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Bodine

[11] **3,783,954**

[45] **Jan. 8, 1974**

[54] **SONIC RESONANT DRIVING OF A COLUMN MEMBER UTILIZING COMPLIANT RESONATOR ELEMENT**

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[52] **U.S. Cl.** **173/49**

[51] **Int. Cl.** **E02d 7/18**

[58] **Field of Search** 173/49; 175/56; 299/14, 37

[56] **References Cited**

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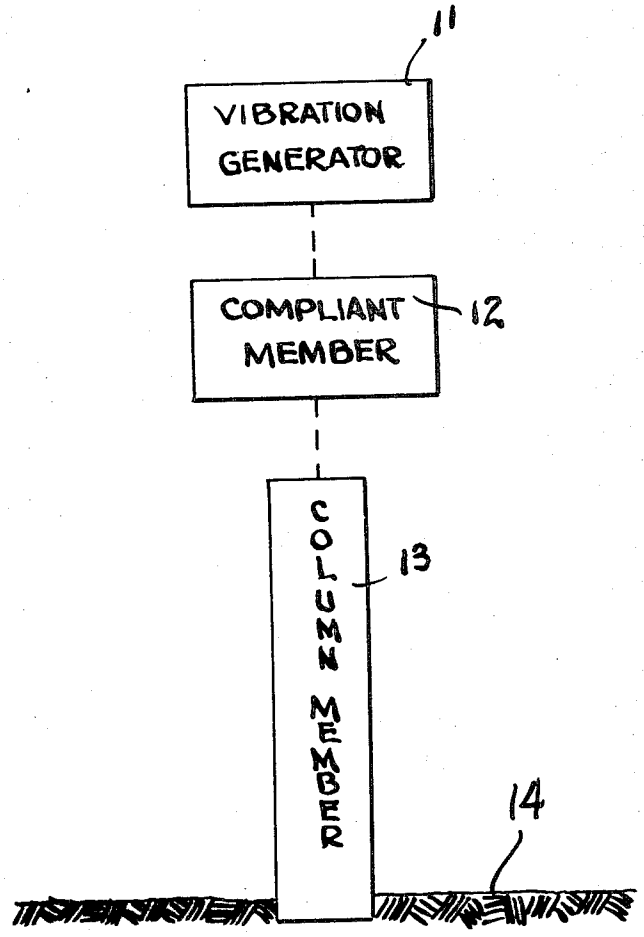
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Primary Examiner—Werner H. Schroeder
Attorney—Edward A. Sokolski et al.

[57] **ABSTRACT**

A column member which may comprise a piling, casing, shaft or the like, is driven into the ground by means of sonic energy generated by a vibration generator. The vibration generator, which may comprise an orbiting mass oscillator, is coupled to the column member by a high impedance compliant element, the compliancce of this element and the mass of the column forming a resonant vibration system. The vibration generator is operated at a frequency such as to cause resonant vibration of the system with the compliant element providing lumped constant compliance and the column member providing lumped constant mass in such system.

