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SEIJI KATO
METHOD AND APPARATUS FOR FORMING UNDERGROUND
CONSTRUCTION IN SITU

3,499,293

Filed Nov. 20, 1968

3 Sheets-Sheet 1

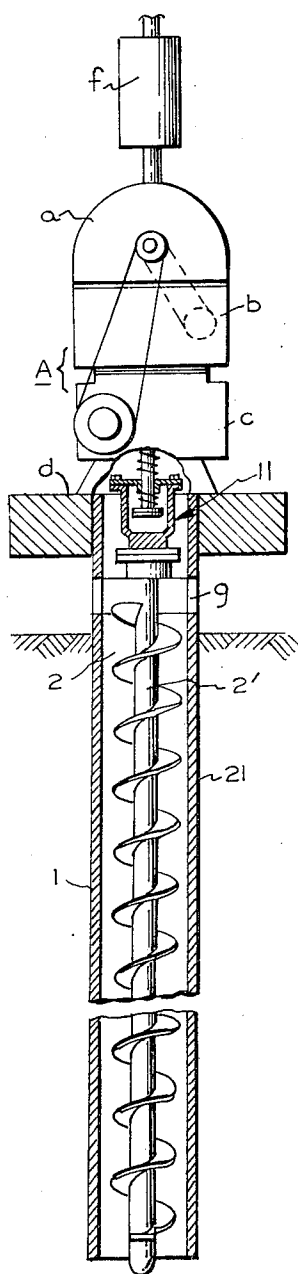


FIG. 1

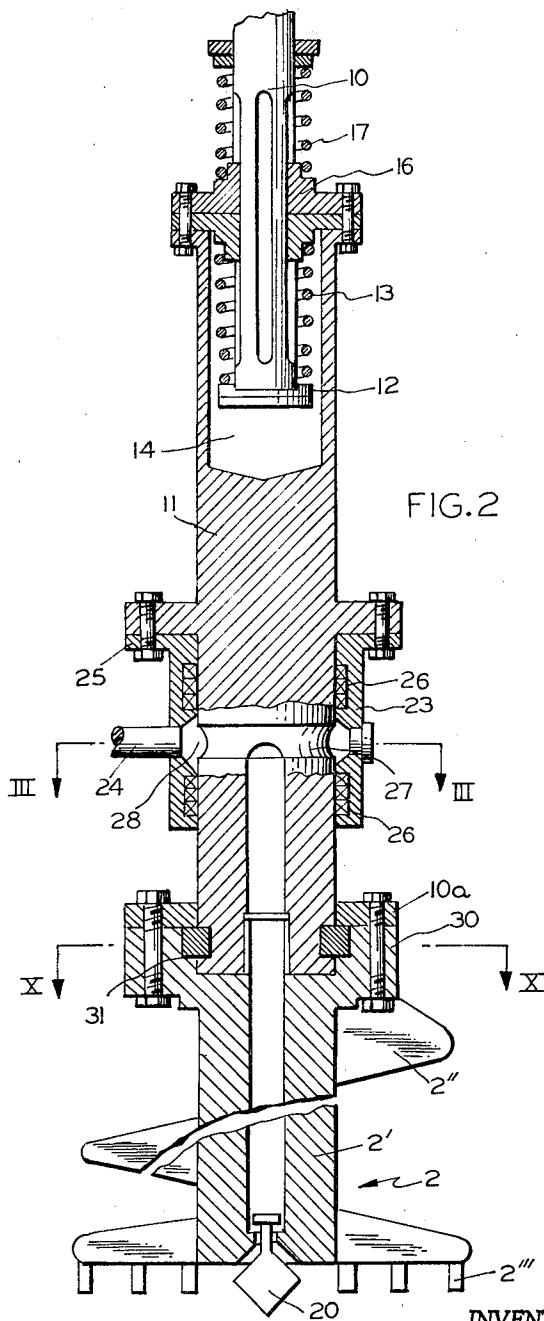


FIG. 2

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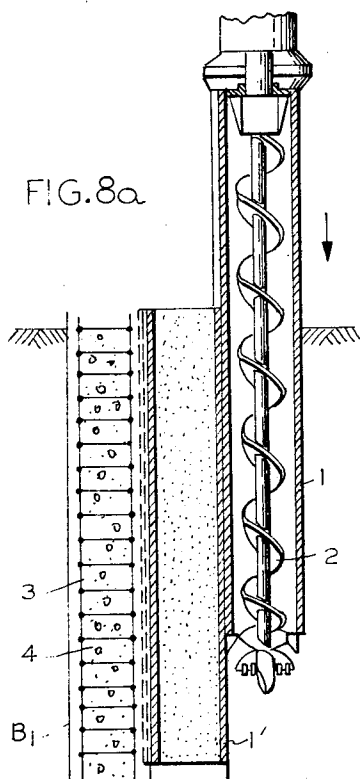
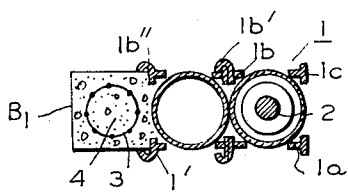
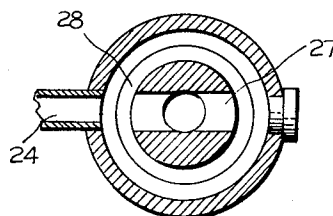
