.

A very small clearance space may be provided between the skirt 124 of the release piston 126 and the releasing cylinder 134 surrounding it. Thus, the inside diameter (I.D.) of the releasing cylinder sleeve 134 may be a few thousandths of an inch larger than the outside diameter (O.D.) of the piston skirt 124. This small clearance assures that a pneumatic flushing venting action as provided by the clearance passages 186, 186A or 186B is also provided around the skirt 124 to prevent fine grit from working past the peripheral piston portion material material that may work its way into the release chamber 135 will in time be flushed out by the air bleed 188.

The clearance between the skirt 124 and the sleeve 134 does not affect the charge of pressurized air in the charge chamber 130 since it is maintained therein by the seal formed by engagement of the lower lip 122 of the skirt 124 and the movable seal ring 128. Grit is kept out of the charge chamber 130 by the sudden release of the pressurized air through the ports 60. In the event any fine grit should manage to get into the charge chamber 130 it will fall to the bottom thereof and remain settled and be removed when the chamber is disassembled for cleaning or inspection.

Where it is desired to remove or expel ground water and the like from a depth in the soil 18 (FIGS. 1 and 2) columns 20 of coarse granular material 82 are produced extending up at least from that depth to the surface of the ground. These granular columns allow the ground water to percolate up to the surface. The ground water is released from the sub-surface soil 18 by the intense impulses created by the repeated firing of at least one air gun 30. This air gun is positioned at a depth below the surface corresponding generally to the depth from which it is desired to expel the ground water. In other words, the repeated firing of the air gun exerts a radial pressure on the surrounding soil. This expells the ground water and forces the water to percolate up through the nearby columns of granular material 82. As the ground water is released, the soil compacts around the columns 20 to increase the load-bearing ability of the surrounding soil.

I claim:

1. In an air gun energy source adapted to be submersible in material such as water, mud, sand, gravel, marshland, concrete slurry or the like having a discharge port and also having release means, said release means being movable between a closed position in which the discharge port is blocked by said release means and an open position in which the discharge port is open for releasing pressurized air from the source through the discharge port into the surrounding material, the improvement comprising the inclusion of means for providing a flushing venting of pressurized air about the release means and flowing toward the port to prevent the material surrounding the submerged source from working its way into the source and release means moving parts, in which the release means comprises a piston having a shaft, said shaft passing through a bore opening in a wall between a plurality of chambers for containing a charge of pressurized air in the energy source, said shaft being positioned in said opening such that a small passage is provided between the shaft and the bore opening whereby pressurized air from one of the chambers is permitted to pass through said passage to provide an air bleed around the release member and out of the discharge port when the release means is in its open position, in which the clearance is formed by providing a plurality of axially extending vent channels in the inside surface of the bore around said shaft.

2. In an air gun energy source adapted to be submersible in material such as water, mud, sand, gravel, marshland, soil, concrete slurry or the like and having a discharge port and also having release means, said release means being movable between a closed position in which the discharge port is blocked by said release means and an open position in which the discharge port is open for releasing pressurized air from the source through the discharge port into the surrounding material, the improvement comprising the inclusion of means for providing a flushing venting of pressurized air about the release means and flowing toward the port to prevent the material surrounding the submerged source from working its way into the source and release means moving parts, in which the release means comprises a piston having a shaft, said shaft passing through a bore opening in a wall between a plurality of chambers for containing a charge of pressurized air in the energy source, said shaft being positioned in said opening such that a small passage is provided between the shaft and the bore opening whereby pressurized air from one of the chambers is permitted to pass through said passage to provide an air bleed around the release member and out of the discharge port when the release means is in its open position, in which the clearance is formed by providing a plurality of axially extending vent channels in the inside surface of the bore around said shaft.

