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Dynamical Effects in Process of Piles Vibrodriving

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Abstract **- Vibration driving of elements into a soil is a complex mechanical process, accompanied with such phenomena, as a changing of structure of surrounding the driving element soil, liquefaction of them, the decreasing of friction forces between soil and surface of the driving element. A vibration method is used for driving of elements with the comparatively small cross section area: metallic sheet piles and pipes; length of sinking elements is not limited. When periodically changing axial force is acting on the driving elements there is possibility of loss of dynamical stability of element because of parametric resonance. Such possibility appears when motion of element bottom end is obstructed by the layers of very hard soil (for example, rocky) or because of densification of the liquefied sandy soil after technological pause in vibrodriving. In this work it is suggested to check up the parameters of vibrators using the simulation of pile driving process and examination of pile dynamical stability. The plastic model of shaft and toe resistance of soils during vibrodriving is developed taking into account the change of properties of soils on the depth, equation of motion of pile in soil is derived and solved numerically. The analysis of numerical solution shows the possibility of element driving to required depth by one vibrator with given performance figures, or the necessity of additional static set-on-weight, additional vibrator or changing of vibrator. The possibility of origination of dynamical instability and condition of resonance is examined on the models of pile as a perfectly solid and as a flexible beam. Possibility of dynamic stability loose on the higher mode of vibrations is proved for the driving elements from the often applied metallic rolled sections, examined as flexible beams.**

Keywords **- vibration, parametric load, dynamical stability, friction, liquefaction.**

I. Introduction

The driving of solid into resisting environment under the influence of constant and sign-variable forces is called vibrodriving. A process of driving of body into soil under vibration is a very complex mechanical process. The vibrator of the directed action, excited the longitudinal vibrations of pile, exerts different mechanical influences on soil and pile: at low frequencies weak vibrations of pile arises, the soil layers surrounding a pile move together with it, a pile does not sink; when frequency of vibrator increases the separation of pile from soil and slipping of it lateral surfaces on soil take place, soil resistance to driving decreases [1], [2], [3].

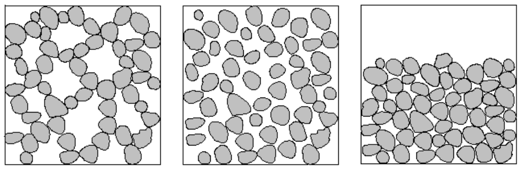
Soil resistance consists of toe (or front) resistance, acting on the bottom end of pile, and shaft resistance, acting on its walls. Under vibrating the forces of soil resistance are decreasing depending on the physical-mechanical properties of soil, its mineralogical composition and mode of vibrations. In dense clayey and slightly wet sandy soils a dynamic toe resistance remains approximately equal to static, lateral resistance also decreases insignificantly. In the water-saturated soils dynamic toe-resistance decreases approximately twice, lateral resistance - tenfold, therefore it is most effectively to use of vibration method in the water-saturated sandy and plastic clayey soils [2], [4], [5].

During high-frequency vibrations acting on non-cohesive granular sandy soils there is destruction of the formed structure which is not restored after stopping of vibration. The stages of liquefaction of sandy soils for moist sands during vibrating are shown in Fig.1:

a) loose water-saturated sand before liquefaction,

b) a moment of liquefaction - break of connections between particles - decoupling,

c) compacted sand after stopping of vibration and squeezing out water.



a) b) c)

Fig. 1. Liquefaction of sandy soil under vibration

Reason of liquefaction of clay-like soils is their thixotropy, physical - chemical phenomenon, occurring in some colloidal dispersed systems, consisting in convertible weakening of structural connections between the mineral particles of cohesive earth material under mechanical agitation. Under specific mechanical action (shaking, vibrating) the transition of the combined water into free occurs that results in structural bonds strength decreasing and soil liquefaction, the action termination leads to return transition of water from free state into the connected and to consolidating and hardening of soil.

Vibration method is used for driving of elements with the comparatively small cross-section area: metallic sheepiles, pipes, hollow shell-piles, and also at borings works. The length and mass of driving elements is not limited, as distinct from the impact method of pile driving when the length of sinking element is limited by the length of wave extended in it.

The purpose of this work – to develop the model of soils behaviour during vibrodriving process for more correct choice of vibrodrivers, as well as to examine the possibilities of the loss of dynamical stability as the result of periodically changing longitudinal force action on the sinking elements.

II. ANALYTICAL MODEL OF PILE VIBRATORY DRIVING

In Fig.2 the schematic layout of pile vibratory driving and simulation model of it are shown.