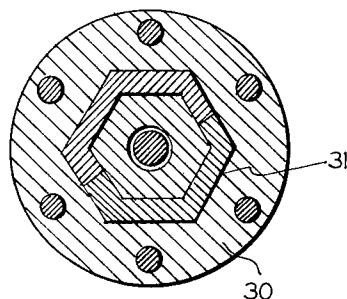
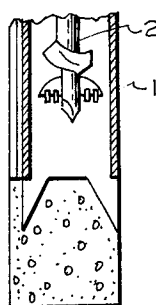
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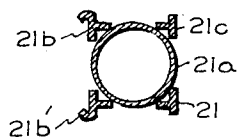


FIG. 4

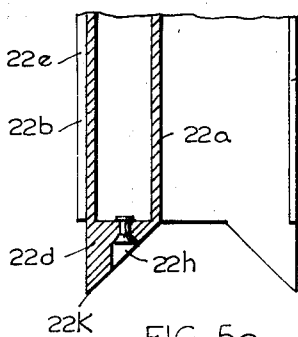


FIG. 5a

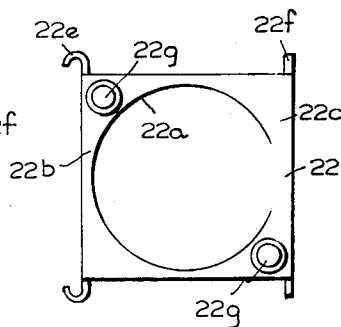


FIG. 5b

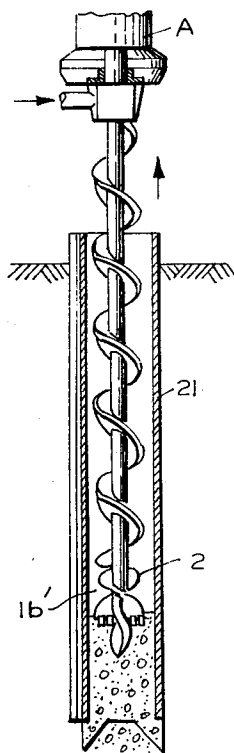


FIG. 6

FIG. 7a

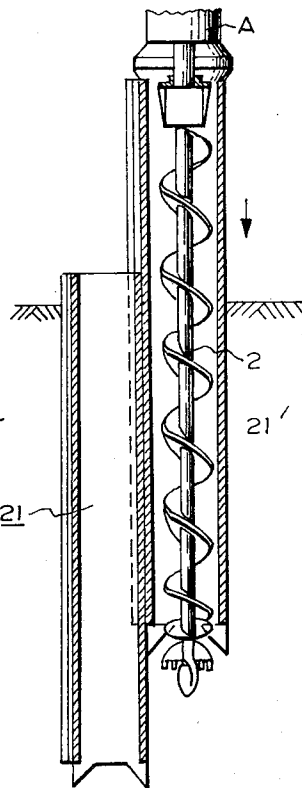
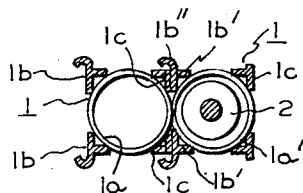


