

DESCRIPTION

PILE-DRIVING METHOD AND VIBRATION CONTROL METHOD

TECHNOLOGICAL FIELD

[0001]

5 The present invention relates to a pile-driving method that uses resonant vibrations to drive a pile into the ground, and a vibration control method that controls the vibrations applied to the pile when driving it into the ground.

 The present application claims priority on Japanese Patent Application No. 2010-007054, filed on January 15, 2010, the content whereof is incorporated herein.

10 BACKGROUND ART

[0002]

 There is a conventional resonant vibration pile-driving method that uses a pile-driver to vibrate a pile and drive it into the ground. In this resonant vibration pile-driving method, the excitation frequency applied to the pile is made to match the
15 natural frequency depended on a length of the pile. Using resonant vibrations generated when the excitation frequency and the natural frequency are matched, the pile is driven into the ground. This resonant pile-driving method is advantageous in that, since the pile is spontaneously vibrated by resonant vibrations, a large vibration response (to acceleration and vibration) can be obtained with low energy, and the pile can be driven
20 with efficient use of low energy. Moreover, since the excitation frequency is high frequency along the main pile length than a pile-driving method using rigid vibration, this resonant pile-driving method has an advantage that ground vibrations can be reduced.

 Examples of this type of resonant pile-driving method are one that drives the
25 pile by means of resonant vibrations mainly using a resonance mode at one-quarter

wavelength with the head of the pile as a node (hereinafter simply referred to as
'pile-head node method') (for example, see Patent Literatures 1 to 3), and one that drives
the pile by means of resonant vibrations mainly using a resonance mode at one-half
wavelength with the head of the pile as an antinode (hereinafter simply referred to as
5 'pile-head antinode method') (for example, see Patent Literature 4).

PRIOR ART LITERATURE

PATENT LITERATURE

[0003]

[Patent Document 1] Japanese Unexamined Patent Application, First
10 Publication No. S56-25518

[Patent Document 2] Japanese Unexamined Patent Application, First
Publication No. S59-98928

[Patent Document 3] Japanese Unexamined Patent Application, First
Publication No. S61-92212

15 [Patent Document 4] Japanese Patent Publication No. 2807794

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0004]

However, in the pile-head node method described in Patent Literatures 1 to 3,
20 since the node with the greatest strain (the amount of change in the displacement per unit
of length along the length of the pile) is set at the pile-head, the load is greatest at the
pile-head. This makes it difficult to control the resonant vibrations with the fixing force
of a pile driver and pile, and increases the possibility that the pile driver will break down.
Therefore, the pile-head node method has a problem of being difficult for practical use.

25 In comparison with the pile-head node method, the pile-head antinode method

described in Patent Literature 4 has a lower vibration response at the tip of the pile (hereinafter simply referred to as 'pile-tip'), leading to a problem that it has a lower driving capability than the pile-head node method. The tip is defined as the end of the side that is buried in the ground.

5 Moreover, in the pile-head node method and the pile-head antinode method, since the resonant vibrations are determined by the length of the pile, the range of drivable pile lengths is limited, leading to a problem of low versatility.

[0005]

It is an object of the present invention to provide a pile-driving method and a vibration
10 control method that are easy for practical use, have high driving capability, and high versatility.

MEANS FOR SOLVING THE PROBLEM

[0006]

To achieve the above-mentioned objects, the present inventors carried out
15 thorough research, and perfected the present invention based on the results as described below.

[0007]

To achieve the above-mentioned objects, the invention employs the following means.

20 (1) A pile-driving method according to an aspect of the invention utilizes resonant vibrations depended on a length of a pile to drive the pile into the ground. The method includes applying a load to a pile-head of the pile, the load being equivalent to 0.26 times or more and 3 times or less the mass of the pile, and vibrating the pile by using resonant vibrations corresponding to a resonance mode in which the pile-head is
25 an antinode.

[0008]

(2) Preferably, in the pile-driving method of (1), the resonance mode is a one-half wavelength resonance mode and a one-wavelength resonance mode; the one-half wavelength resonance mode or the one-wavelength resonance mode is selected based on the length of the pile, and the pile is vibrated by using resonant vibrations corresponding to the resonance mode that was selected.

(3) Preferably, in the pile-driving method of (1) and (2), the pile-head of the pile is gripped by a pile clamp, and the load is applied to the pile-head gripped by the pile clamp.

(4) Preferably, in the pile-driving method of (3), the pile clamp includes a main unit, and gripping parts that are provided to the main unit and arranged so as to surround the pile-head of the pile; a weight is provided inside the main unit, and the sum of the masses of the weight and the pile clamp is 0.26 times or more and 3 times or less the mass of the pile.