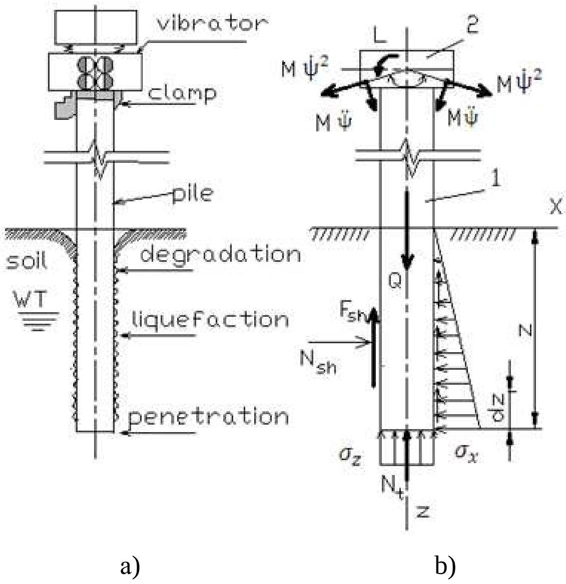


Fig. 2. a) Schematic layout of pile vibratory driving
b) Analytical model: 1- pile, 2 – vibrodriver

To the head of pile, embedded in ground on the insignificant depth, the vibrator of the directed action exciting longitudinal vibrations of pile is jointed with the help of clamp. The electric motor is settled down on plate which can be jointed to the vibrator rigidly or by means of springs.

Agreed notations:

ψ – angle of rotation of eccentric mass,
$\dot{\psi}$ – angular speed of rotation,
M – a total static moment of eccentric mass of vibration exciter,
L – torque of the engine reduced to shaft of vibration exciter,
$Q = (m+m_0)\,g$ – weight of the vibrating system,
m – mass of pile, m_0–static mass of vibrodriver,
N_t – dynamic toe-resistance of soil,
N_{sh} –resultant force of normal pressure of soil on lateral pile surface,
F_{sh} – shaft resistance: resultant force of dynamic friction resistance of soil on the lateral surface of pile,
z – the distance from ground surface to the bottom end of the pile, measured off vertically downwards.

Soil resistance

For theoretical researches of the vibrodriving process the different calculation models of interaction of soil and driving element are used. Basically two schemes of soil resistance are applied [2], [4]: 1) perfectly plastic model of shaft and toe resistance on the lateral and front surfaces of the element, assuming that between lateral surfaces of pile and soil the forces of dry friction are acting, dynamic front resistance does not depend on sinking of pile; 2) combined model–perfectly plastic model of resistance on lateral surface and elastic-plastic on front surface.

In this work perfectly plastic model of shaft and toe soil resistance is developed, taking into account the change of properties of soil depending on a depth.

Because the area of dislocation and liquefaction of soil grain near the driving pile is small, it is assumed that active soil pressure on the vertical surface of pile remains the same as static, and the coefficient of friction between the surface of pile and soil diminishes, in consequence of this shaft resistance decrease.

Normal soil pressure on lateral surface of pile σ_x:

$$\sigma_x(z) = \gamma(z) z \lambda_a = \gamma(z) \tan^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right), \qquad (1)$$

where:

$\gamma(z)$ - specific gravity of soil, depending on the depths of bedding, law of changing is set by tests;
φ – internal friction angle of soil,
λ_a – coefficient of active pressure of soil.

Tangential shear stress of soil on lateral pile surfaces:

$$\tau(z) = \sigma_x f_\eta = \gamma(z) z \lambda_a f_\eta, \qquad (2)$$

where:

f_η - factor of internal friction depending on acceleration ratio $\eta = w/g$ according to D.D.Barkan [5]:

$$f_\eta = \tan\varphi_\eta = (f_{st} - f_\infty)e^{-\beta\eta} + f_{\infty,} \qquad (3)$$

where:

w - acceleration of pile, g - acceleration of gravity,
f_{st}- internal friction factor in the absence of vibrations,
f_∞- ultimate minimal value of internal friction factor,
β– parameter, characterizing intensity of decrease of internal friction angle,

Resultant force of dynamic shaft resistance of soil:

$$F_{sh} = \int_0^z p\sigma_x(z)dz = \int_0^z p\gamma(z) z \lambda_a f_\eta dz, \qquad (4)$$

where p - perimeter of the driving element.

Resultant of dynamic toe resistance of soil:

$$N_t = sN_{tst} = sA\sigma_z(z), \qquad (5)$$

where:

s- coefficient of static pressure decrease, proposed value $s = 0{,}5$,
A - cross-section area of element,
$\sigma_z(z)$ - axial normal static stress.

Law of changing of axial normal static stress is assumed linear, depending on the depth of sinking, or with accordance to specified formulas given in [6].

Differential equation of pile motion

For the calculation of basic parameters of driving, exciting force of F(t) can be accepted changing in accordance to harmonic law:

$$F(t) = M\omega^2 \sin \Omega t = F_1 \sin \Omega t, \qquad (6)$$

where Ω - cycles frequency of excitation.