6 Claims, 8 Drawing Figures



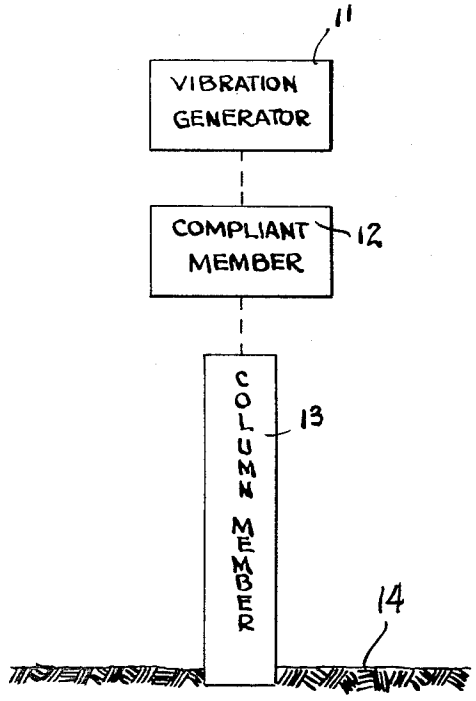


Fig. 1

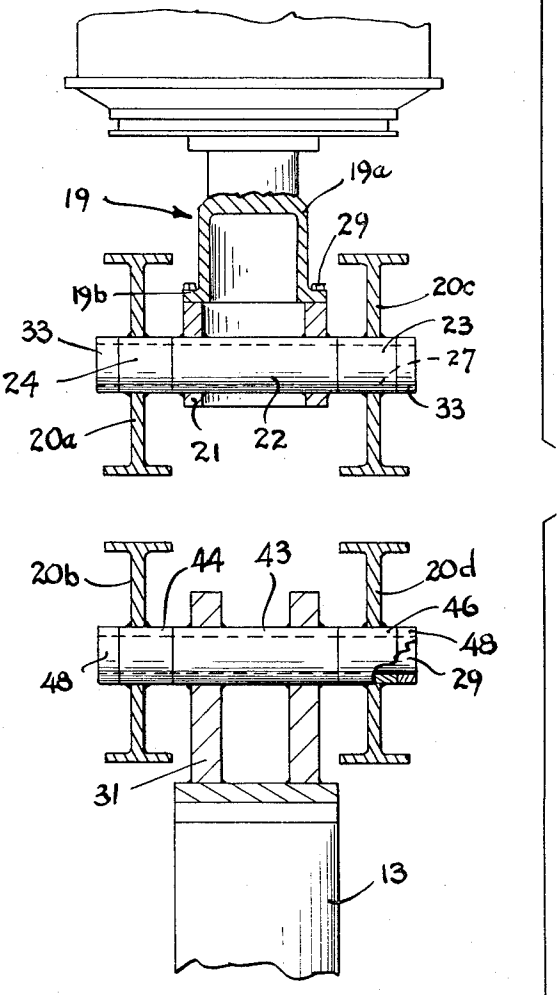


Fig. 4

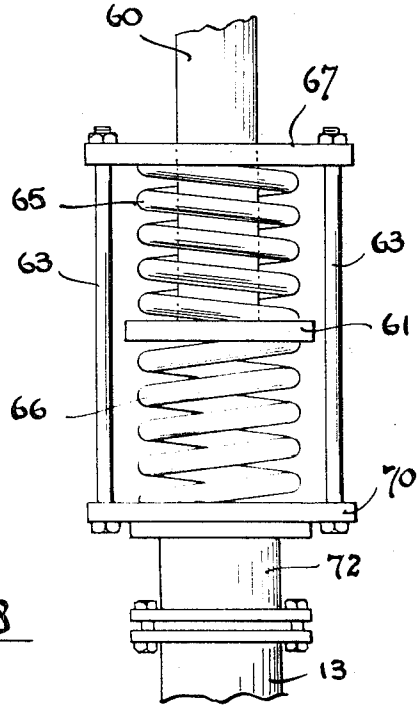


Fig. 8

Fig. 2

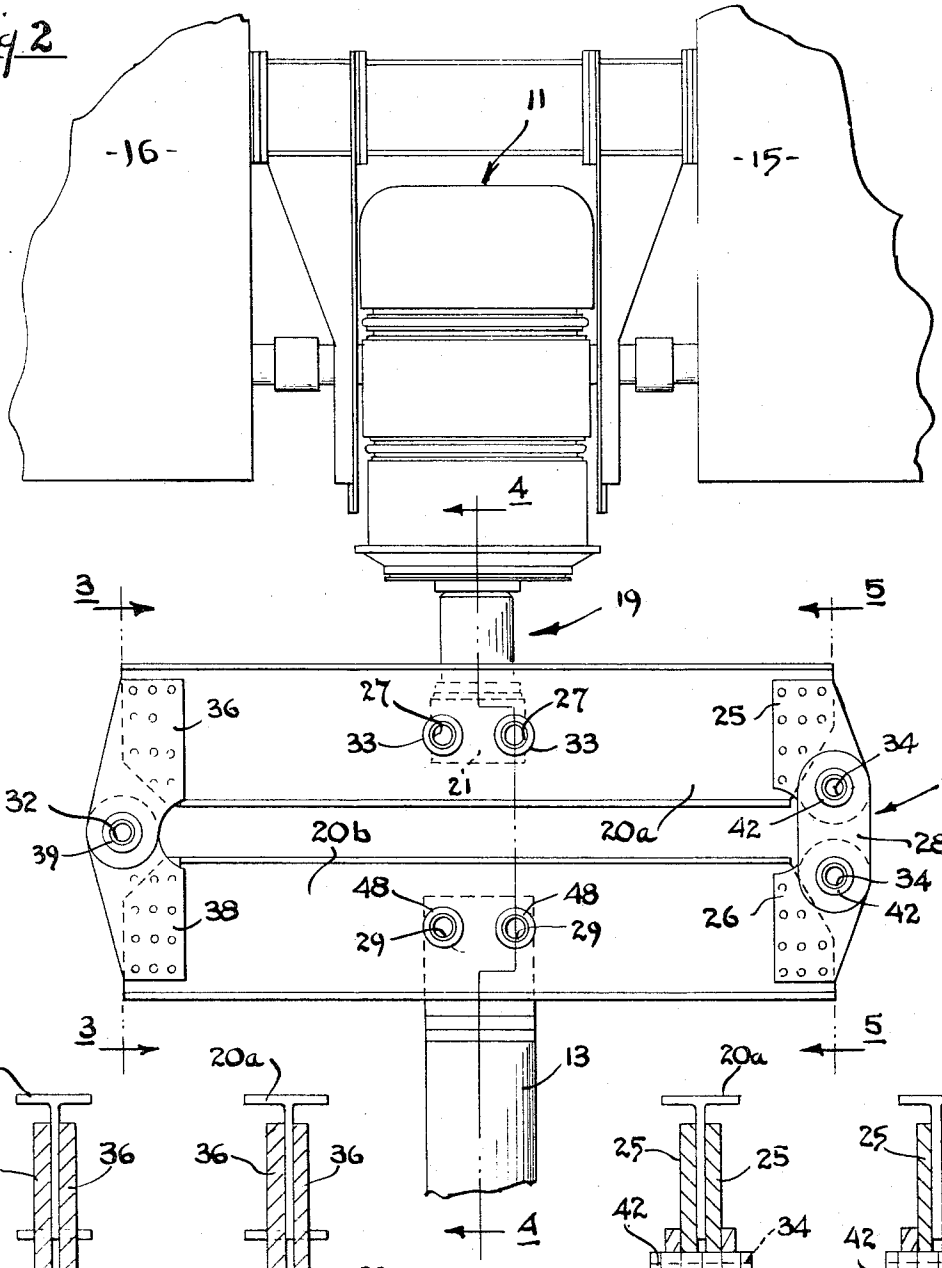


