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CONSOLIDATION ZONES FEATURES FORMATION OF A GROUND AROUND SQUARE SHAPED PILES

Necessity to resolve the problem of concerning the analytical dimensions definition and constructing forms of compacted zones of ground around the lateral surface of square cross section pile in normal to pile axis direction are shown in this article. Various analytical methods of ground compacted zones radius determination around cylindrical elements driven into the ground considering its initial state were analyzed. Graph-analytical method of ground compaction zones construction around square cross-section piles was developed. Efficiency of the developed methodology and analytical expressions using possibility to determine the radius of compaction zone of a ground around the driven or jacked-in elements is confirmed by comparing obtained solutions with the experimental data. The developed methodology allows increasing the efficiency and reliability of piles and pile foundations use due to their rational design.

Keywords: *pile, bearing capacity, compaction zone of a ground, movement zone of a ground, cross-section, jacking.*

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ОСОБЛИВОСТІ УТВОРЕННЯ УЩІЛЬНЕНИХ ЗОН ҐРУНТУ НАВКОЛО КВАДРАТНИХ ПАЛЬ

Доведено доцільність вирішення питання щодо аналітичного визначення розмірів та побудови форми ущільнених зон ґрунту навколо бічної поверхні квадратної палі в нормальному до осі палі напрямку. Проаналізовано різні аналітичні методи визначення радіуса ущільненої зони ґрунту навколо циліндричних елементів, що заглиблюються у ґрунт з урахуванням його початкового стану. Розроблено графоаналітичну методику побудови ущільнених зон ґрунту навколо палей квадратного поперечного перерізу. Ефективність розробленої методики та можливість використання аналітичних виразів для визначення радіуса ущільненої зони ґрунту навколо забивних або вдавлюваних елементів підтверджено шляхом порівняння отриманих рішень з експериментальними даними. З'ясовано, що розроблена методика дозволяє підвищити ефективність та надійність використання палей і пальових фундаментів за рахунок їх раціонального конструювання.

Ключові слова: *палля, несуча здатність, зона ущільнення ґрунту, зона переміщення ґрунту, поперечний переріз, вдавлювання.*

Introduction. The present-day constructions in large cities situation is often accompanied by negative engineering-geological conditions and processes. They require from the constructors to use safety and efficiently foundations and in most cases it can be piles. However in spite of their fairly significant distribution a considerable volume of factors are not currently studied. They affects diving conditions and pile working in pile foundations. The construction experience shows that diving of square cross-section piles in a pile group at a distance up to $4d$ leads to a pile turning around its axis by 45° during piling (Fig. 1). It is due to the uneven distribution of stresses and as a consequence uneven ground base compaction around the square pile.