(5) A vibration control method according to an aspect of the invention controls vibrations of a pile when the pile is driven into the ground using resonant vibrations. The method includes adjusting a load applied to a pile-head of the pile within a range of 0.26 times or more and 3 times or less the mass of the pile, based on a driving depth of the pile or a hardness of the ground, and vibrating the pile by using resonant vibrations corresponding to a resonance mode in which the pile-head is an antinode.

(6) Preferably, in the vibration control method of (5) the resonance mode is a one-half wavelength resonance mode and a one-wavelength resonance mode, the one-half wavelength resonance mode or the one-wavelength resonance mode is selected based on the length of the pile, and the pile is vibrated by using resonant vibrations corresponding to the resonance mode that was selected.

EFFECTS OF THE INVENTION

[0009]

It has conventionally been thought that, when a load is applied to a pile, the total mass of the target object being made to resonant vibrate will increase and the driving capability will be diminished. However, with resonant vibrations where the pile-head is an antinode, a load is applied to the pile-head and the pile is vibrated while changing the vibration frequency. At this time, the force applied to the pile stays the same even if the vibration frequency is changed.

As a result, the inventors discovered that, as the load increases, the resonance frequency decreases, the vibration response of the pile-tip (pile-head) increases, and in addition, the strain on the pile-head is less than in resonant vibrations where the pile-head is a node. They also discovered that there is almost no change in the resonance frequency if the load applied to the pile-head exceeds 3 times the mass of the pile.

The present invention has been perfected in accordance with these findings.

[0010]

According to the pile-driving method described in (1) and the vibration control method described in (5), by applying the above-mentioned load to the pile-head of a pile and vibrating the pile with resonant vibrations in which the pile-head is an antinode, or by vibrating the pile after adjusting the load applied to the pile-head based on at least one of the pile-driving depth and the ground hardness, the acceleration response of the pile-tip can be increased in comparison with a case where no load is applied, and the driving capability can be enhanced. Since resonant vibrations are generated with the pile-head as an antinode, it is possible to set a node where the strain is greatest in an intermediate part of the pile. Therefore, the resonant vibrations can be controlled without increasing the securing force of the pile driver and the pile-head, the possibility

that the pile driver will break down can be reduced, and it is made more practical to use.

Moreover, since the resonance frequency can be adjusted with the load applied to the pile-head, the versatility of the pile-driving method can be enhanced without limited by the range of the pile lengths. At this time, there is no change in the reduction
5 of ground vibrations, which is one of the advantages of a vibratory pile-driving method.

In the pile-driving method according to the aspect of the invention, the load applied to the pile-head is more preferably equivalent to 0.26 times or more and 1.1 times or less the mass of the pile. In the vibration control method according to the aspect of the invention, the load applied to the pile-head is more preferably adjusted within a
10 range of up to 1.1 times the mass of the pile.

If the load exceeds 1.1 times, there are cases where the amount of change in the resonance frequency with respect to the amount of increase in the load noticeably decreases in comparison with a case where it is 1.1 times or less; in addition, the total mass of the vibrated target increases, as does the load on the pile driver.

15 [0011]

According to the pile-driving method described in (2) and the vibration control method described in (6), when generating resonant vibrations only in a one-half wavelength resonance mode (primary resonance mode), the longer the pile, the lower the resonance frequency and the greater the ground vibrations.

20 When it is determined that the pile P is long, and the reduction of ground vibrations is too small at the resonance frequency of the one-half wavelength resonance mode, the pile driver 1 excites resonant vibrations in the pile P in a one-wavelength resonance mode. By vibrating the pile after selecting the resonance mode in accordance with the length of the pile in this manner, the resonance frequency of the pile increases
25 and the ground vibrations decrease, without changing the length of the pile.

[0012]

According to the pile-driving method described in (3), since the pile-head of the pile is gripped by the pile clamp 3, driving can be made easy.

According to the pile-driving method described in (4), since the weight is
5 provided inside the main unit, by changing the weight, the load applied to the pile-head of the pile can be adjusted such that it is not less than 0.26 and not greater than 3 times the mass of the pile. This makes it possible to increase both the resonance frequency band and the vibration response, using a simple method.

[0013]

10 According to the pile-driving method and the vibration control method described above, in comparison with a case where a load is not applied to the pile-head, the acceleration response of the pile-tip can be increased, and the driving capability can be enhanced. Further, the resonant vibrations can be controlled without increasing the fixing force of the pile driver and the pile-head, the possibility that the pile driver will
15 break down can be reduced, and it can be made more practical to use. Moreover, the versatility of the pile-driving method can be enhanced without limiting the range of pile lengths that can be driven. The invention can also achieve reduction of ground vibrations, which is one of the advantages of a vibratory pile-driving method.

