METHOD FOR DETERMINING WORKING REGIMES WITH REASONABLENESS OF EQUIPMENT CASING PIPES BY ROTARY PRESS – IN

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According to the collected data of soil mass in the cone penetration test, the research paper defines a drag on the steel casing pipe used for constructing bored pile by the rotary press – in method. Hence, this paper proposes a way of defining the working regime with the reasonableness of equipment casing by this technique, which will be regarded as a necessary step to design the installation of the equipment on the available base machine in Vietnam with the intention of not only maximizing the capacity of transmission but also improving the machine’s productivity as well. It makes a contribution to reduce the investment’s costs and increase the effective exploitation of this equipment in Vietnam.

Key words: equipment casing, rotary press – in method, base machines, reasonable working regimes

INTRODUCTION

The construction of bored pipe by the method used the casing for the whole drill hole is applied to the complicated geology condition, allowing to ensure the quality and trust of bored pile. Thus, this method has been widely applied in over the world and this is also the first time to apply in Viet Nam for executing big projects with the complicated geology condition (i.e., My Thuan Bridge, Can Tho Bridge…). In addition, the technology and executed equipment has been recently developed and improved by many companies as shown in [1-3]. The set of equipment casing by a rotary press – in method (RPM) for constructing the bored pile pointed out in Figure 1. It comprises a base machine 1 working with the equipment 4 and connecting to the structure 5 [1-3]. The working equipment consists of two main parts which are pressing mechanism and rotary mechanism used for penetrating the casing pipe 2 into the ground according to the spiral orbit. The function of the base machine is not only to provide the transmission source for working equipment but also prevent working equipment from a rotating by connecting to the structure 5 as well. Nowadays, this kind of the equipment has a great demand to use for constructing the bored piles in construction on the ground with complicated geological conditions (it should be noted that this equipment is able to ensure the quality of the constructed bored pile). Hence, the studies on designing, manufacturing and exploiting for this equipment are effectively necessary.


Table 1: The specification of rotary – press in equipment [1-3]

<table>
<thead>
<tr>
<th>Name (brand)</th>
<th>LIEBHERR-LEFFER</th>
<th>SOILMEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque Mmax, [KN.m]</td>
<td>2300</td>
<td>2900</td>
</tr>
<tr>
<td>Speed n, [rpm]</td>
<td>0 ÷ 1.1</td>
<td>0 ÷ 1</td>
</tr>
<tr>
<td>Pressing force Nmax, [KN]</td>
<td>1890</td>
<td>2400</td>
</tr>
<tr>
<td>Kind of base machine</td>
<td>HS 833 HD</td>
<td>HS 855 HD</td>
</tr>
<tr>
<td>Weight, [KN]</td>
<td>320</td>
<td>420</td>
</tr>
</tbody>
</table>

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By comparing specification of the type of equipment produced by famous brands presented in Table 1 [1-3], it is clear that the available bored pile drilling rig can be used as the base machine in the set of equipment in order to reduce the cost and improve the exploited efficiency. The process of penetrating casing steel pipe into the ground by working equipment shown in Figure 2 is cyclical (lowered depth is equivalent to the stroke length of cylinder 8). At the starting point of cycle, the cylinder 8 is in the fully extended status, and the controlling cylinder 6 through the frame 5 is lower than wedge 3 for connecting to the inner ring of rotary headrest device installed on the main frame 2 with casing pipe 4. Simultaneously, the pulling cylinder 8 with the opening of rotary mechanism 9 is used for the lower casing pipe 4 via the main frame 2, rotary headrest device 7 and wedge 3. When the cylinder 8 reaches to the maximum point of stroke length, the cylinder 6 is able to separate the wedge 3 from the casing pipe 4. It is also extended to start a new cycle.