FIG. 7b

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METHOD AND APPARATUS FOR FORMING UNDERGROUND CONSTRUCTION IN SITU

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Continuation-in-part of application Ser. No. 552,308,
May 23, 1966. This application Nov. 20, 1968, Ser. No.
777,216

Int. Cl. E02d 5/34, 5/00, 7/00

U.S. Cl. 61—53.64

10 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus for forming an underground construction such as a pile or one element of a wall. A casing is first driven into the ground using an auger and vibrating means, and preferably forcing water or liquid into the hole being formed ahead of the auger and conducting the soil excavated at the bottom of the hole up the spiral blade of the auger along with the water or other liquid. Thereafter, and before all of the earth is forced out of the auger, mortar is forced into the casing through a conduit in the auger or in the casing under pressure, the auger and the earth in the blade thereof acting as a plug against which the pressure can be exerted. Either the auger alone or the auger and casing together can be withdrawn while continuing to vibrate both the auger and the casing. Thereafter a reinforcing cage can be lowered into the mortar. Where a wall is to be built, further casings are placed side by side.

This application is a continuation-in-part of application Ser. No. 552,308, filed May 23, 1966 and now abandoned.

The present invention relates to an improved method and apparatus for building underground constructions, such as walls and piles, in situ, and more particularly to an improved method for building walls and piles underground by utilizing a vibrating means to vibrate an auger and a casing used to form the hole in which the wall or pile is to be built.

One object of the present invention is to provide a simple and improved method and apparatus for building underground walls and piles in situ.

Another object of the present invention is to provide an economical method and apparatus for building underground walls and piles.

A further object of the present invention is to provide an easy method for building underground walls and piles by utilizing casings which have been slightly modified so as to be suitable for carrying out the present invention.

A still further object of the present invention is to provide an improved method for building underground walls in a continuous operation by employing at least a pair of relatively movable casings in conjunction with a shaft excavator such as a vibrating auger.

It is a still further object of the present invention to provide an improved method and apparatus for building underground walls and piles in which pressure grouting of mortar or concrete into the holes formed in the ground can be carried out while withdrawing the shaft excavator only or while withdrawing both the shaft excavator and the casing.

Still another object of the present invention is to provide an improved method and apparatus for forming underground piles and walls in which, after the casings have been placed in the ground, pressure grouting while vibrating the casing can be performed, and in which vibration of the casing can be carried out while withdrawing the casing from the ground.

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The apparatus according to the invention which is used to drive casings into the ground and which is also used in certain of the pressure grouting steps comprises an earth auger having driving means connected directly thereto and having vibrating means connected thereto through a spring connection. The vibrating means also bears directly on a casing to be driven into the ground. Either the auger or the casing can have conduit means as a part thereof through which water or other liquid can preferably be forced during the operation of driving the casing into the ground, and through which mortar or concrete can be forced when pressure grouting is carried out to fill the casing with mortar or concrete.

In carrying out the method of forming a pile or one element of a wall according to the invention, the casing is first driven into the ground using the auger and vibrating means, and preferably forcing water or liquid into the hole being formed ahead of the auger and conducting the earth removed at the bottom of the hole up the spiral blade of the auger along with the water or other liquid. Thereafter, and before all of the earth is forced out of the auger, mortar is forced into the casing through the conduit in the auger or in the casing under pressure, the auger and the earth in the blade thereof acting as a plug against which the grouting pressure can be exerted. Either the auger alone or the auger and casing together can be withdrawn while continuing to vibrate both the auger and the casing. Thereafter, a reinforcing cage can be lowered into the mortar.

Where a wall is to be built, a sufficient number of casings (usually four or five) are driven using the last driven casing as a guide before they are withdrawn. Then, after the first casing has been withdrawn and mortar has been grouted therein, as is described above, it is driven down along the last driven casing on the other end using the last driven casing as a guide. These steps are repeated until the wall is completed.