BRIEF DESCRIPTION OF THE DRAWINGS

20 [0014]

FIG. 1 is a side diagram of the schematic configuration of a pile driver according to an embodiment of the invention.

FIG. 2 is a side diagram of a method for testing an example of the invention.

FIG. 3 is a graph of the relationship between excitation frequency ratio and tip
25 acceleration ratio.

FIG. 4 is a graph of the relationship between applied load ratio and half-wavelength resonance frequency ratio.

FIG. 5 is a graph of the relationship between applied load ratio and limit reach depth ratio.

5 FIG. 6 is a graph of the relationship between applied load ratio and driving speed ratio.

FIG. 7 is a diagram of vibration response distribution and strain distribution in Comparative Example 2.

10 FIG. 8 is a diagram of vibration response distribution and strain distribution in Comparative Example 3.

FIG. 9 is a diagram of vibration response distribution and strain distribution in Example 5.

BEST MODES FOR IMPEMENTING THE INVENTION

[0015]

15 As an embodiment of the invention, a pile-driving method and a vibration control method will be explained based on the drawings.

FIG. 1 is a side diagram of the schematic configuration of a pile driver of this embodiment.

20 In FIG. 1, a pile driver 1 of this embodiment is a device that uses resonant vibrations to drive a pile P into the ground G. The pile driver 1 includes a vibration exciter 2 that excites the pile P, a pile clamp 3, and a control device (not shown).

The pile clamp 3 is attached to the vibration exciter 2, and grips the head Ph of the pile P. The control device (not shown) controls the entire pile driver 1. The pile-tip Pf is the end of the side of the pile P that is driving in the ground G.

25 [0016]

The vibration exciter 2 excites at a frequency that generates resonant vibrations corresponding to a resonance mode at one-half wavelength (primary resonance mode) and a resonance mode at one-wavelength (secondary resonance mode), with the pile-head Ph as an antinode.

5 The pile clamp 3 includes a main unit 31 that is substantially box-shaped and has an internal hollow cavity, and a number of gripping parts 32 for gripping the pile-head Ph of the pile P. The gripping parts 32 are arranged so as to surround the pile-head Ph of the pile P, and protrude downwards from the main unit 31. The control device (not shown) operates the gripping parts 32 such that they grip the pile-head Ph.

10 One or a number of weights prepared beforehand is/are provided inside the main unit 31. The mass of the weights 33 is set such that the sum of the mass of this weight or number of weights 33 and the mass of the pile clamp 3 (containing the main unit 31 and the gripping parts 32) is between 0.26 and 3 times the mass of the pile P. When the weight or number of weights 33 is/are provided inside the main unit 31, a load
15 of 0.26 times or more and 3 times or less the mass of the pile P is applied to the pile-head Ph. That is, the sum of the masses of the pile clamp 3 and the weights 33 is equivalent to the load applied to the pile-head.

[0017]

Subsequently, a method of driving the pile P using the pile driver 1 (vibration
20 control method) will be explained.

Firstly, an operator selects a pile P of appropriate length or thickness (outer diameter) based on the hardness of the ground G and the driving depth of the pile P (the distance from the ground G to the pile-tip Pf, in other words, the target driving depth), and grips it with the pile clamp 3. He then adjusts the load applied to the pile-head Ph of
25 the pile P such that the sum of the mass of one or a number of the weights 33 and the

mass of the pile clamp 3 is between 0.26 and 3 times the mass of the pile P. That is, he arranges weights 33 of an appropriate mass in the pile clamp 3.

The operator then manipulates the control device of the pile driver 1 and operates the vibration exciter 2. He excites the pile P, which a load of between 0.26 and 3 times the mass of the pile P is being applied to, at a frequency that generates resonant vibrations in a resonance mode at one-half wavelength, and drives it into the ground G. The load applied to the pile P is more preferably between 0.26 and 1.1 times the mass of the pile P.

In this way, by applying a load to the pile-head Ph of the pile P and exciting it, the acceleration response of the pile-tip Pf is greater than in a case where resonant vibrations are excited in a resonance mode at one-half wavelength without applying a load to the pile-head Ph of the pile P; in addition, the pile P is driven with less strain of the pile-head Ph than in a case where resonant vibrations are excited with the pile-head Ph as a node.

[0018]

When the operator determines that the pile P gripped by the pile clamp 3 is a long one and that there will be a low reduction effect of ground vibrations at the resonance frequency for the one-half wavelength resonance mode, he makes the vibration exciter 2 excite the pile P so as to obtain resonant vibrations in the one-wavelength resonance mode.