**Figure 2: The diagram of equipment casing by rotary press – in method**


For the purpose of ensuring the stability of working machine during working process, the weight of working equipment with the counterweight 14 keeps working machine from “uplifting” the under pressing force N. Together with the restraint 13, it is not only the friction force between working equipment and the ground but also the friction force between the base machine and the ground (through the frame 5 – as shown in Figure 1) that prevent working equipment from being rotated by a shaft torque (M).

### Determination of Resistances on Casing Pile Penetrated by the RPM According to Data from Cone Penetration Test (CPT)

The equipment casing by the RPM and a steel casing pipe are bearred by the combination of a rotational jacking force (torque) and a vertical jacking force. The soil’s resistance on a pile is combined with forces that have no any relevance to the interaction of the pile soil, including the pile’s weight and the chucking part’s weight of the equipment casing pipe. By omitting unnecessary forces, these components are synthesized into the vertical resistance N and the rotational torque in the horizontal plane M. The model for determining the drag acting on the casing pipe is shown in Figure 3, where parameters (N and M) consist of the resistive components at the tip of the base component (base force (Nb) and base torque (Mb)) and the resistance on a shaft component (vertical shaft force Ns, shaft torque Ms) is expressed in the below equations, i.e.

\[
N = N_b + N_s, \quad (1)
\]

\[
M = M_b + M_s, \quad (2)
\]

where the term \(N_b\) is calculated by the Lehane, Xu and Kempfert methods [4-6], including the influence of the soil mass inside the casing pipe and change state of soil mass in the bottom casing pipe when being lowered.

\[
N_b = q_b \pi D^2 \frac{4}{4}, \quad (3)
\]

where \(q_b\) includes the effect of resistance of the soil mass in the bottom casing pipe [5, 6] being the intensity of closed-ended casing pipe with the outer diameter D (large diameter pipe). Thus, it is defined as:

\[
q_b = (0.15 + 0.45A_r)q_c, \quad (4)
\]

where \(A_r = 1-(d/D)^2\) is given by Figure 3(b), \(q_c\) is defined according to the CPT tip stress at piling depth (KN/m²) [7, 8], and the parameters of d and D are respectively the internal and external diameters of the casing pipe respectively (the unit is in m). The vertical resistance generated by sliding resistance and distributed on the shaft casing pipe is determined by the below equation:

\[
N_s = N_{sp} + N_{is}, \quad (5)
\]

where \(N_s\) is the vertical resistance of the casing pipe and \(N_{sp}\) the vertical resistance force of the outside casing pipe. When a factor of the surface area of the casing...
Figure 3: Model for determining the resistance force acting on the steel wall pipe a) force balance diagram, b) the pipe area element in the axial direction (z), c) diagram of the stress components of the soil acting on the wall pipe during lowering, d) earth pressure acting on the wall of the pipe, e) velocity on the pipe surface.

The pipe is calculated by $dA = \pi D dz$ (Figure 3, b), the sliding resistance distributed on the casing pipe surface is $\tau = \sigma' \tan \delta_s + c_c$ [9]. For that, one has: $dN_{sp} = \tau_s dA = \tau_s \pi D dz = \pi D (\sigma' \tan \delta_s + c_c) dz$, (6) where $\sigma'_h$ is the horizontal effective stress (KN/m$^2$) (Figure 3, d), $\delta_s$ is the friction angle between soil and the steel casing pipe (degree) and $c_c$ is the force created by cohesion of soil and steel casing pipe taken from the CPT (KN/m$^2$) [7, 8]. It should be noted that if $v_t$ is the long velocity in the horizontal plane, $v$ is the slide velocity and $v_d$ is the vertical velocity of any point B on the surface casing pipe (Figure 2 and Figure 3 (d)). The term $\alpha$ is the angle between the slide velocity and long the horizontal velocity. Hence, one gets:

$$\tan \alpha = \frac{v_d}{v_t}, \; n = \frac{60v_d}{\tan \alpha D n}; \; a = 0^0 \div 90^0,$$

(7)