3. In a gas gun energy source adapted to be submersible in material such as water, mud, sand, gravel, soil, concrete, slurry, and the like, and having a discharge port and also having release piston means, said release piston means being movable between a closed position in which the discharge port is blocked by said release piston for containing a charge of pressurized gas in the source and an open position in which the discharge port is open for suddenly releasing pressurized gas from a pressure release chamber in said source through the discharge port into the surrounding material, the improvement comprising the inclusion of means for providing a gas bleed around the perimeter of said release piston and out through the discharge port when the release piston is in its open position whereby any of the material surrounding the submerged source is pre-
vented from entering the port and working its way into the energy source moving parts.

4. In a gas gun energy source for abruptly releasing pressurized fluid such as air or gas or the like, and adapted to be submerged in environmental material such as water, mud, sand, gravel, soil, liquid concrete mix and the like, and having at least one discharge port with a release piston located in a release cylinder suddenly movable in said release cylinder between a closed position in which said release piston blocks said port and an open position in which said port is suddenly unblocked for suddenly releasing the pressurized fluid through said port, said gas gun also having an operating piston connected by a piston shaft to said release piston, said operating piston being located in an operating cylinder and engaging a firing seal when said release piston is in its closed position, and said gas gun having a firing chamber which is separated from said operating cylinder when said operating piston engages said firing seal, the improvement comprising means defining a passage extending from said firing chamber into said release cylinder, said passage communicating with said release cylinder on the opposite side of said release piston from said port, whereby upon firing of said gas gun, pressurized fluid flows from said firing chamber into said release cylinder and around the perimeter of said release piston and out through said port for inhibiting the entry of such environmental material through said port.

5. In a gas gun energy source for abruptly releasing pressurized fluid as claimed in claim 27, the further improvement comprising a gland surrounding said piston shaft and defining said passage extending from said firing chamber into said release cylinder.

6. In an air gun energy source adapted to be submersible in surrounding material such as water, sand, gravel, soil, marshland, concrete slurry, or the like, for repeatedly abruptly releasing pressurized air into the surrounding material, and having a discharge port and also having a movable shuttle therein including a pressurized air release piston and an operating piston with a shaft interconnecting said pistons, said release piston being movable in a release cylinder between a closed position in which the discharge port is blocked by the release piston and an open position in which the discharge port is opened by the release piston, said operating piston being movable in an operating cylinder to a seated position in which the operating piston is seated against a stop for holding the release piston in its closed position and being movable to an unseated position in which the operating piston is spaced from the stop for moving the release piston to its open position for abruptly releasing pressurized air from the source through the discharge port into the surrounding material and said operating piston being movable in said operating cylinder back to its seated position for returning the release piston to its closed position, the invention comprising means providing a venting passage from said stop extending into said release cylinder for providing a flushing venting of pressurized air from said operating cylinder into said release cylinder during the time when the operating piston is unseated from said stop to prevent the entry of grit into the release cylinder when the discharge port is opened by said release piston.

7. In an air gun energy source adapted to be submersible in surrounding material such as water, sand, gravel, soil, marshland, concrete slurry, or the like, the invention as claimed in claim 6, in which said shaft interconnecting said release piston and said operating piston passes through a bore opening in wall means positioned between said release cylinder and said operating cylinder, said means providing a venting passage being an enlarged bore in said wall means defining a communicating space between said release cylinder and said operating cylinder when said operating piston moves away from said stop.

8. In an air gun energy source adapted to be submersible in surrounding material such as water, sand, gravel, soil, marshland, concrete slurry, or the like, the invention as claimed in claim 7, in which said bore in said wall means has a diameter several thousandths of an inch larger than said shaft.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,808,822 Dated May 7, 1974

Inventor(s) Stephen V. Chelminski

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

In the title, "PROCESS AND SYSTEM FOR INCREASING LOAD-BEARING CAPACITY OF SOIL" should read -- AIRGUN ENERGY SOURCE SUBMERSIBLE IN WATER, SAND, SOIL AND THE LIKE --

Signed and Sealed this Seventeenth Day of June 1980

[SEAL]

Attest:

SIDNEY A. DIAMOND

Attesting Officer Commissioner of Patents and Trademarks
UNITED STATES PATENT OFFICE
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