Fig. 3

Fig. 5

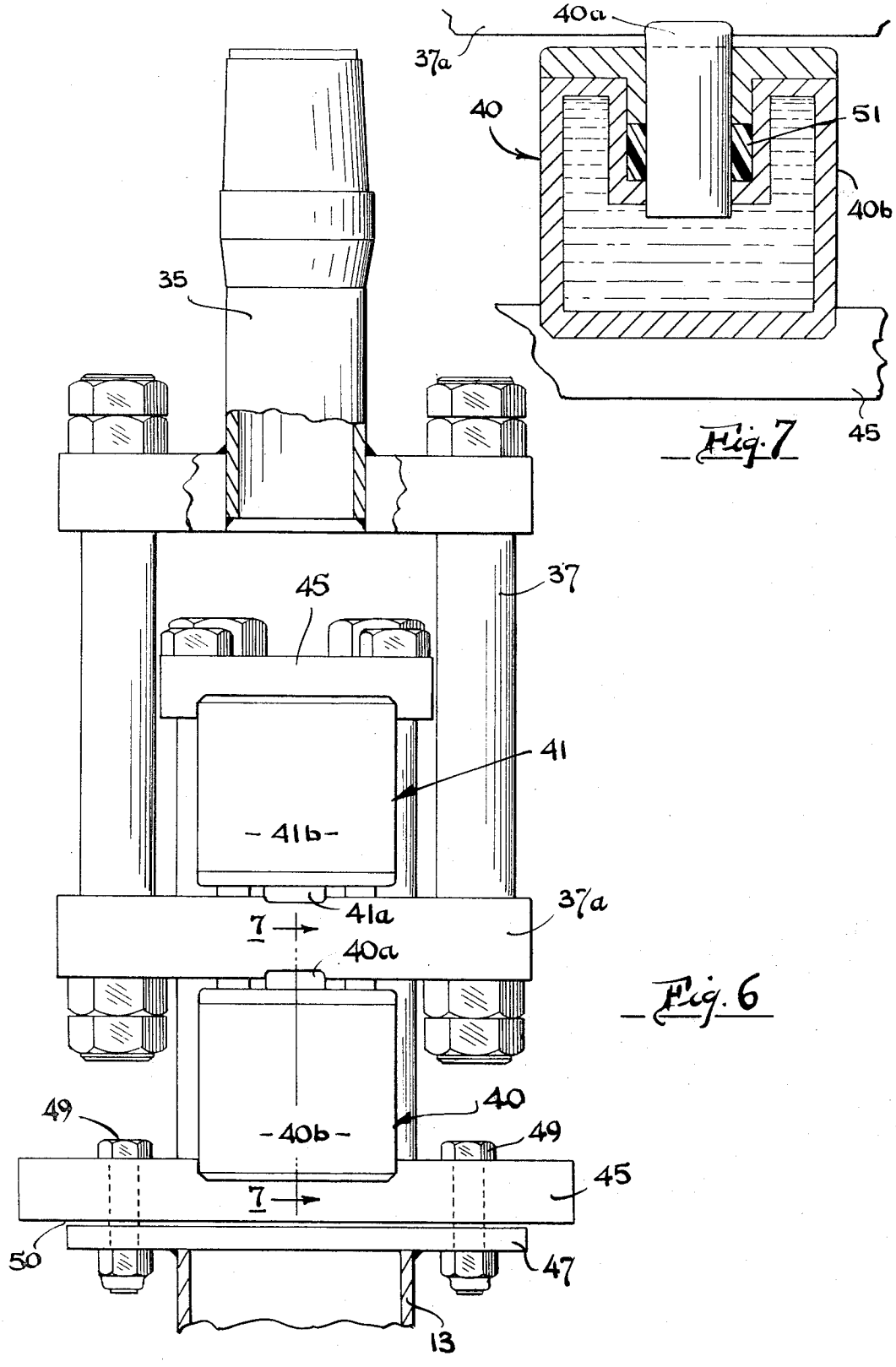

40a
37a
40
51
40b
35
45
37
41
41b
41a
37a
7
40a
40
40b
49
49
45
7
50
47
13

Fig. 7

Fig. 6

SONIC RESONANT DRIVING OF A COLUMN MEMBER UTILIZING COMPLIANT RESONATOR ELEMENT

This invention relates to means for driving column members, such as pilings and the like, into the ground and more particularly to such means utilizing sonic energy in achieving the desired end results.