By selecting a resonance mode and exciting vibrations in accordance with the length of the pile P in this manner, the resonance frequency of the pile P is increased and the ground vibrations are reduced without changing the length of the pile P.

[0019]

According to the embodiment described above, weights 33 with a load between

0.26 and 3 times the mass of the pile-head Ph is applied to the pile-head Ph, and the pile P is vibrated by resonant vibrations with the pile-head Ph as an antinode. Therefore, it is possible to achieve reduction of ground vibrations, which is an advantage of the vibration pile-driving method, while increasing the acceleration response of the pile-tip Pf in comparison with a case where a load is not applied to the pile-head Ph, and it is also possible to increase a predetermined driving capability. Further, in this embodiment, since the pile P is vibrated by resonant vibrations with the pile-head Ph as an antinode, the strain on the pile-head Ph can be reduced to less than in a case where the pile-head Ph is a node. The resonant vibrations can therefore be controlled without increasing the gripping force of the pile clamp 3, and the possibility that the pile driver 1 will break down can be reduced. This makes practical use much easier. Moreover, since the resonant vibrations can be adjusted by adjusting the load applied to the pile-head in accordance with the length of the pile or the mass of the pile, resonant vibrations can be generated irrespective of the length of the pile, thereby increasing the versatility.

15 [0020]

While the load applied to the pile P was between 0.26 and 3 times the mass of the pile P, the load is more preferably adjusted to between 0.26 and 1.1 times the mass of the pile P. This makes it possible to minimize the increase in total mass of the excitation targets of the vibration exciter 2, namely, the pile clamp 3, the weight 33, and the pile P, and makes it possible to achieve the effects mentioned above while suppressing the load of the pile driver 1. Furthermore, by selecting the resonance mode of the pile P at one-half wavelength or one-wavelength in accordance with the length of the pile P, the ground vibrations can be controlled without changing the pile P. It is also possible to select the resonance mode at one-half wavelength or one-wavelength based on the frequency when vibrating the pile P.

Furthermore, since the pile-head Ph is gripped in the pile clamp 3, driving is easy.

EXAMPLES

[0021]

5 Subsequently, examples of the invention will be explained.

In these examples, the effects of applying load to the pile-head Ph were investigated.

[0022]

The relationship between the load applied to the pile P, the resonance frequency
10 of the pile P, and the acceleration of the pile-tip Pf during vibration (hereinafter simply referred as to 'tip acceleration') was investigated.

As shown in FIG. 2, acceleration gauges A were attached at equal intervals at five points along the length of the pile P. The pile clamp 3 attached at the tip of the vibration exciter 2 was made to grip the pile P. Weights 33 that obtained the values
15 shown below in Table 1, obtained by dividing the mass of the pile P from the sum of the masses of the pile clamp 3 and the weight 33 (hereinafter simply referred as to 'applied load ratio'), were provided in the pile clamp 3. While keeping the power of the vibration exciter 2 constant, the frequency of vibrating the pile P (hereinafter simply referred as to 'excitation frequency') was changed, and the relationship between the resonance
20 frequencies in Examples 1 to 4 and the acceleration of the pile-tip Pf during vibration (hereinafter simply referred as to 'tip acceleration') was investigated.

[0023]

[Table 1]

[0024]

25 In a Comparative Example 1, instead of using the pile clamp 3, a pile P with five

acceleration gauges A attached thereto was bonded to the tip of the vibration exciter 2 using bolts and welding. The pile P was then made to vibrate in the same manner as in Examples 1 to 4, and the relationship between the resonance frequency and the acceleration was checked. The applied load ratio in Comparative Example 1 was 0.08
 5 ($\neq 0$).

[0025]

FIG. 3 shows the relationship between the excitation frequency ratio and the tip acceleration ratio in Examples 1 to 4 and Comparative Example 1. The excitation frequency ratio is the value obtained by dividing the one-half wavelength resonance
 10 frequency in Comparative Example 1 from the excitation frequency in Examples 1 to 4 and Comparative Example 1. The tip acceleration ratio is the value obtained by dividing the tip acceleration of the one-half wavelength in Comparative Example 1 from the tip acceleration in Examples 1 to 4 and Comparative Example 1.

As shown in FIG. 3, it was confirmed that, as the applied load ratio increases,
 15 the one-half wavelength resonance frequency (the resonance frequency in the one-half wavelength resonance mode) decreases and the tip acceleration ratio increases. At the one-quarter resonance frequency (the resonance frequency in the one-quarter wavelength resonance mode), the increase in the applied load ratio produced little change.