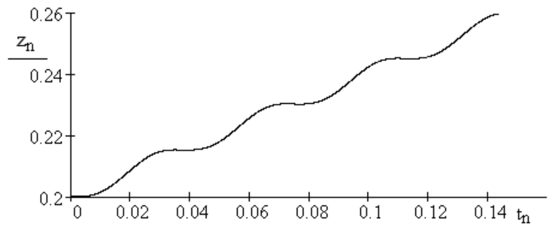
Differential equation of pile motion, considering the pile as solid:

$$(m + m_0)\ddot{z} = Q - F_{sh} sign(\dot{z}) - N_t + F_1 \sin \Omega t, \quad (7)$$

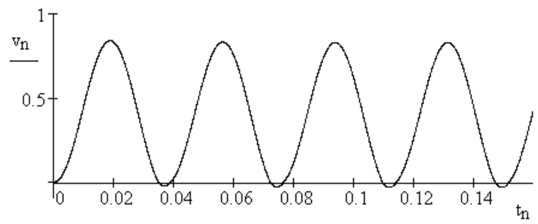
$$F_{sh} = \int_0^z p\gamma z \lambda_a f_\eta dz = p\gamma \frac{z^2}{2} \lambda_a f_{\eta},$$

$$N_t = \begin{cases} 0.5A(\sigma_0 + \Delta\sigma z), & if \quad \dot{z} > 0 \\ 0, & if \quad \dot{z} \le 0 \end{cases}$$

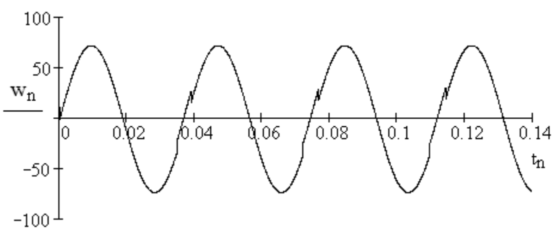
In the case of joining electric motor on springs the proper force is added.



a) z=*z(t)*

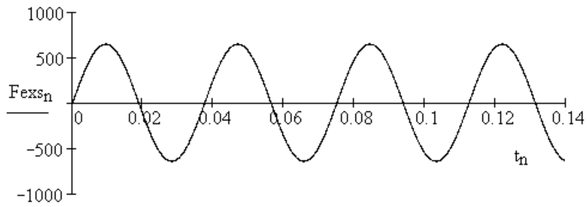


b) v=v(t)

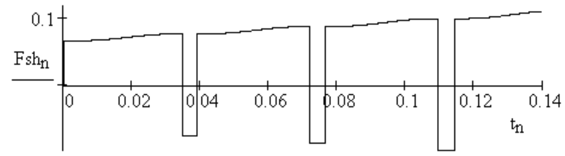


c) *w=w(t)*

Fig. 3. Parameters of motion dependence on time:
a) displacement z=z(t), b) velocity v=v(t),
c) acceleration w=w(t)



a)



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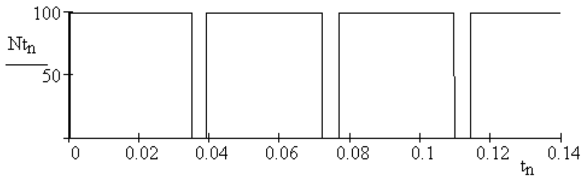


c)

Fig. 4. Acting forces dependence on time: a – exciting force, b –shaft soil resistance, c –toe resistance

Numerical example. The modelling of vibrodriving of sheet pile into dense wet sandy soil with constant specific gravity γ*=18 kN/m*^{3}, β*=26,* $\varphi=\varphi_{st}$*=36˚,* φ_∞*=10˚,* σ_0*=6820 kPa,* $\Delta\sigma$*=106,25 kPa.* Double Z- shaped pile with length *L=18 m*, mass *m= 4.464 t*, cross-section area *A=316 cm*^{2} and perimeter *p= 3.98 m* s is sinking on the depth *l= 17.5 m* with help of vibrator with maximal exciting force F_1*= 645кН*, frequency *N=26.67Hz*, angular speed Ω*=167.55s*$^{-1}$, amplitude *a=16 mm* and mass m_0*= 4.39 t*.

Differential equation (7) is solved numerically using Euler's method. In Fig. 3÷6 the graphs of dependence of displacement, velocity, accelerations, shaft and toe soil resistance on time at the beginning and at the end of driving process are presented.

Making a plots of pile motion parameters it is possible to reveal correctness of selection of vibrodriver, i.e. possibility of driving given pile into given soil on required designed depth with given vibrator, or necessity of the additional static set-on-weight, the additional vibrator with other frequency or changing of vibrator.