In my U.S. Pat. No. 3,291,227, the driving of pilings into the ground by means of sonic energy generated with an orbiting mass oscillator is described. In the device of this patent, the oscillator is operated at a frequency such as to set up resonant elastic standing wave vibration in the piling. By utilizing such resonant vibration, highly efficient driving action is attained. There are certain situations, however, where it is impossible or impracticable to elastically vibrate the piling member or other such member being driven. First, there are certain situations where the piling member is of a fragile material such as concrete which cannot stand the elastic resonant stresses involved in standing wave vibration without fracturing. In such situations it is therefore impossible to utilize the aforementioned prior art technique efficiently without hazarding damage to the member being driven. Further, where the column members are relatively short in length, such as in situations involving large diameter caissons and sheet pilings, the natural longitudinal mode resonant vibration frequency of the member to be driven is too high to achieve efficient driving action into the ground (frequencies in the range of 20–200 cps generally being preferred).

The system of this invention overcomes the shortcomings of the prior art in dealing with the aforementioned types of situations by utilizing a lumped constant compliant element which is interposed between the vibration generator and the column member being driven into the ground. This compliant member provides a lumped constant compliance which operates in conjunction with a column member acting as a lumped constant mass, to form a resonant vibration system. The column thus is not elastically vibrated at its natural vibration frequency and therefore relatively short column members can be used with an appropriate compliant element to resonantly vibrate therewith at a frequency for optimum driving action. Further, in view of the fact that the column member is not elastically vibrated but rather bodily vibrated as a unitary member, it is not subjected to the elastic stresses involved in resonant elastic vibration. This avoids the hazard of fracturing frangible column members such as concrete pilings and the like.

It is therefore an object of this invention to facilitate the sonic driving of frangible column members.

It is another object of this invention to improve the efficiency of the sonic resonant driving of relatively short column members.

Other objects of this invention will become apparent as the description proceeds in connection with the accompanying drawings, of which:

FIG. 1 is a schematic drawing illustrating the basic operation of the device of the invention,

FIG. 2 is an elevational drawing illustrating one embodiment of the device of the invention,

FIG. 3 is a cross-sectional view taken along the plane indicated by 3—3 in FIG. 2,

FIG. 4 is a cross-sectional view taken along the plane indicated by 4—4 in FIG. 2,

FIG. 5 is a cross-sectional view taken along the plane indicated by 5—5 in FIG. 2,

FIG. 6 is an elevational view illustrating a second embodiment of the device of the invention with partial cutaway section,

FIG. 7 is an elevational view with partial cutaway section of a third embodiment of the device of the invention; and

FIG. 8 is an elevational view of a fourth embodiment of the device of the invention.

Briefly described, the device of the invention comprises a high impedance compliant element which is interposed between a vibration generator and a column member to be driven into the ground, the compliant element and the column member providing the compliance and the mass for a resonant vibration system. The vibration generator, which may comprise an orbiting mass oscillator, is run at a frequency such as to cause resonant vibration of the vibration system, the column member being resonantly vibrated along its longitudinal axis to effect the driving thereof into the ground. The compliant member is preferably designed so that it can be readily attached and detached in the field so it can be utilized as needed where the situation demands. In one embodiment, the compliant member is formed by a bending beam structure; in another embodiment, it is formed by a hydraulic spring device; and in a third embodiment, it is formed by heavy duty coil springs.

It has been found most helpful in analyzing the operation of this invention to analogize the acoustically vibrating circuit utilized to an equivalent electrical circuit. This sort of approach to analysis is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonics" by Hueter and Bolt, published in 1955 by John Wiley and Sons. In making such an analogy, force F is equated with electrical voltage E, velocity of vibration u is equated with electrical current i, mechanical compliance C_m is equated with electrical capacitance C_e, mass M is equated with electrical inductance L, mechanical resistance (friction) R_m is equated with electrical resistance R and mechanical impedance Z_m is equated with electrical impedance Z_e.