Then unit friction slide is illustrated in Figure 4 (a) and the vertical force generated by the resistance on the surface shaft casing pipe is computed by the below equation:

$$N_{sp} = \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \int_0^z dN_{sp} = \frac{\pi D}{\sqrt{1 + \tan^2 \alpha}} \int_0^z (\sigma'_h \tan \delta_s + c_c) dz.$$

(8)

Figure 4: Lower wall pipe through n layers of soil
a) Unit friction slide, b) Effective stress across multiple soil layers
The casing pipe is penetrated through n layers of soil, if \( \sigma'_{r_i} \) is taken as the mean effective stress value of the \( i \)-th soil layer (KN/m²), \( \delta_{s_i} \) is the friction angle of the \( i \)-th soil layer and the steel casing pipe (degree), \( c_i \) is the soil cohesion of \( i \)-th soil layer and steel casing pipe which is taken from the CPT (KN/m²) [7, 8]. The equation (8) is then written as:

\[
N_{sp} = \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \pi D \left( \sum_{i=1}^{n} h_i (\sigma'_{r_i} \tan \delta_{s_i} + c_i) \right),
\]

(9)

where \( h_i \) is the \( i \)-th soil layer thickness. In the same way, the vertical force friction of the soil mass in the bottom casing pipe \( N_i \) is defined by the below equation:

\[
N_i = \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \pi dh_p (\sigma'_{r_p} \tan \delta_{s_p} + c_p),
\]

(10)

where \( \sigma'_{r_p} \) is the horizontal effective stress of the load of the soil mass in the bottom casing pipe (KN/m²), \( \delta_{s_p} \) is the friction angle of the soil mass in the bottom casing pipe and the steel (degree), \( c_p \) is soil cohesion of the soil mass in the bottom casing pipe and steel taken from the CPT (KN/m²) and \( h_i \) is the effective height of the soil column at the bottom casing pipe which is empirically taken 0.8h (m) [4-6]. The torque in the horizontal plane at the tip of the casing pipe is considering as an elemental area on the cross-sectional area of the casing pipe \( dA=2\pi r \)dr, where \( r (d/2÷D/2) \) is the distance between the center of the tube and the inside and outside of the casing pipe surface (Figure 3, b). The elemental friction sliding force between the soil and the tip of the casing pipe is calculated by the below equation:

\[
dF_b = q_b \tan \delta_{sp} \, dA = 2\pi qr_b \tan \delta_{sp} \, dr.
\]

(11)

The friction moment of an elemental area on the center of the section is expressed as:

\[
dM_b = 2\pi qr_b \tan \delta_{sp} \, r \, dr
\]

(12)

\[
N = \frac{\pi D^2}{4} + \frac{\pi D \tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \left( \sum_{i=1}^{n} h_i (\sigma'_{r_i} \tan \delta_{s_i} + c_i) \right) + \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \pi dh_p (\sigma'_{r_p} \tan \delta_{s_p} + c_p) \cdot kN
\]

(17)

\[
M = \frac{\pi q_b \tan \delta_{sp} (D^3 - d^3)}{12} + \frac{\pi D^2 (\sum_{i=1}^{n} h_i (\sigma'_{r_i} \tan \delta_{s_i} + c_i))}{2\sqrt{1 + \tan^2 \alpha}} + \frac{\pi d^2 h_p (\sigma'_{r_p} \tan \delta_{s_p} + c_p)}{2\sqrt{1 + \tan^2 \alpha}} \cdot kNm
\]

(18)

Therefore, the parameters of the geological condition and equipment of casing pipe, \( N, M, v_p \) and \( n \) used for the design of equipment casing by rotary press – in method are able to be calculated by the equations (7), (17) and (18). However, in the equations (7), (17), (18), the value of the functions \( N, M, v_p, n \) depends on the term of \( \alpha \). On the other hand, each value of \( q \) leads to a different set of parameters \( (N, M, v_p, n) \), which is specific for working regime of working machines.