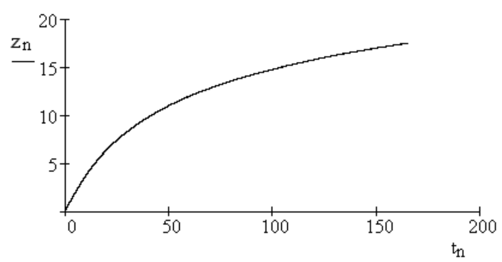


Fig. 5. Plot of pile displacement dependent on time

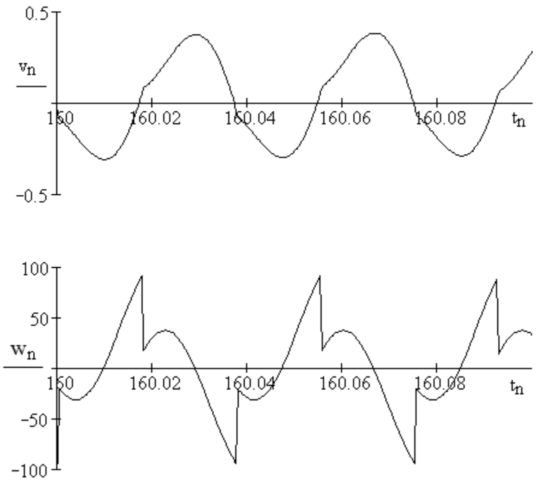


Fig. 6. Velocity and acceleration dependence on time at the end of process

III. Dynamical stability of a driving pile

For structural elements like bars or rods under action of the longitudinal periodic force the origination of the considerable lateral vibrations – loss of dynamical stability or parametrical resonance is possible [7], [8], [9]. Such possibility exists for piles and sheetpiles, which are driving into a soil by means of vibrator, the destruction of such piles occurs, especially after rest and densification of soil. Nevertheless, usually the dynamic models of piles vibrodriving are not examined and model tested in practice does not exist.

In this work three models of sheetpile are examined: perfectly rigid bar with elastic hinge, hinged-supported flexible beam and rigid-fixed flexible cantilever.

Differential equations are brought to Mathieu equation in standard form:

$$\ddot{\varphi} + (a - 2b\cos 2\tau)\varphi = 0 . \qquad (8)$$

Special functions ((Mathieu functions), which were studied in detail, are the solutions of this equation.

These solutions may be either limited, or increasing without limit. Allocation of parameters *a* and *b* regions, corresponding to these cases, leads to the stability diagram – the diagram of Eins – Strett [8], [9]. The boundaries between the regions of stability and instability are the periodic motions.

Model of perfectly rigid bar

When driving of pipe or rigid sheetpile the element may be considered as perfectly rigid bar with the lumped weight (vibrodriver) on the top end and with support resiliently resisting to the rotation (elastic hinge) in the bottom end (рис.7).

Such model is acceptable to the short rigid elements which being sank on a small depth, meet a considerable toe resistance.

Agreed notations:

φ- rotation angle of bar (deviation from avertical),

m_1 – mass of vibrodriver,

m – mass of driving element,

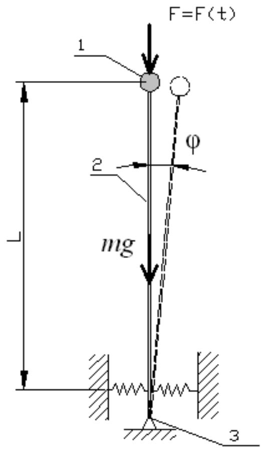


Fig. 7. Scheme of perfectly rigid bar with elastic hinge: 1-vibro-driver, 2 - pile, 3 - the elastic hinge

C – stiffness coefficient of the elastic hinge,

$M = C\varphi$ - the restoring moment in the hinge.

The equation of static equilibrium of pile and value of critical force:

$$Fl\varphi + \frac{mgl\varphi}{2} - C\varphi = 0,$$

$$F_{kr} = \frac{C}{l} - \frac{1}{2}mg.$$

Differential equation of motion of element under action of the exciting force $F(t) = F_0 + F_1 \sin\Omega t$:

$$\left(\frac{ml^2}{3} + m_0 l^2\right)\ddot{\varphi} = (F_0 + F_1 \sin\Omega t) l\varphi + mg\frac{l\varphi}{2} - C\varphi,$$

or:

$$\ddot{\varphi} + \frac{3}{(m+3m_0)l}\left(\frac{C}{l} - \frac{mg}{2} - m_0 g - F_1 \sin\Omega t\right)\varphi = 0 \qquad (9)$$

For reduction of this equation to the form (8) let assume $2\tau = \frac{\pi}{2} + \Omega t,$ then *a* and *b* coefficients will be:

$$a = \frac{12}{(m+3m_0)\Omega^2 l}\left(\frac{C}{l} - \frac{mg}{2} - m_0 g\right),$$

$$b = \frac{6F_1}{(m+3m_0)\Omega^2 l}.$$

When the frequency Ω of excitation force encrease, parameters *a* and *b* decrease, but ratio of these parameters remains constant and the successive states of the system are determined by image points on the ray of $a=b/k$, where angular coefficient *k* is:

$$k = \frac{b}{a} = \frac{F_1}{2\left(\frac{C}{l} - \frac{mg}{2} - m_0 g\right)} = \frac{F_1}{2(F_{kr} - F_0)}. \qquad (10)$$

The frequency of the exciting force corresponding to the given parameter *b*:

$$\Omega = \sqrt{\frac{6F_1}{b(m+m_0)l}} . \qquad (11)$$

Numerical example: In Fig. 8. Eins – Strett diagram of stability is plot as a=f(b), on the diagram stability areas are shown by dark colour. The boundaries of regions of stability are built according to the known, described in literature equations [7], [6].