The invention will now be described in greater detail in connection with the accompanying drawings, in which:

FIG. 1 is a side elevation view, partly in section, of an auger and casing driving apparatus;

FIG. 2 is an enlarged elevation view, partly in section and partly broken away, showing the auger and coupling to the driving and vibrating means;

FIG. 3 is a cross section view of the swivel which can be used with the present invention, and taken on line III—III of FIG. 2;

FIG. 4 is a cross sectional view of one form of casing which can be used with the present invention;

FIGS. 5a and 5b are an elevation view partly in section and a top plan view, respectively, of an improved form of casing which can be used with the present invention;

FIG. 6 is a sectional elevation view showing one way of carrying out pressure grouting for forming an underground pile or wall according to the invention;

FIGS. 7a and 7b are a sectional elevation view and a transverse sectional view, respectively, of a second step of forming an underground wall according to the present invention;

FIGS. 8a and 8b are a sectional elevation view and a transverse sectional view, respectively, of a further step of forming an underground wall according to the present invention;

FIG. 9 is a view similar to that of FIG. 6 showing another way of carrying out pressure grouting for forming an underground pile or wall according to the invention; and

FIG. 10 is a cross sectional view of the hexagonal split cotter which can be used with the present invention, taken on line X—X of FIG. 3.

As shown in FIGS. 1 and 2, the shaft excavator, which

can be conveniently employed for carrying out the novel method, generally comprises a drive mechanism A. The drive mechanism A includes an electric motor *a* adapted to be actuated by any suitable actuating means (not shown), an eccentric vibromotive device *b* operatively connected through a suitable power transfer means such as a belt to the motor *a* and adapted to be driven by the motor, and an auger drive device *c* operatively connected through a suitable power transfer means such as a separate belt to the motor and adapted to be driven by the motor independently of the vibromotive device *b*. A cylindrical air chuck or other easily actuated coupling device *d* is provided beneath the drive mechanism A, and this chuck is adapted to removably secure a casing (the construction of the casing will be explained in detail hereinafter) to the drive mechanism. The auger drive device *c* has a depending output shaft 10 and the lower end of the output shaft is connected to a rotary auger 2 by a vibration damping coupling.

The lower end of the shaft 10 and abutment member 12 are housed in a grease box 14 in the upper end of the coupling member body 11. A flange member 16 is attached over the end of the grease box 14. The coupling further comprises a lower spring 13 around the shaft 10 and extending along the shaft, being confined between the abutment member 12 and the flange member 16, and an upper spring 17 around the shaft 10 and extending along the shaft, being confined between the flange member 16 and the housing of the driving device. The flange 16 and shaft 10 are splined and flange 16 is slidable along the shaft 10 so that the coupling member body 11 is free to move up and down relative to the shaft 10, its movement being damped by the lower and upper springs 13 and 17. A flange 10a on the lower end coupling member body 11 is connected to an upper flange 30 of the auger 2. A swivel base 23 is attached around the damping coupling, and mortar can be pressure grouted from a mortar inlet pipe 24 provided therein through an opening 27 and a mortar recess 28 in the coupling into the central hollow shaft 2' of the auger 2.

A hexagonal split cotter 31, shown clearly in FIG. 10, is provided in the lower part of the coupling member body 11 for transmittal of torque from the coupling to the auger and to permit easy mounting and removal of the swivel base 23.

The auger shaft 2' has a spiral blade 2'' thereon and is provided at its tip or lower end with a cutter means 2''' for cutting away earth as the auger is driven into the ground by the eccentric vibromotive device *b* and auger drive device *c*. The auger shaft 2' is preferably hollow, for a purpose which will be described hereinafter, and it has at its closed lower end a one-way valve 20 which prevents flow from below the auger back into the hollow shaft 2'.