**METHOD OFF DEFINING REASONABLE WORKING REGIMES**

The aim of problems is to define the reasonable working regimes of the equipment casing by the RPM, which is suitable for the base machine in Vietnam. Based on the input parameters known in advance (geological conditions of soil mass; casing steel pipe; selected base machines), the value of \( q \) corresponding to the reasonable working regime \( (N, M, v_p, n) \) of the working equipments is defined to bring into play a maximum power of machines and powers, and to obtain the highest point of the productivity of the machine (\( v_p^{max} \)). This means that it will be satisfied the requirements of the process of lowering casing steel pipe given in equations (7), (17), (18) and ensuring the stability of working equipment with small counterweight.
The law of variation and the relation of specific parameters for working regimes of working equipments

The law of variation of pressing force (N) and rotary torque (M) regarding to the papermeter (α) is defined by the equations (17) and (18) (see Fig. 5). On the other hand, the pressing speed (νp) and rotary speed (n) depend on each other in the equation (7). Therefore, each value of α defines the corresponding values of N and M according to the Figure 5. However, the n and νp are proportional to each other by α in the equation (7) to ensure the process of lowering casing pipe into the ground.

Figure 5: The law variation of M and N flowing to α

The power (P_e) of the base machine used for transmitting mechanism of pressing casing pipe is defined as:

\[ P_e = \frac{N \nu_d}{\eta_e} \cdot kW, \]

(19)

\[ N = q_p \frac{\pi D^2}{4} + \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \pi D \left( \sum_{j=1}^{n_j} h_j (\sigma'_j, \tan \delta'_j + c_p) \right) + \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} \pi d h_p (\sigma ''_p, \tan \delta''_p + c_p) \]

\[ M = \frac{\pi q_b \tan \delta w}{12} (D^3 - d^3) + \frac{\pi D^2 (\sum_{j=1}^{n_j} h_j (\sigma'_j, \tan \delta'_j + c_p))}{2\sqrt{1 + \tan^2 \alpha}} + \frac{\pi d^2 h_p (\sigma ''_p, \tan \delta''_p + c_p)}{2\sqrt{1 + \tan^2 \alpha}} \]

(21)

\[ n = \frac{60 \nu_d}{\eta_e} \frac{\tan \alpha D \pi}{12} \]

\[ P_x = \frac{N \nu_d}{\eta_e} \]

\[ P_P = \frac{\pi M n}{30 \eta_e} \]

Steps of solving problems for determining reasonable working regimes of working equipments

Required parameters

- Geological conditions of soil mass necessary for lowering steel casing pipe are the inner geological section (n, D, L); physical-mechanical properties of soil layers (q, q', q'', σ', σ'', δ', δ'', δ_w', c, c_p) according to the CPT and CPTu [7, 8];
- The requirements with casing pipe needs to be lowered (D, d, L, h);

and the mechanism of rotating casing pipe (P_x) is determined by the following equation:

\[ P_x = \frac{\pi M n}{30 \eta_e}; kW, \]

(20)

where \( \eta_e \) and \( \eta_v \) is the transmission efficiency of the pressing and rotating mechanism, respectively. Figure 5 shows that the smaller the value of α is, the smaller the value of N and is and the greater the value of M is. If the value of α is small, the research question will be solved easily, because when the value of N is small, the value v_d is then great and the machine efficiency is high. On the other hand, if the value of N is small, the counterweight is small as well. However, if the value of N is small, the value of rotary torque M is great. In addition, with a great value of v_cr, which is given by the equation (3), the value of n is great. This leads to a high capacity of rotating casing, resulting in source capacity of base machine not being adapted. Therefore, in order to determine the reasonable working regime of working equipment, it is vital to calculate the values of (N, M, ν_cr, n) with (α = 50°÷900°) and define ν_cr max and N min, which meets with requirement of not only the process of lowering casing pipe but also keeping transmission source of base machine enough to drive the working machine in this working regime. The general mathematical model is stated as in the equation (21).