Two variants of pile vibrodriving of double Z-shaped cross-section profile with length of l=12m and mass m=1.754t are considered:

- using of vibro-driver with normal frequency N=*26.67Hz*, *Ω=167.55s*$^{-1}$, dynamic and static force values $F_0 = m_0 g = 43.09$ *kN*; $F_1 = 645$ *kN;*
- using of high-frequency vibro-driver with *N=43.33Hz*, *Ω=272.27s*$^{-1}$, $F_0 = m_0 g = 14.33$ *kN*, $F_1 = 410$ *kN.*

At value of stiffness coefficient of the elastic hinge *C*=20000*kNm*, for the first case the coefficient *k1=0.200* is received, for second *k2=0.125*. Representation rays are shown on the plot.

The first ray crosses the boundaries of regions in points *b=0.166; 0.248; 0.789; 0.854 etc.*, in which frequency of exciting force *Ω=11.41; 9.34; 5.235; 5.031 s*$^{-1}$, etc.

The second ray crosses boundaries of regions in points *b = 0.111; 0.143; 0.496; 0.512* etc., in which *Ω = 17.38; 15.33; 8.21; 8.08 s*$^{-1}$ etc.

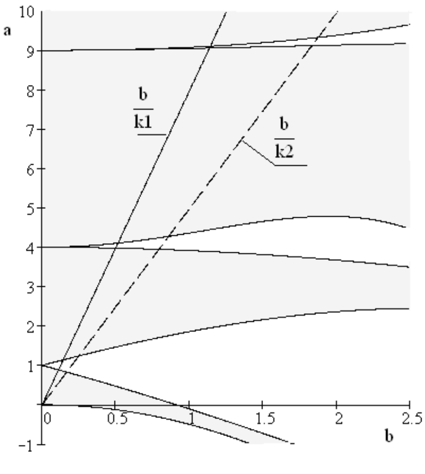


Fig. 8. Eins–Strett diagrams of the stability regions for double Z- profile and representation rays for *k1=0.200 и k2=0.125*

For both cases of the real systems, examined in accordance with such model, the system does not lose stability, because frequency of both variants of vibro-drivers is considerably higher.

Models of flexible beam

Most of widely applied as piles U- and Z- shaped profiles have less cross-sections and must be considered as flexible. The equation of flexural vibrations of uniform cross section beam:

$$\frac{\partial^2 z}{\partial t^2} + \frac{EI}{m}\frac{\partial^4 z}{\partial x^4} = 0, \qquad (12)$$

where:
m – mass of beam distributed on unit of length,
EI- beam stiffness.

Differential equation of elastic bending vibrations of uniform cross-section beam (Fig.9-a) under longitudinal force, in linear approach (Belyaev's problem):

$$\frac{\partial^2 z}{\partial t^2} - \frac{N}{m}\frac{\partial^2 z}{\partial x^2} + \frac{EI}{m}\frac{\partial^4 z}{\partial x^4} = 0 .$$

In the case of periodically changing axial force $F(t) = F_0 + F_1 \sin \Omega t$:

$$EI\frac{\partial^4 z}{\partial x^4} + (F_0 + F_1 \sin \Omega t)\frac{\partial^2 z}{\partial x^2} + \frac{EI}{m}\frac{\partial^4 z}{\partial x^4} = 0 . \qquad (13)$$

Supposing the solution in the form of $z = A(t)\sin\frac{n\pi x}{l}$, where *n=1; 2; 3; …*, we receive:

$$\ddot{A} + \frac{n^2\pi^2}{ml^2}\left(\frac{EIn^2\pi^2}{l^2} - F_0 - F_1 \sin \Omega t\right)A = 0 . \qquad (14)$$