Thus, it can be shown that if a system is vibrated by means of an acoustical sinusoidal force $F_o \sin \omega t$ (ω being equal to 2π times the frequency of vibration), that

$$Z_m \; 32 \; R_m + j[\omega M - (1/\omega C_m)] = F_o \sin \omega t/u \qquad (1)$$

Where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance Z_m is equal to the mechanical resistance R_m, the reactive impedance components ωM and $1/\omega C_m$ cancelling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, power factor is unity, and energy is more efficiently delivered to a load to which the resonant system may be coupled. It can also be shown that the resonant vibration frequency, f of the system, (ω being equal to $2\pi f$) is as follows:

$$f = 1/2\pi \sqrt{MC_m} \qquad (2)$$

It is important to note the significance of the attainment of high acoustical Q in the resonant system being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of power.

As for an equivalent electrical circuit, the Q of an acoustically vibrating circuit is defined as the sharpness of resonance thereof and is indicative of the ratio of the energy stored in each vibration cycle to the energy used in each such cycle. Q is mathematically equated to the ratio between ωM and R_m. Thus, the effective Q of the vibrating circuit can be maximized to make for highly efficient high-amplitude vibration by minimizing the effect of friction in the circuit and/or maximizing the effect of mass in such circuit.

It is also to be noted that orbiting mass oscillators are utilized in the implementation of the invention that automatically adjust their output frequency and phase to maintain resonance with changes in the characteristics of the load. Thus, in the face of changes in the effective mass and compliance presented by the load with changes in the conditions of the work material as it is sonically excited, the system automatically is maintained in optimum resonant operation by virtue of the "lock-in" characteristic of Applicant's unique orbiting-mass oscillators. Furthermore in this connection the orbiting mass oscillator automatically changes not only its frequency but its phase angle and therefore its power factor with changes in the resistive impedance load, to assure optimum efficiency of operation at all times. The vibrational output from such orbiting mass oscillators also tends to be constrained by the resonator to be generated along a controlled predetermined coherent path to provide maximum output along a desired axis.

Referring now to FIG. **1**, the basic operation of the system of the invention is schematically illustrated. Vibration generator **11** which may comprise an orbiting mass oscillator such as described in my aforementioned U.S. Pat. No. 3,291,227, is coupled to compliant element **12**, the compliant element **12** in turn being coupled to column member **13**. Column member **13** is positioned on the surface of the ground **14** for driving therein. Compliant element **12** has a very high stiffness value so that it and column member **13** form a resonant vibration system with the compliant element providing most of the compliance for such system and column member **13** providing most of the mass. Vibration generator **11** is operated at a frequency such as to cause resonant vibration of the system with the mass of column member **13** being effectively vibrated longitudinally on the "spring" formed by compliant element **12**. It is to be emphasized that in this system column member **13** ideally is subjected to no elastic vibration but rather experiences a longitudinal vibratory displacement. It is to be noted by reference to equation (2) that in this manner, even with a relatively large mass comprising the column member, that a relatively high resonant vibration frequency can still be attained by virtue of the high rate compliance provided by compliant element **12**. It is further to be noted that column member **13** can be of a relatively frangible material without a significant danger of fracturing in view of the fact that this member is not elastically vibrated.