20 [0026]

FIG. 4 shows the relationship between the applied load ratio and the one-half wavelength resonance frequency (the value obtained by dividing the one-half wavelength resonance frequency of Comparative Example 1 from the one-half wavelength resonance frequency of each applied load ratio (Examples 1 to 4)), obtained
 25 from FIG. 3. In FIG. 4, the solid line represents actual measurements, and the two-dot

chain lines represent approximate curves obtained from the actual measurements.

When the applied load ratio is less than 1.1, the one-half wavelength resonance frequency decreases as the applied load ratio increases. However, when the applied load ratio exceeds 1.1, the one-half wavelength resonance frequency hardly changes.

5 [0027]

In FIG. 4, the one-dot chain line represents logical values derived from a wave equation (explained in detail below).

The approximate curve of the actual measurements mentioned above has a slightly large value with respect to the logical value, and has a divergence of roughly 5%
10 in the region where the mass ratio is 1.0 or more. However, the logical value and approximate curve each tend to converge to a constant one-half wavelength resonance frequency ratio as the mass ratio increases, suggesting that the logical value confirms the accuracy of the approximate curve based on the actual measurements above.

Conceivably, the logical value and approximate curve converge to a constant
15 one-half wavelength resonance frequency ratio as the mass ratio increases due to a shift from one-half wavelength resonance to one-quarter wavelength resonance when no load is applied.

Conceivably, the high value of the approximate curve with respect to the logical value is due to some problems with the device during the test. For example, an error to
20 arrange the pile P and the weight 33 at an exact perpendicular when attaching them to the pile clamp 3, with the result that they deviated slightly from the perpendicular direction.
[0028]

The logical value can be derived by the following process.

The resonance mode of a one-dimensional elastic body such as the pile P can be
25 determined from a wave equation and boundary conditions.

Firstly, the following wave equation is conventionally known.

[0029]

[Equation 1]

[0030]

- 5 In Equation 1, u is the displacement in the axial direction, x is the position, t is the time, E is the Young's modulus, and ρ is the density.

The displacement u in the axial direction can be expressed by a function of the position x and the time t , as in the following equation. Here, ω is the angular frequency, c is the elastic wave velocity, and C and D are coefficients.

10 [0031]

[Equation 2]

[0032]

- In addition to Equations (1) and (2) given above, if the boundary conditions are set at both ends of an elastic body ($x=0$, $x=1$), the resonance mode of a one-dimensional
15 elastic body can be determined.

When the boundary conditions are both free ends, the strain is 0, giving the following equation.

[0033]

[Equation 3]

20 [0034]

From Equations (2) and (3), $D = 0$, and the resonance angular frequency is as follows. Incidentally, i is a whole integer, and, in the one-half mode, $i = 1$.

[0035]

[Equation 4]

25 [0036]

Thus the resonance mode is expressed with the following equation.

[0037]

[Equation 5]

[0038]

- 5 That is the calculation when both ends are free ends. In contrast, when a load is applied to one end as in the embodiment, the boundary conditions are as follows.

Since the end where no load is applied (the pile-tip Pf side, $x=0$) is a free end, the following equation is established according to Equation (3).

[0039]

- 10 Equation 6

[0040]

At the end where a load is applied (pile-head Ph side, $x=1$), the inertia force of the applied load M balances the elastic body, giving the following equation.

[0041]

- 15 [Equation 7]

[0042]

Due to temporal differentiation of u in Equation (7), the equation is developed as follows.

[0043]

- 20 [Equation 8]

[0044]

The following equations are then obtained from Equations (7) and (8).

[0045]

[Equation 9]

- 25 [0046]

[Equation 10]

[0047]

At the end where no load is applied (the pile-tip Pf side, $x=0$), Equations (6) and (10) give $D = 0$ (the same as when both ends are free ends).

- 5 At the end where a load is applied (pile-head Ph side, $x=1$), the following equation is obtained from Equations (6) to (10).

[0048]

[Equation 11]

[0049]

- 10 A value for ω that satisfies Equation (11) is the resonance angular frequency when a load is applied to one end.

The resonance mode in this case is as follows.

[0050]

[Equation 12]

- 15 [0051]

In Equation (11), if we postulate Equation (13), we derive Equation (14).

[0052]

[Equation 13]

[0053]

- 20 [Equation 14]

[0054]

The following equation is thus obtained. Equation (15) shows that, when the length of the pile is constant, the mass ratio of the pile and the applied load determines the resonance frequency.

- 25 [0055]

[Equation 15]

[0056]

Based on Equation (15), in accordance with the conditions of the measurements described above, the frequency ratio of mass ratio 0.08 (Comparative Example
5 corresponding to 0) and mass ratio 0.25 to 3.0 (contained within this embodiment) was determined and the logical values represented by the one-dot chain line in FIG. 4 were obtained.