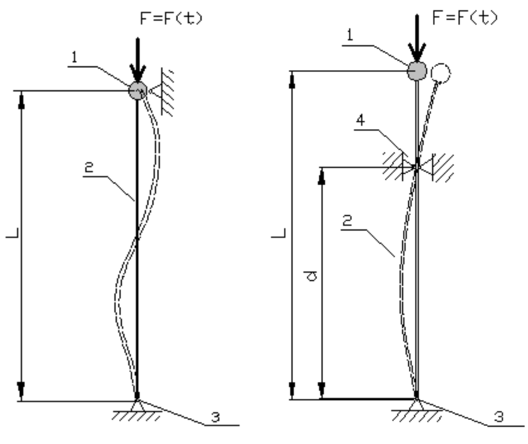
Taking into account that Euler's critical force (buckling force) F_{kr} is equal:

$$\frac{EIn^2\pi^2}{l^2} = F_{kr}, \qquad (15)$$

equation (14) may be written:

$$\ddot{A} + \frac{n^2\pi^2}{ml^2}\left(F_{kr} - F_0 - F_1 \cos\left(\Omega t + \frac{\pi}{2}\right)\right)A = 0 \;; \qquad (16)$$

$$a = \frac{4n^2\pi^2(F_{kr} - F_0)}{m\Omega^2 l^2}; \quad b = \frac{2n^2\pi^2 F_1}{m\Omega^2 l^2} . \qquad (17)$$



a) b)

Fig. 9. Cases of hinged-supported beam: a) single-span
b) single-span with overhanging

Frequency of natural lateral vibrations of single-span hinge-supported beam is equal:

$$\omega_0 = \frac{\pi^2 n^2}{l^2}\sqrt{\frac{EI}{m}} \quad . \qquad (18)$$

Frequency of natural lateral vibrations of single-span hinge-supported beam, taking into account longitudinal force:

$$\omega = \omega_0\sqrt{1+\frac{Nl^2}{\pi^2 n^2 EI}} = \omega_0\sqrt{1+\frac{N}{F_{kr}}} \quad .$$

In case of compressing longitudinal force F_0:

$$\omega = \omega_0\sqrt{1-\frac{F_0}{F_{kr}}}. \qquad (19)$$

Taking into account (19) equation (14) may be written as following:

$$\ddot{A} + \omega^2\left(1 - \frac{F_1}{F_{kr}-F_0}\sin\Omega t\right)A = 0\,. \qquad (20)$$

Then coefficients of Mathieu equation will be equal:

$$a = \frac{4\omega^2}{\Omega^2}; \qquad b = \frac{2\omega^2}{\Omega^2}\frac{F_1}{(F_{kr}-F_0)}.$$

Let us denote frequency ratio $p=\omega/\Omega$, and then coefficients of Mathieu equation will be written:

$$a = (2p)^2; \qquad b = 2p^2\frac{F_1}{(F_{kr}-F_0)}\,.$$

Significant importance for the arising of dynamic resonance have the points: a=1,4,9,16….and, therefore, frequency ratio $p = \frac{1}{2}\sqrt{a} = \frac{1}{2},\ \ 1,\ \ \frac{3}{2},\ \ 2,\ \ \frac{5}{2},\ldots$

For other cases of beam supports formulae (15), (18) and (19) in the first approximation may be written:

$$F_n = \frac{EI\alpha_n{}^2}{l^2}\,, \qquad (21)$$

$$\omega_0 = \frac{\alpha_n{}^2}{l^2}\sqrt{\frac{EI}{m}}\,, \qquad (22)$$

$$\omega = \omega_0\sqrt{1-\nu_n\frac{P_0}{P_n}}\,, \qquad (23)$$

where:

α_n – root of characteristic equation (12) of the beam lateral vibration without axial force,

ν_n – coefficient, characterizing the boundary conditions and vibrations mode.

Equation (20) for any case of beam supports:

$$\ddot{A} + \omega^2\left(1 - \frac{F_1}{F_n-\nu_n F_0}\sin\Omega t\right)A = 0\,. \qquad (24)$$

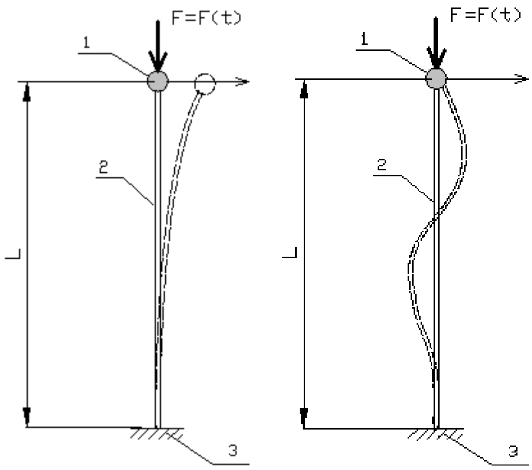


Fig. 10. Scheme of flexible console beam with rigid fixing

Numerical example. Two cases of flexible beam models are examined for U-shaped pile with *m=76.9kg/m*, $I=7.2{*}10^{-5}\ m^{-4}$, $E=2.1{*}10^{8}\ kN/m^2$, which is drived by the vibrator with frequency N=*26.67Hz*, $\Omega=167.55s^{-1}$, $F_0= m_0g =43.09\ kN$; $F_1=645\ kN$.