Referring now to FIGS. **2–5**, one embodiment of the device of the invention is illustrated. In this embodiment a very stiff bending beam structure is utilized for the compliant element. Orbiting mass oscillator **11** comprises a pair of rotors which are driven in opposite directions by means of gasoline engines **15** and **16**. The oscillator may be of the type described in my aforementioned U.S. Pat. No. 3,291,227. The rotors of motors **15** and **16** are phased so as to produce vibrational energy along the longitudinal axis of column member **13**, which is to be driven into the ground. The housing of oscillator **11** is removably attached to upper beam section **20***a* of beam **20**, which forms the compliant member, by means of coupler unit **19**. As can best be seen in FIG. **4**, coupler unit **19** comprises a cylindrical member **19***a* which may be welded or otherwise fixedly attached to the casing of the oscillator. A ring-shaped flange **19***b* runs around the edge of coupler **19** and has a plurality of holes formed therein. Bolts **29** fit through the holes formed in flange **19***b* and are used to attach the coupler to cylindrical member **21** which is welded to sleeve member **22** which fits through apertures formed in member **21**. Beam section **20**a is welded to sleeve member **24** while beam section **20***c* is welded to sleeve member **23**. Sleeve members **22, 23** and **24** are joined together by means of associated pins **27** which fit therethrough and end caps **33**. The ends of beams **20***a* and **20***b* are attached together, and the ends of beams **20***c* and **20***d* are attached together, the central portions of these two beams being spaced apart from each other vertically. Pins **32** operating in conjunction with upper plates **36** and lower plates **38** are used to join one end of the beams together, the pins fitting through sleeves **39** which are fitted through apertures in the overlapping plates. Plates **36** are fixedly attached to beam sections **20***a* and **20***c*, as the case may be, while plates **38** are fixedly attached to associated beam sections **20***b* and **20***d*. Similarly, linking plates **25, 26** and **28** are utilized in conjunction with pins **34** and sleeves **42** into which the pins are fitted, to join the opposite ends of beams **20***a* and **20***b* and **20***c* and **20***d* together, respectively. Piling **13** is fixedly attached to beam portions **20***b* and **20***d* in the following manner: Cylindrical member **31**, which is fixedly attached, such as by bolting, to the top of piling **13** is welded to sleeve member **43**. Beam sections **20***b* and **20***d* are welded to sleeve members **44** and **46** respectively. Sleeve members **43, 44** and **46** are joined together by means of associated pins **29** which fit therethrough and end caps **48**.

In operation, oscillator **11** is driven at a frequency such as to resonantly vibrate the vibration system formed by bending beam assembly **20** which provides most of the compliance for the system, and column member **13** which provides most of the mass for such system.

In an operative embodiment of the device of the invention in accordance with FIGS. **2–5**, a 4,000-lb. caisson, 42 inches in diameter, was driven with the system being resonant in a frequency range around 80 cycles per second.

Referring now to FIGS. **6** and **7**, a second embodiment of the invention is illustrated, this embodiment utilizing hydraulic springs for the compliant element. As for the first embodiment, and orbiting mass oscillator (not shown) is utilized for providing vibrational energy along the longitudinal axis of the pile **13**, this oscillator being driven such as described in my U.S. Pat. No. 3,291,227. The oscillator assembly is coupled through coupler element 35 to frame 37. Fixedly attached to cross plate 37*a* of the frame are piston members **40***a* and **41***a* of hydraulic springs **40** and **41** respectively. The casings **40***b* and **41***b* of hydraulic springs **40** and **41** respectively are fixedly attached to the frame structure **45**. The frame structure **45** in turn is attached to pile **13** through plate **47** which is fixedly attached to the pile and bolted to plate **45** by means of bolt **49**. A small

amount of play may be left between plate 45 and 47 to form a rectifier gap 50 which appears during the upward vibratory excursions.

The details of the hydraulic spring structure are illustrated in FIG. 7. As can be seen, piston element 40*a* is slidably fitted in the casing 40*b* with a liquid tight seal being formed between the sides of the piston and the casing by means of Teflon packing ring 51. The inside of housing 40b forms a hollow container which is filled with a suitable liquid such as silicone oil. Hydraulic spring 41 is identical in construction to spring 40. Frame 37 is thus connected to frame 45 through the spring elements formed by pistons 40*a* and 41*a* operating in conjunction with the oil baths against which they are driven in response to the vibratory energy.