When the novel method is carried out, at least two casings must be employed when making a wall and one must be employed when making a pile. Several forms of casings can be employed. Since the several casings employed in making a wall have the same construction, it will be sufficient to describe the construction of only one such casing. One form of casing is shown in section in FIG. 4. The casing 21 generally comprises a hollow cylindrical body 21a, and the body has two pairs of substantially right angle section corner frames 21b and 21c, equally angularly spaced around the outer periphery of the body 21a. These pairs of corner frames 21b and 21c extend along substantially the full length of the body 21a and are rigidly secured to the body by any suitable means such as welding. One arm of each of the first pair of corner frames 21b extends beyond the other arm of the associated corner frame and hooks outwardly with a curvature, as shown at 21b', while one arm of each of the second pair of corner frames 21c also extends beyond the other arm of the associated corner frame, but is not bent as in the case of the corner frames 21b. The purpose of provision of the

particular construction of the one arms of the respective angular section corner frames will be clear from the explanation of the operation of the shaft excavator set forth hereinafter. The casing 1 further has the upper end open to allow soil discharge adjacent to the upper end thereof so that removed soil can continuously be taken out of the casing during the operation. The lower ends of the corner frames 21b and 21c are pointed to make them penetrate the earth more easily.

Another form of casing, preferably for use with an auger which has a solid shaft, is shown in FIGS. 5a and 5b. The casing 22 has a hollow cylindrical body 22a and a generally square outer casing 22b which is closed at both the top, by a wall 22c, and at the bottom, by a wall 22d. Hook shaped guide members 22e are provided on one side of the outer casing 22b, and straight guide members 22f are provided on the other side of the casing 22b. Openings 22g are provided in the top walls 22c, and one-way valves 22h are provided in the bottom wall 22d. As with the form of casing shown in FIG. 4, the lower ends of the casing are pointed at 22k.

In carrying out the novel method, the above-mentioned shaft excavator is hung from a suitable mounting mechanism such as a scaffolding (not shown) for upward and downward movement along the guide pillar of the scaffolding (not shown). Then a casing 21 is secured to the drive mechanism A by the air chuck *d*. When the electric motor *a* is actuated, the eccentric vibromotive device *b* is actuated from the motor through its associated power transfer means and at the same time the auger drive device *c* is also actuated from the same motor and its associated transfer means independently of the vibromotive device. The combined effect of the weight of the drive mechanism A and the vibration produced by the actuated vibromotive device *b* drives the casing 1 deep into the ground while the rotating auger drive device *c* causes the auger 2 to descend with the casing while rotating therein. If necessary, water or other drilling liquid may be forced into the vicinity of the lower end of the auger through the hollow shaft 2' and the valve 20 at the lower end, or through the spaces at the corners of casing 22 and valve 22h.

The vibrations of the vibromotive device *b* are transmitted directly to the casing through the air chuck *d*. The vibrations are transmitted to the auger shaft 2' through the damping coupling. The vibrations pass through the upper spring 17 to the flange 16 while the spring 18 damps the vibrations between the flange 16 and the drive shaft 10 so that the vibrations are not transmitted back to the drive means. As a result of the spring connection between the vibromotive device and the auger shaft 2', the auger shaft, and hence the blade, and the casing 21 vibrate at different frequencies. Therefore, the excavated soil being conveyed upwardly within the casing 21 between the spires of the auger blade 2'' will be subjected to different vibration frequencies, being vibrated at one frequency where it contacts the blade and the shaft, and at another frequency where it contacts the casing. As a result, the excavated soil will be kept free within the casing and will be conveyed much better than if both the auger and the casing were vibrated at the same frequency. A similar improvement is produced at the excavating end of the casing and auger, the earth being acted on by the auger tip vibrating at one frequency and the bottom edge of the casing vibrating at another frequency.

Thus it will be understood that resistance which the casing 21 will encounter as the casing is driven into the ground will be greatly reduced and the driving of the casing can be greatly accelerated because the vibration transmitted to the casing 21 eliminates the cohesive force of soil and the vibrating auger 2 discharges removed soil out of the top casing opening during the driving of the casing 21 into the ground. The auger 2 also serves to reduce the frictional force of the driven casing 21 against the surrounding soil as it digs out the ground in the vicinity of the fore end of the casing. It is preferred that the out-

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side diameter of the auger blade be only slightly less than the inside diameter of the casing 21, so that the excavated soil or other materials removed at the bottom of the auger will be carried up the casing and substantially no material will remain in the casing.