Sequence of defining specific parameters for working regimes of working equipments (N_j, M_j, ν_cr_j, n_j) corresponding to a value of \( \alpha_j \)

- Step 1: with the given value of \( \alpha_j \), the value of N_j, M_j is defined via the equations (17) and (18);
- Step 2: With the given value \(N_j, M_j\) the value of pressing speed \(v_{dj1}\) is defined via the equation (19) (maximizing the capacity of pressing mechanism). With the value of \(v_{dj1}\), the rotary speed \(n_{j1}\) is determined via the equation (7);

- Step 3: By using the equation (20), the value of rotary speed \(n_{j2}\) is defined via the values of \(M_j\) and \(P_x\) (maximizing the capacity of rotating structure), and also by using the value of \(n_{j2}\), the value of \(v_{dj2}\) is defined via the equation (7);

- Step 4: If the value of \(n_{j1}\) ≤ the value of \(n_{j2}\), the capacity \(P_x\) is enough to rotate casing pipe. For the value of \(q_j\), the specific parameters of working regime are \((N_j, M_j, v_{dj1} = v_{dj2}, n_{j} = n_{j2})\);

- Step 5: If the value of \(n_{j1}\) > the value of \(n_{j2}\), the capacity \(P_x\) is not enough to rotate casing pipe. For the value of \(\alpha_j\), the specific parameters of working regime are \((N_j, M_j, v_{dj1} = v_{dj2}, n_{j} = n_{j2})\).

### Determining the reasonable working regime of working equipment

The reasonable working regime of working equipments is the one which is corresponding to a reasonable \(\alpha\) angle with a maximum speed of pressing casing pipe \((v_d = v_{d max})\). Hence, it is vital to investigate and define specific parameters \((N, M, v_{dj}, n_j)\) as process stated in Section 3.2.2, with \(\alpha\) in its definite domain from \(5^\circ\) ÷ \(90^\circ\) (\(\alpha_1 = 5^\circ\), \(\alpha = \alpha_1 + \Delta, \alpha_m = 90^\circ\), the number of iterations \(m = (90 - 5)/\Delta\)). In order to determine the reasonable working regime with \(v_{d max} = \max(v_d, \text{with} \ j = 1 ÷ m)\), the process of iterations can be programmed on a computer with \(m\) times of iterations to find out \(v_{d max}\) with the diagram given in Figure 5. After defining the working regime of working equipments, it is able to use specific parameters \(M, N, v_d, n\) as inputs to design the working equipment, that is:

- Calculating the mechanism of the working equipment: the structure of pressing casing pipe, the structure of rotating casing pipe, the structure of controlling wedge;

- Calculating the steel structure, the platform system of working equipment and determining its own weight of the working equipment \(- G_0\);

- Calculating counterweight \(G_d\) which ensures stable condition to prevent the working equipment form “uplifting” under the pressure of compression force \(N\):

\[
G_d = k_1 N - G_0, \tag{22}
\]

where \(k_1 = 1.1 ÷ 1.2\) is the safety factor longitudinal stability.

- Calculating anti-rotation area \(F\) (\(m^2\)) which ensures stable anti-rotation condition of the working equipment under the effect of rotary torque \(M\) [10, 11]:

\[
2pFA + f(G_0 + G_d)A + f M_a = k_2 M \Rightarrow F = \frac{k_2 M - f(0.5(A(G_0 + G_d) + aG_{c2})}{2pA}, \tag{23}
\]

where \(k_2 = 1.1 ÷ 1.2\) is the safety coefficient horizontal stability, \(f\) is the friction coefficient between the platform of equipment and the chain of the base machine to the ground, parameters \((A\ and\ a)\) is given in Figure 1 and 2, \(G_{c2}\) is the weight of base machine (\(kN\)) and \(p\) is allowable stress of the ground (\(kN/m^2\)).