As for the previous embodiment, the oscillator is driven at a frequency such as to cause resonant vibration of the system including pile 13 which primarily contributes mass to the system, and the very stiff hydraulic springs 40 and 41 which primarily contribute compliance to the vibration system. Rectifier gap 50 engenders unidirectional drive of the pile in response to the vibratory energy, i.e., drive solely in the downward direction, the drive mechanism being effectively decoupled from the pile on the upward excursions. Utilizing such a sonic rectifier is especially desirable with certain sheet pilings where both upward and downward rubbing in the tongue and groove joints along the edges of the piling sheets tends to cause overheating. Further, with this type of rectification, the load is decoupled from the energy source during the upward half cycles which contributes to a higher Q in the resonant system. Hydraulic springs 40 and 41 should be designed to provide the necessary compliance to achieve resonance for each particular pile or similar member to be driven at an optimum drive frequency. This can be determined theoretically and empirically by considering the relationships set forth in equation (2).

In an operative embodiment of the invention in accordance with FIGS. 6 and 7, resonance is achieved in driving a solid concrete pile at a frequency of 90 cycles per second. In another operative embodiment, a 20-foot length of steel H-beam pile was operated in a resonant vibration system at 105 cycles per second. It is estimated that this same beam would resonate in its longitudinal mode elastically at about 400 cycles per second.

Referring now to FIG. 8, another embodiment of the invention is illustrated. In this embodiment, a pair of high rate opposing coil springs are utilized for the compliant element. As for the other two embodiments, an orbiting mass oscillator (not shown), such as described in my aforementioned U.S. Pat. No. 3,291,227, is coupled to the compliant element to drive pile 13 vibratorily along its longitudinal axis. The oscillator casing is removably attached to shaft 60 which has a drive plate 61 attached to the end thereof. Mounted in a cage structure formed by vertical rods 63 are a pair of stiff coil springs 65 and 66. Spring 65 is supported between top plate 67 which is attached to the upper ends of rods 63 and the top surface of plate 61. Spring 66 is positioned between bottom plate 70 which is attached to the bottom ends of rods 63, and the bottom surface of plate 61. Bottom plate 70 is connected to pile 13 by means of coupler 72. Thus it can be seen that spring elements 65 and 66 are connected in series between shaft 60, which receives the vibratory energy directly from the oscillator, and pile 13. In this manner, a lumped constant compliant element is provided between the sonic energy source and the member being driven to form the desired resonant vibration system.

Thus, the device of this invention provides means for achieving resonant vibratory driving of a column member such as a pile, casing, or the like, without elastically vibrating such column member. This facilitates the attainment of resonant operation with relatively short column members at frequencies for optimum driving. Also, in situations where the driven member is frangible, this avoids elastic stressing of such member which might cause it to fracture.

While the device of the invention has been described and illustrated in detail, it is to be clearly understood that this is intended by way of ilustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the following claims.

I claim:

1. A device for driving a column member into the ground comprising:

a vibration generator,

a compliant member for coupling said vibration generator to said column member,

said compliant member and said column member forming a resonant vibration system with most of the compliance of said system being provided by said compliant member and most of the mass of said system being provided by said column member, and

means for driving said vibration generator at a frequency such as to cause resonant vibration of said system with said column member vibrating unitarily as a lumped mass and thereby penetrating into the ground.

2. The device of claim 1 wherein said compliant member comprises an elastic beam structure, said structure including paired plates, the ends of said plates being connected to each other and the central portions of said plates being separated from each other.

3. The device of claim 2 wherein said structure comprises two pairs of similar oppositely positioned plates.

4. The device of claim 1 wherein said compliant member comprises hydraulic spring means.

5. The device of claim 4 wherein said hydraulic spring means comprises a pair of hydraulic springs, each of said springs having a piston element connected to said vibration generator, a housing connected to said column member, and oil contained in said housing, said piston being slidably mounted in said housing in driving engagement with said oil.

6. The device of claim 1 wherein said compliant member comprises a pair of coil springs, housing means for supporting said springs, drive plate means positioned between said springs and said housing means, and means for coupling said drive plate means to said vibration generator.

* * * * *