One preferred method of filling the casing with a filling material is to carry out pressure grouting. When the casing 21 has reached the desired depth, mortar is forced through the auger or the casing into the space at the bottom of the casing and the auger. The mortar thus forced in will fill the crevices around the bottom of the casing and auger which have been formed by the action of the auger and the casing being driven, and will even force the excavated soil in the blade of the auger part way up the auger. This initial pressure grouting is continued until a head of mortar is built up in the casing. Then the vibromotive device *b* and preferably auger drive means *c* are driven and the casing and the auger are slowly withdrawn as the mortar is continuously fed into the space left by the casing and auger, as shown in FIG. 9. It is understood that there is no need of joint or disjoint operation for this performance. Alternatively, when the casing 22 of FIGS. 5*a* and 5*b* is used, a simple mortar pipe can be coupled to the opening 22*g* at the top thereof for forcing mortar down the space within the outer casing 22*b*. Then the vibromotive device is driven, and the casing and the auger are slowly withdrawn as the mortar is continually fed into the space left by the casing and auger, as shown in FIG. 9.

Alternatively, the auger can be partially withdrawn while vibrating the casing and the auger, and while forcing mortar into the casing under pressure, as shown in FIG. 6, and after a head of mortar has been built up the auger and casing are simultaneously withdrawn while mortar is fed under pressure into the space left by the casing and auger.

Just as the mortar under pressure will fill the crevices around the bottom of the casing and the auger, and thus increase the bearing support function of the resulting underground element, so also will the mortar under pressure be forced into intimate contact with the earth surrounding the space left when the auger and casing are withdrawn. This pressure in combination with the vibration of the mortar through the auger and casing serves to greatly increase the friction support function of the resulting underground construction. The vibration of the auger and casing also frees the casing from the surrounding earth so that it can be withdrawn more easily, and together with the pressure also increases the density of the mortar. It is not necessary to use bentonite as in the prior art to coat the walls of the hole when the casing has been removed. The method is useful for building underground constructions in sandy soil as well as hard soil.

After the auger and casing have been withdrawn and the hole filled with mortar, if it is desired to provide a reinforcement for the underground construction, a cage of reinforcing rods is lowered into the mortar filling the hole.

If the underground element is to be made of reinforced concrete instead of mortar, the pressure grouting as described above cannot be carried out in the same way as with mortar. Instead, after the casing has been driven to a sufficient depth, the auger is withdrawn and the reinforcing rod cage is inserted into the casing. A concrete conveying conduit is then inserted into the casing, the conduit extending to near the bottom of the casing. Concrete is then forced into the bottom of the casing through the conduit to a level above the level of the end of the conduit for building up a head of concrete. Then, while continuing to feed the concrete under pressure and withdrawing the conduit, the casing is withdrawn and simultaneously vibrated. The space occupied by the casing and surrounding the reinforcing cage is filled with concrete as the casing and conduit are withdrawn.

It will be seen that the single underground construction just described will function by itself as a pile. In actual

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practice it has been found that the process described above has increased the strength of such piles sufficiently so that only 80% as many are needed as compared with piles formed by conventional methods.