[0057]

Subsequently, the effect of applying a load on driving capability was
10 investigated.

In Examples 1 to 4 and Comparative Example 1, at each one-half wavelength resonance frequency, with the power of the vibration exciter 2 constant, the pile P was driven into the ground in an excited state, and the relationship between the applied force, the limit reach depth, and driving speed was investigated.

15 [0058]

FIG. 5 shows the applied load ratio and the limit reach depth ratio in Examples 1 to 4 and Comparative Example 1. For the limit reach depth ratio, Comparative Example 1 is taken as a reference, and Examples 1 to 4 are made non-dimensional.

As shown in FIG. 5, as the applied load ratio increases, it was confirmed that the
20 limit reach depth ratio becomes increases.

[0059]

FIG. 6 shows the applied load ratio and driving speed ratio in Examples 1 to 4 and Comparative Example 1. For the driving speed ratio, the time required from the start of driving to the end of driving in Comparative Example 1 is taken as the reference, and
25 Examples 1 to 4 are made non-dimensional.

As shown in FIG. 6, as the applied load ratio increases, it was confirmed that the driving speed ratio becomes fast.

[0060]

Subsequently, the effect of applying a load on driving was investigated.

5 As shown in Table 2 below, the effects were investigated under each of these conditions: the one-half wavelength resonance mode of the Comparative Example (hereinafter referred as to Comparative Example 2), a one-quarter wavelength resonance mode of Example 3 (hereinafter referred as to Comparative Example 3), and a one-half wavelength resonance mode of Comparative Example 3 (hereinafter referred as to
10 Example 5).

[0061]

[Table 2]

[0062]

FIG. 7, FIG. 8, and FIG. 9 show vibration response distribution and strain
15 distribution in Comparative Examples 2 and 3, and Example 5 respectively.

[0063]

As shown in FIG. 7, in Comparative Example 2, since the applied load ratio is almost 0, the node of the resonant vibrations was approximately in the center of the long direction. Consequently, the vibration response was greatest at the pile-head Ph and the
20 pile-tip Pf, and the strain was greatest in the approximate center of the long direction of the pile P. The greatest vibration response and the greatest strain in Comparative Example 2 are both expressed as 1.0.

[0064]

As shown in FIG. 8, in Comparative Example 3, the node of the resonant
25 vibrations was at the pile-head Ph, obtaining the greatest vibration response at the

pile-tip Pf and the greatest strain at the pile-head Ph. When 1.0 expresses the greatest vibration response and strain in Comparative Example 2, the vibration response and strain in Comparative Example 3 were respectively 3.5 and 3.5.

[0065]

5 As shown in FIG. 9, in Example 5, due to the effect of the load being applied, the node of the resonant vibrations was more to the pile-head Ph side than in Comparative Example 2 shown in FIG. 7. The strain was greatest at this node position, and the vibration response was greatest at the pile-tip Pf. When 1.0 expresses the greatest vibration response and strain in Comparative Example 2, the vibration response
10 and strain in Example 5 were respectively 2.5 and 2.5.

[0066]

As shown in evaluation No. 1 in Table 2, in Comparative Example 2, the driving preparation time took more than 30 minutes, whereas in Comparative Example 3 and Example 5 it took less than 10 minutes. Thus it was confirmed that the driving
15 preparation time (the time take to join the pile P to the pile driver) in Comparative Example 3 and Example 5, in which the pile clamp 3 grips the pile P, was shorter than in Comparative Example 2, where the pile P is joined by welding and bolts.

As shown in evaluation No. 2, the resonant vibrations in Comparative Examples 2 and 3 depend only on the length of the pile. In contrast, in Example 5, it was
20 confirmed that the frequency of the resonant vibrations can be controlled by the mass of the pile clamp 3.

Moreover, as shown in evaluations Nos. 3 and 4, while the resonance frequency range of Comparative Example 3 is 25Hz to 127Hz, the resonance frequency range of Example 5 is 37.5Hz to 190.5Hz. It was thus confirmed that Example 5 maintains the
25 characteristics of the one-half wavelength resonance mode, which achieves a higher

resonance frequency and better reduction of ground vibrations than the one-quarter wavelength resonance mode (Comparative Example 3).

As shown in evaluations Nos. 5, 6, and 7, in Example 5, although the one-half wavelength resonance mode normally has lower driving capability than the one-quarter wavelength resonance mode (Comparative Example 3), the vibration response can be increased by applying a load. It was thus confirmed that driving capability, such as the driving speed and the limit reach speed, can be enhanced.