The first case is single-span hing-supported beam (Fig. 9.a) of length *L=22 m*, *the second* - beam with rigid fixing (Fig. 10) of length *L=18.5 m.*

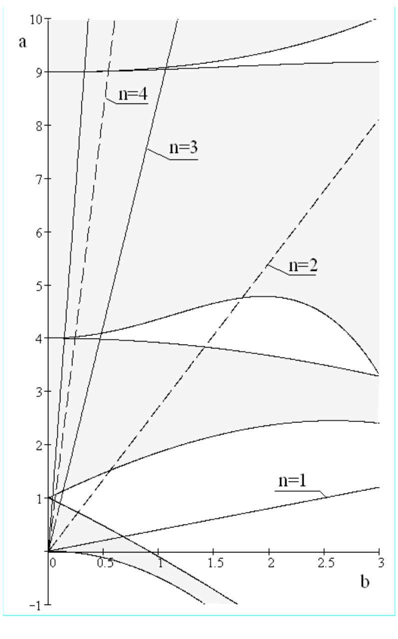


Fig. 11. Eins–Strett diagrams of the stability regions for U - profile hing-supported single span beam, *L=22 m*

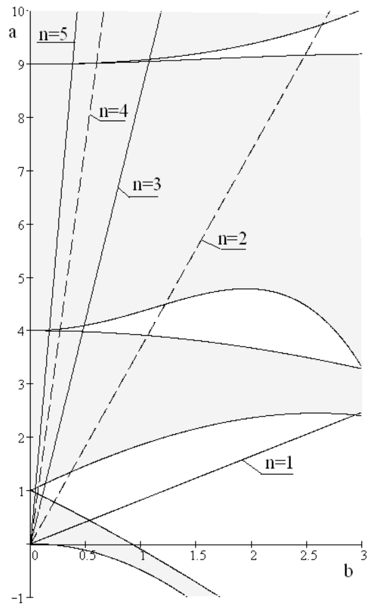


Fig. 12. Eins–Strett diagrams of the stability regions for U - profile beam with rigid fixing, *L=18,5 m*

The case of beam with rigid fixing is more possible when long-size elements are driving into dense soil, for this case the coefficient $\alpha_n = (2n-1)\pi/2$, where *n*- number of natural vibration mode

Eins–Strett diagram for the first case is given in Fig. 11, for the second - in Fig. 12, representation rays for the first five mode of vibration are shown on each plot.

Dynamic instability of hing-supported single span beam is possible for *n=3*, gap of coefficient *b* is *0.105 < b <0.134,* consequently, dangerous frequency lies within the limits of *151.9 < Ω < 170.9.*

Dynamic instability of cantilever beam with rigid fixing is possible for n=4, where *0.106 < b < 0.135* and *150.0 < Ω < 178.7.*

IV. Conclusion

Usually choosing of vibrodriver is guided by reasoning that total loading on pile must be sufficient for overcoming of forces of soil resistance and do not exceed static critical force. Nevertheless sometimes breakage of sheetpile may occur during driving, and it is noticed that failures happen during piles post-driving after some pause; it can be (technological interruption on replacement of vibrator etc.). These failures may be explained by densification of sandy soils after stopping of action of high-frequency vibrations and decreasing of the possibility of their liquefaction. Thus the bottom end of pile can appear both rigid-fixed and hinged. In spite of the fact that longitudinal central force well below than static critical force, for the element under periodic axial loading the possibility exists of loss of dynamical stability or parametrical resonance. The basic difference of parametrical resonance from usual resonance of the beam:

1. dynamical instability arises not at one (for given *n-th* vibration mode) relation of natural frequency of beam *ω* to frequency of exciting force *Ω*, but at the relations close to: *p = j/2, j=1,2,3 …;*
2. practical value have the areas close to the frequencies ratio *p =1/2, 1*, (coefficient *a=1;4*), i.e. areas with the minimal threshold of excitation of vibrations, further the origin of vibrations becomes difficult;
3. for the origin of loss of dynamical stability a presence of initial imperfections - axis curving, disalignment, eccentricity of application point of resultant force and so on, is a necessary factor.

Choosing the vibrators, which will be able to drive the pile to the required depth, except check the conditions of drivability $Q + F_1 > F_{sh} + N_t$ and static critical force, it is necessary to carry out the examination of dynamical stability of driving elements. It is especially important to carry out check of dynamical stability for piles which have the big free length remained (piles for offshore structures, for borings works etc.)