The method of forming the underground construction can be carried out to produce a series of side by side elements which together form an underground wall. When the first casing has been driven into the ground to the desired depth, instead of carrying out pressure grouting with mortar as described above, the auger is withdrawn, and a second casing 21', which has the same construction as the first casing 21, is secured to the excavator 10 by means of the air chuck *d* in the same manner as the first casing 21. Then the electric motor *a* is actuated so as to drive the vibromotive device *b* and auger drive means *c* in the same manner as in the case of the first casing 21. The actuation of the auger drive device *c* causes the auger 2 to rotate in the casing while digging out the ground, and discharging excavated soil out of the top of the casing, and the actuation of the vibromotive device *b* drives the second casing 21' deep into the ground in the same manner as the first casing 21. However, as the second casing 21' is driven, the outwardly bent ends of the arms 21*b*' of the first pair of the corner frames engage the adjacent arms 21*c* of the second pair of corner frames on the first casing 21 and slide down along the latter (see FIGS. 7*a* and 7*b*) to the same depth as the first casing. The second casing 21' is thus guided by and held in position in laterally close contact with the first casing 21. After the second casing has been driven to the predetermined depth side by side with the first casing, the auger 2 is pulled out of the second casing 21'. Then the auger is again placed in the casing 21. The pressure grouting as described above is then carried out in the casing 21, at the end of which step the casing 21 has been replaced with an underground construction of mortar 4 and adjacent to it is a hollow casing 21'. Thereafter, if desired, cages of reinforcing rods can be inserted into the mortar.

Thereafter, the first casing 21 is secured to the excavator 10 and again it is driven into the ground along the casing 21' as a guide, as shown in FIGS. 8*a* and 8*b*, in the same manner as the casing 21' was driven in along the casing 21. When it has been driven to the required depth, the auger is withdrawn, and the pressure grouting step is carried out for the second casing 21'. Then the second casing is driven in using the first casing for a guide, the first casing is filled with mortar by a pressure grouting step, and the elements are successively formed in this manner until there are sufficient elements to form an underground wall of the desired length.

It will be understood that the above-mentioned procedure can be so modified as to drive a required number of casings first and then follow the same steps with the first and the last casings as if they were the first and the second casings in the above description. Usually, depending upon the soil condition and the configuration of the casing, four or five casings are required to prevent lateral slide of those casings possibly caused by the drilling pressure.

Since the casings have a substantially square cross sectional shape, and the sides of the finished elements will abut each other, it is seen that there is formed a substantially rectangular cross section wall. Moreover, because the elements can be formed quite rapidly, particularly where the earth is relatively soft and it does not take long to drive a casing to the required depth, the mortar in the individual elements will be jointed to the mortar in the adjacent elements before it sets, thereby forming a strong integral wall.

Many variations on this method will be readily apparent to those skilled in the art. For example, it would be possible within the scope of the method of the present invention to leave the auger in the first casing and use a second auger to drive the second casing, or even to leave the auger with the shaft excavator apparatus at-

ached thereto and use a completely different excavator apparatus and auger for the second casing. This, of course, requires more equipment than will normally be available on any given job.

The sequence of operations is slightly different where the pressure grouting step is not used, but instead concrete, i.e. a mortar containing a relatively large aggregate, is used. In this instance, the auger is not reinserted into the casing when it is to be filled with concrete since the concrete must be poured around the reinforcing cage. When the auger is removed, the reinforcing cage 3 is placed in position in the casing, and concrete is poured into the casing around the cage. These two steps can be carried out after the second casing is driven, while using the first casing as a guide. Thereafter, after the second casing is driven and preferably filled with concrete, the first casing can be removed from around the poured reinforced concrete, preferably while applying vibrations to the casing by the vibromotive device *b*. The first casing is driven again using the second casing as a guide, and the steps are repeated in the same way, but with the differences as described, in order to produce a wall of reinforced concrete.

Also in this case, a required number of casings can be used before removing the first casing from around the concrete. The first casing is driven again using the last driven casing as a guide.

It is thought that the invention and its advantages will be understood from the foregoing description, and it is apparent that various changes may be made in the form, construction and arrangement of the parts without departing from the spirit and scope of the invention or sacrificing its material advantages, the forms hereinbefore described and illustrated in the drawings being merely preferred embodiments thereof.

What is claimed is:

1. A method of forming an underground construction *in situ*, comprising the steps of driving a hollow casing into the ground by vibrating the casing at a first frequency while applying a force to one end thereof, and simultaneously driving an auger within the hollow casing or excavating soil from the bottom of the casing and conducting it upwardly out of the top of the casing while vibrating the auger at a different frequency from said first frequency, and when the casing has been driven to sufficient depth, forcing mortar into the space at the bottom of the casing and the auger, and thereafter, while again vibrating the casing and auger at different frequencies and while continuing to force mortar into the space beneath the auger, withdrawing the auger and casing together, whereby the space occupied by the casing and auger is filled with mortar as the casing and auger are withdrawn, and an underground construction is formed.