As shown in evaluations Nos. 8 to 10, since the gripping force of the pile clamp 3 is designed in accordance with the strain on the pile-head Ph, the greater the strain on the pile-head Ph, the higher the demanded gripping force. In Example 5, since the demanded gripping force is approximately half that of the one-quarter wavelength resonance mode (Comparative Example 3), it was confirmed that the load on the pile driver 1 is greatly reduced and the vibratory pile-driving method has good operability.

Therefore, Example 5 was the one that obtained good measurements in regard to each of the driving preparation time, the resonance frequency range, the ground vibration reduction, the driving speed, and the durability of the pile driver. That is, by applying a load of 0.77 times the mass of the pile P to the pile-head Ph, it becomes possible to increase the acceleration response of the pile-tip Pf, and to enhance the driving capability.

While in this embodiment, a load of 0.77 times the mass of the pile P is applied to the pile-head Ph, similar effects can be obtained by applying a load of 0.26 times or more and 3.0 times or less.

[0067]

The present invention is not limited to the embodiment described above, and includes other configurations that can achieve the object of the invention, and

modifications such as the following.

For example, while in the embodiment, the pile clamp 3 is made to grip the pile P, this is not limitative of the invention. The weight 33 can be removably secured to the tip of the vibration exciter 2 by a bolt or the like, and the pile P can be removably secured to the tip of the weight 33. In such a configuration, if the pile P can be secured to the vibration exciter 2 without the weight 33 therebetween, the load applied to the pile P can be adjusted to within three times. Also, the resonance mode of the pile P can be set only to one-half wavelength. The configuration can also be one where, when the control device has determined that the ground vibration detected by a ground vibration sensor is greater than a reference set beforehand, the resonance mode of the pile P is automatically switched from one-half wavelength to one-wavelength.

[0068]

While optimum configurations, methods, and the like for realizing the invention have been disclosed above, the invention is not limited to these. While the invention has been illustrated and described mainly in relation to a specific embodiment, a person skilled in the art will be able to make various modifications to the shapes, materials, quantities, and other configurative details of the embodiment described above, without departing from the technological ideas and intended scope of the invention. Therefore, the foregoing descriptions of shapes, materials and the like are examples for facilitating understanding of the invention, and are not limitative of it. Names of members that partly or wholly differ from those defining the shape, materials, and the like in the foregoing description are also contained within the present invention

REFERENCE NUMERALS

[0069]

25 3 PILE CLAMP

P	PILE
Ph	PILE-HEAD
G	GROUND

Equation 1

$$\frac{\partial^2 u}{\partial t^2} = \sqrt{\frac{E}{\rho}} \frac{\partial^2 u}{\partial x^2} \quad \cdot \cdot \cdot (1)$$

Equation 2

$$u = X(x)\phi(t) = \phi(t) \left(C \cos \frac{\omega}{c} x + D \sin \frac{\omega}{c} x \right) \quad \cdot \cdot \cdot (2)$$

Equation3

$$\frac{\partial u}{\partial x} = 0 \quad \cdot \cdot \cdot (3)$$

Equation4

$$\omega = \frac{ic\pi}{l} \quad \cdot \cdot \cdot (4)$$

Equation5

$$u = \phi(t) \cos \frac{\pi}{l} x \quad \cdot \cdot \cdot (5)$$

Equation6

$$EA \frac{\partial u}{\partial x} = 0 \quad \cdot \cdot \cdot (6)$$

Equation7

$$EA \frac{\partial u}{\partial x} = -M \frac{\partial^2 u}{\partial t^2} \quad \cdot \cdot \cdot (7)$$

Equation8

$$\phi(t) = \lambda e^{i\omega t} \quad \dots (8)$$

Equation9

$$\frac{\partial^2 u}{\partial t^2} = (C \cos \frac{\omega}{c} x + D \sin \frac{\omega}{c} x)(-\lambda \omega^2 e^{i\omega t}) \quad \dots (9)$$

Equation10

$$\frac{\partial u}{\partial x} = (-\frac{\omega}{c} C \sin \frac{\omega}{c} x + \frac{\omega}{c} D \cos \frac{\omega}{c} x) \lambda e^{i\omega t} \quad \dots (10)$$

Equation11

$$\tan \frac{\omega}{c} l = -\frac{Mc\omega}{EA} \quad \dots (11)$$

Equation12

$$u = \phi(t) \cos \frac{\omega}{c} x \quad \dots (12)$$

Equation13

$$\frac{\omega}{c} l = p \quad \dots (13)$$

Equation14

$$\frac{1}{p} \tan p = -\frac{Mc\omega}{EA} * \frac{1}{p} = -\frac{M}{EA l} c^2 = -\frac{M}{m} \quad \dots (14)$$