References

1. **Blechman, I. I.** *Vibrational Mechanics: Nonlinear Dynamics Effects, General Approach, Applications*. World Scientific Publishing Co. Ltd., 2003, 509 p.
2. *Vibrations in engineering. V. 4. Vibration processes and machines.* Lavendel E.E., editor, Moscow: Mashinostroenie, 1981. 509 p. (in Russian)
3. **Voznesensky, E.A.** Earthquakes and Soil Dynamics. *Soross educational magazine*, N 2, 1998, 101-108 p. (in Russian)
4. **Holeyman A. Vender Borge & J.-F. Charue, N.** *Vibratoty Pile Driving and Deep Soil compactiopn*. Liss, the Netherland: Swets & Zeitlinger B. V., 2002. 246 p.
5. **Harhuta, N., Vasiljev, J.** *Strength, Stability and Compression of Ground bed of Highways*. Moscow: Transport, 1975, 288 p. (in Russian)
6. **Polukoshko, S., Kononova, O., Sokolova, S.** Research of Pile Driving Process in Various Tipe of Soil by Impact Method. *Scientific Proceedings of Riga Technical University. Transport and Engeneering,* seria 6, vol. 28, 2008, 151-160 p.
7. *Vibrations in engineering .V. 1. Vibrations of the linear systems.* Bolotin, V.V., editor. Moscow: Mashinostroenie, 1978, 352 p. (in Russian)
8. **Mangus, L.** *Vibrations*. Moscow: Mir, 1982, 304 p. (in Russian)
9. *Vibrations in engineering. V. 2. Vibrations of the nonlinear mechanical systems.* Blechman, I. I., editor. Moscow: Mashinostroenie, 1979, 351 p. (in Russian)

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Svetlana Polukoško, Olga Kononova, Svetlana Sokolova. Dinamiskie efekti pāļu vibroiegremdēšanas procesā
Pāļu vibroiegremdēšana gruntīs ir sarežģīts mehānisks process, kurā tiek novērotas tādas parādības kā gremdējamo elementu apkārtējās grunts struktūras izmaiņas, berzes spēka starp grunti un gremdējamā elementa virsmu pazemināšanās. Vibrācijas pielieto, iegremdējot elementus ar salīdzinoši mazu

šķērsgriezuma laukumu: metāla rievpāļus un caurules. Iegremdējamo elementu garums nav ierobežots. Pie periodiski mainīgu ass spēku darbības uz gremdējamajiem elementiem rodas dinamiska elementa līdzsvara zaudēšanas iespēja parametriskās rezonanses dēļ, ja elementa apakšgala pārvietojums ir apgrūtināts ar cietu, piemēram, klinšainas grunts starpslāni vai sašķidrinātas smilšainas grunts sablīvēšanās dēļ.
Šajā darbā piedāvāts pārbaudīt vibratoru parametrus ar elementu iegremdēšanas norises matemātisku modelēšanu un to dinamiskās noturības pārbaudi. Piedāvāts sāniskas un frontālas grunts pretestības plastisks modelis, ievērojot grunts īpašību izmaiņas dziļumā, un pāļa kustības vienādojums, kas atrisināts skaitliski. Skaitliskā rezultātu analīze rāda elementu iegremdēšanas iespēju vajadzīgajā dziļumā ar vienu vibratoru ar dotajiem raksturlielumiem vai papildus statiskas slodzes pielikšanu, vai vibratora nomaiņu. Ir pārbaudāma dinamiskas nestabilitātes rašanās iespēja un rezonanses nosacījumi, modelējot pāli kā absolūti cietu ķermeni un kā lokanu siju. Ir pierādīta dinamiskās noturības zaudēšanas iespēja pēc iegremdējamo elementu svārstību augstākajām formām. Elementi izvēlēti no visbiežāk pielietotajiem velmētiem metāla profiliem un ir aplūkojami kā lokani stieņi.

Светлана Полукошко, Ольга Кононова, Светлана Соколова. Динамические эффекты при вибропогружении свай

Вибрационное погружение элементов в грунты является сложным механическим процессом, сопровождающимся такими явлениями, как изменение структуры грунтов, окружающих погружаемый элемент, разжижением их, снижением сил трения между грунтом и поверхностью погружаемого элемента. Вибрационный способ применяется при погружении элементов со сравнительно малой площадью поперечного сечения металлического шпунта и труб. При действии на погружаемые элементы периодически меняющихся продольных сил возникает возможность потери динамического равновесия элемента из-за параметрического резонанса, когда перемещение нижнего конца элемента затруднено из-за прослоек прочного грунта или уплотнения грунта.
В данной работе предлагается проверять параметры вибраторов путём математического моделирования процесса погружения элементов и проверки их динамической устойчивости. Предлагается пластическая модель бокового и лобового сопротивления грунтов при вибропогружении с учётом изменения свойств грунтов по глубине, записывается уравнение движения сваи в грунте, которое решается численно. Анализ численного решения показывает возможность погружения элементов на данную глубину одним вибратором с данными характеристиками, или необходимость в дополнительном статическом пригрузе, дополнительном вибраторе или смене вибраторов. Проверяется возможность возникновения динамической неустойчивости и условия резонанса при моделировании сваи как абсолютно твёрдого тела и как гибкой балки. Доказана возможность потери динамической устойчивости по высшим формам колебаний погружаемых элементов из часто применяемых металлических прокатных профилей, рассматриваемых как гибкие стержни.