2. A method as claimed in claim 1 further comprising the step of inserting into the mortar of the underground construction a reinforcing cage of reinforcing rod.

3. A method as claimed in claim 1 further comprising the step of partially withdrawing the auger while vibrating it and feeding mortar into the space beneath it prior to simultaneously withdrawing the auger and the pile.

4. A method as claimed in claim 1 further comprising the steps of, after the casing has been driven to a sufficient depth, withdrawing the auger, carrying out the same steps for driving a second casing along said first casing as a guide, withdrawing the auger from the second casing, inserting it in the first casing, carrying out the steps of withdrawing the first casing and the auger while filling the space left thereby with mortar, carrying out the same steps for driving the first casing along the second casing, withdrawing the auger from the third casing and reinserting it into the second casing, withdrawing the second casing and the auger while filling the space left thereby with mortar in the same manner as the first casing was filled, and repeating the sequence of steps of driving a

casing and filling the space left by the preceding casing with mortar, whereby an underground wall is formed.

5. A method as claimed in claim 4 further comprising the steps of inserting a reinforcing rod cage into the mortar of each element of the wall after the mortar has been forced into place.

6. A method as claimed in claim 4 in which the step of withdrawing the auger from the driven casing includes the step of vibrating the auger during withdrawal.

7. A method of forming an underground construction *in situ*, comprising the steps of driving a hollow casing into the ground by vibrating the casing at a first frequency while applying a force to one end thereof, and simultaneously driving an auger within the hollow casing for excavating soil from the bottom of the casing and conducting it upwardly out of the top of the casing while vibrating the auger at a different frequency from said first frequency, and when the casing has been driven to a sufficient depth, withdrawing the auger, inserting into the casing a reinforcing cage of reinforcing rod, inserting a concrete conveying conduit into the casing and extending it to adjacent the bottom of the casing, forcing concrete into the bottom of the casing and to a level above the level of the end of the conduit for building up a head of concrete, and while continuing to feed the concrete under pressure, simultaneously vibrating and withdrawing the casing and withdrawing the conduit from the hole formed by the casing, whereby the space occupied by the casing is filled with concrete around the reinforcing cage as the casing and concrete conduit are withdrawn, and an underground construction is formed.

8. A method as claimed in claim 7 further comprising the steps of carrying out the same steps for driving a second casing along said first casing as a guide, carrying out the same steps of filling the second casing with concrete around a reinforcing cage, and repeating the sequence of steps of driving a casing and filling the casing with concrete whereby an underground concrete wall is formed.

9. A method of pressure grouting for forming an underground construction, comprising forcing mortar into the space beneath the end of an auger which has been driven into the ground within a casing driven simultaneously with the auger to a desired depth, and thereafter while vibrating the casing and auger at different frequencies and while continuing to force mortar into the space beneath the auger, withdrawing the auger and casing together, whereby the space occupied by the casing and auger is filled with mortar as the casing and auger are withdrawn, and an underground construction is formed.

10. An apparatus for driving a casing into the ground for forming an underground construction, said apparatus comprising a drive mechanism having a motor means, a vibromotive device driven by said motor means and an auger drive device driven by said motor means, a vibration damping coupling connected to said auger drive device and said vibromotive device, an auger connected to said coupling, said damping coupling damping vibrations transmitted to said auger, and an easily releasable chucking device on said vibromotive device for chucking a casing to be driven and transmitting vibrations to said casing, said vibration damping coupling comprising a coupling body member having a recess in the upper end thereof and having attaching means at the lower end thereof for attachment to the auger, a flange member over the end of the recess, said auger drive device having a shaft extending into said recess through said flange, an abutment member on the end of said shaft in said recess, spring means extending between said abutment member on the end of said shaft in said recess, spring means extending between said abutment member and said flange, and further spring means extending from said flange and adapted to abut the vibromotive device.

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U.S. Cl. X.R.

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