### Figure 6: Block diagram of the method of defining the working regime with reasonableness of working equipment

#### APPLICATION TEST

**Required parameters:**

- The geological section of the soil mass of P6 pillar of My Thuan bridge in Viet Nam is illustrated in Figure 7 and their physical-mechanical properties are given in Table 2.
Table 2: The physio-mechanical properties of the soil mass

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( h [m] )</th>
<th>( q_c [KN/m^2] )</th>
<th>( \gamma [KN/m^3] )</th>
<th>( \delta [\circ] )</th>
<th>( c [KN/m^2] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue-gray clay mud</td>
<td>10.42</td>
<td>750</td>
<td>17.1</td>
<td>6(^\circ)</td>
<td>4.1</td>
</tr>
<tr>
<td>2. Brown-gray clay with sand</td>
<td>16.76</td>
<td>1650</td>
<td>18.3</td>
<td>9(^\circ)</td>
<td>11.16</td>
</tr>
<tr>
<td>3. Brown-gray clay mud</td>
<td>18.82</td>
<td>266</td>
<td>17.2</td>
<td>9(^\circ)</td>
<td>1.4</td>
</tr>
<tr>
<td>4. Soft plastic clay</td>
<td>4</td>
<td>2200</td>
<td>18.7</td>
<td>14(^\circ)</td>
<td>20.2</td>
</tr>
<tr>
<td>5. Small solid sand</td>
<td>15</td>
<td>7420</td>
<td>20.4</td>
<td>34(^\circ)</td>
<td>0</td>
</tr>
</tbody>
</table>

- Size of casing pipe: \( d = 1220mm, D=1300mm, L = 50m, h_p = 3m. \)

- Base machine HS 833 HD produced by Liebherr brand with specifications is expressed as: two internal combustion engines: the first one is D924 TI-E Model with the capacity of 125kW which is used for the transmitting hydraulic pump with flow 1931/min; the second one is D926 TI-E Model with the capacity of 210kW which is used for driving two hydraulic pumps with total flow 4281/min and working pressure 30Mpa. This type of the base machine has an hydraulic circuit with the connector used for the driving equipment casing pipe, including two connectors: the connector with the capacity \( P_x = 160kW \) used for the transmitting rotating mechanism and the connector with the capacity \( P_e = 40kW \) for the driving pressing mechanism.

Calculation results:
By applying the method in section 2 with \( \Delta \alpha = 1, m=85, \alpha_1 = 50 \) and running on the background of C++ and Excel programme, the detailed calculation is stated in document [12]. The graph of resistance force \( N, M \) according to \( \alpha \) is illustrated in Figure 8, and the parameters of the reasonable working regime of the working equipment are listed in Table 3. The parameters of the reasonable working regime are determined in the range of the specifications of the equipment produced by famous brand.

Table 3: Parameters of the reasonable working regime of working equipments

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( \alpha_{hi} [\text{Degree}] )</th>
<th>( M [KN.m] )</th>
<th>( N [\text{Ton}] )</th>
<th>( n [\text{rpm}] )</th>
<th>( v_d [\text{m/min}] )</th>
<th>( P_e [kW] )</th>
<th>( P_x [kW] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>270</td>
<td>2690</td>
<td>185</td>
<td>0.48</td>
<td>1</td>
<td>38.5</td>
<td>160</td>
</tr>
</tbody>
</table>

CONCLUSIONS
By using the specialized knowledge and achievements in moving equipment fields, the research paper has been successfully determined the the reasonable working regime of working equipments used for lowering steel casing pipe to construct bored piles by the RPM on the weak ground with a given base machine. This is a necessary step for designing working equipments used for lowering casing pipe with the given base machine to reduce the cost of buying machine and increase economic efficiency. The developed method can be also used for determining the reasonable working regime of working equipments during the process of penetrating casing pipe through many layers of the ground with different resistance forces. This leads to maximize the capacity of driving source and improving working capacity of the equipment in various conditions. Based on the developments, an automatic software used for calculating the reasonable working regime of equipments can be extended to apply in the operation and exploitation process of equipment.
REFERENCES