Equation 15

$$\frac{1}{p} \tan p = -\frac{M}{m} \quad \cdot \cdot \cdot (15)$$

	APPLIED LOAD RATIO
EXAMPLE 1	0.26
EXAMPLE 2	0.60
EXAMPLE 3	0.77
EXAMPLE 4	1.10
COMPARATIVE EXAMPLE 1	$0.08 \div 0$

Table 1

EVALUATION ITEM No	ITEM	COMPARATIVE EXAMPLE 2	COMPARATIVE EXAMPLE 3	EXAMPLE 5
—	RESONANCE MODE	ONE-HALF WAVELENGTH	ONE-QUARTER WAVELENGTH	LOAD APPLIED ONE-HALF WAVELENGTH
—	MAIN PILE LENGTH (m)	10~50	10~50	10~50
—	JOINING METHOD BETWEEN PILE AND PILE DRIVER	DIRECT JOINING (BOLT AND WELDING)	PILE CLAMP	PILE CLAMP
1	DRIVING PREPARATION TIME	MORE THAN 30 MINUTES	LESS THAN 10 MINUTES	LESS THAN 10 MINUTES
2	RESONANCE CONTROL	DEPENDENCE ON PILE LENGTH	DEPENDENCE ON PILE LENGTH	PILE LENGTH MASS OF PILE CLAMP
—	APPLIED LOAD RATIO	0.08 $\div$ 0	0.77	0.77
3	MAIN RESONANCE FREQUENCY BAND (Hz)	50 (PILE LENGTH 50m) ~254 (PILE LENGTH 10m)	25 (PILE LENGTH 50m) ~127 (PILE LENGTH 10m)	37.5 (PILE LENGTH 50m) ~190.5 (PILE LENGTH 10m)
4	REDUCTION EFFECT OF GROUND VIBRATION	MAXIMUM	MINIMUM	MEDIUM
5	VIBRATION RESPONSE	1.0	3.5	2.5
6	DRIVING SPEED (DEPENDENCE ON VIBRATION)	MINIMUM	MAXIMUM	MEDIUM
7	LIMIT REACH DEPTH RATIO	MINIMUM	MAXIMUM	MEDIUM
8	STRESS OF HEAD (STRAIN)	1.0	3.5	1.7
9	DEMANDED GRIPPING FORCE	1.0	3.5	1.7
10	DURABILITY OF PILE DRIVER	GOOD	BAD	MEDIUM

Table 2

CLAIMS

1. A pile-driving method that utilizes resonant vibrations depended on a length of a pile to drive the pile into the ground, the method comprising:

applying a load to a pile-head of the pile, the load being equivalent to 0.26 times or more and 3 times or less the mass of the pile; and

vibrating the pile by using resonant vibrations corresponding to a resonance mode in which the pile-head is an antinode, wherein:

the pile-head of the pile is gripped by a pile clamp;

the load is applied to the pile-head gripped by the pile clamp;

the pile clamp includes a main unit, and gripping parts that are provided to the main unit and arranged so as to surround the pile-head of the pile;

a weight is provided inside the main unit; and

the sum of the masses of the weight and the pile clamp is 0.26 times or more and 3 times or less the mass of the pile.

2. The pile-driving method according to claim 1, wherein:

the resonance mode is a one-half wavelength resonance mode and a one-wavelength resonance mode;

the one-half wavelength resonance mode or the one-wavelength resonance mode is selected based on the length of the pile; and

the pile is vibrated by using resonant vibrations corresponding to the resonance mode that was selected.

3. A vibration control method that controls vibrations of a pile when the pile is driven into the ground using resonant vibrations, comprising:

adjusting a load applied to a pile-head of the pile within a range of 0.26 times or more and 3 times or less the mass of the pile, based on a driving depth of the pile or a hardness of the ground; and

vibrating the pile by using resonant vibrations corresponding to a resonance mode in which the pile-head is an antinode, wherein:

the pile-head of the pile is gripped by a pile clamp;

the load is applied to the pile-head gripped by the pile clamp;

the pile clamp includes a main unit, and gripping parts that are provided to the main unit and arranged so as to surround the pile-head of the pile;

a weight is provided inside the main unit; and

the sum of the masses of the weight and the pile clamp is 0.26 times or more and 3 times or less the mass of the pile.

4. The vibration control method according to claim 3, wherein

the resonance mode is a one-half wavelength resonance mode and a one-wavelength resonance mode;

the one-half wavelength resonance mode or the one-wavelength resonance mode is selected based on the length of the pile; and

the pile is vibrated by using resonant vibrations corresponding to the resonance mode that was selected.