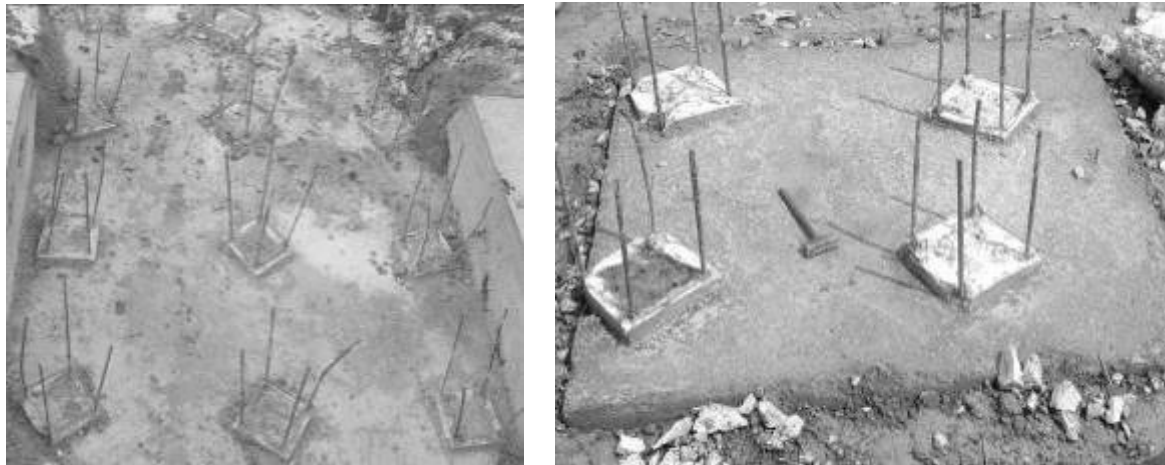


Figure 1 – Square piles turning around its axis by 45° during piling

Moreover, the numerous numbers of analytical calculation methods for determining pile foundations base deformations under the action of vertical compressive static load does not allow to obtain reliable results in comparison with experimental data. In this case the deformation characteristics of the soils given in the reports of engineering surveys are proposed to use during calculations. They do not consider the real state of the ground base, which is associated with the shape and dimensions of piles cross section, its plan position, the angle of rotation around the vertical axis passing through the cross-section of the pile and the sequence of the piling.

Analysis of recent researches and publications. Construction practice shows that the foundations installation without removing soil is accompanied with compaction zones formation. There is a change of natural physical and mechanical soil characteristics within these zones. The creation of such zones makes it possible to improve the base of foundations, enhance their bearing capacity and increase efficiency. The dimensions of these zones, their numerous and qualitative indicators should be considered in the calculation methods for determining bearing capacity and deformations of jacked or driven piles and pile foundations. However, confirmation of the developed methodology results for soil compaction zone sizes determination around jacked or driven piles can be based only on data obtained by experimental research results, for example, after digging or probing. Thus, stress distribution character in sandy base of circle cross-section pile models is given in [9, 12]. The authors of works [2, 3, 10, 11, 13] investigated the deformations of sandy soil in the base of jacking and driving piles, and they have also established the difference between them [4]. Experimental semi-field researches of pile-stamp models with different cross-sections in clay soils are given in [7]. And the peculiarities of the compaction and deformation soil zones formation around the piles under the action of horizontal loading are considered in [14 – 16].

The analytical expressions for determining the size of the soil compaction zones around a cylindrical element divided into the ground are given in [1, 5, 6]:

$$R_1 = \frac{r}{2} + \frac{r}{2} \sqrt{\frac{3(4+3e)}{e}}, \quad (1)$$

$$R_2 = r \left(\sqrt{4 + 6 \frac{m}{n} - 1} \right), \quad (2)$$

$$R_3 = \sqrt{\frac{2\pi \cdot r^2 \left(\frac{W\rho_d}{\rho_w} + \frac{\rho_d}{\rho_s} + V_{c.a.} \right)}{1 - \left(\frac{W\rho_d}{\rho_w} + \frac{\rho_d}{\rho_s} + V_{c.a.} \right)} \frac{1}{\pi} + r^2}, \quad (3)$$

where r – average pile radius; e – soil porosity coefficient; m – relative content of solid particles; n – soil porosity; W – soil moisture; ρ_d – dry density; ρ_w – water density; ρ_s – soil skeleton density; $V_{c.a.}$ – a volume of compressed air between solid particle aggregates and water, $V_{c.a.}$ is accepted ≈ 0 .

Selection of previously unbundled parts of the general problem that the article is devoted to. With a help of formulas (1), (2), (3) it can be determined the radius of compaction zones around the diving into the ground cylinder, or in other words, of the circular cross-section piles. The numerous volumes of jacked or driven piles with significant distribution in construction practice have a square cross-section. So the use of formulas (1), (2), (3) does not allow to obtain the results similar to real conditions, which is not correct.

The purpose of the work is to develop a method for determining sizes and construction forms of compaction zones around the square cross section pile and to perform a comparison of the obtained results with the experimental research data.

Main material and results. For the development of the soil compaction zone radius determination method around the square cross-section pile the symbols are introduced: $R_{i,j}$ is a radius of the compaction zone which directions correspond to the form of the compaction zone obtained experimentally (Fig. 2) [8], and determined in accordance with average radius r_i ($i = I, II, III, \dots, n$), by the formula j ($j = 1, 2, 3$).

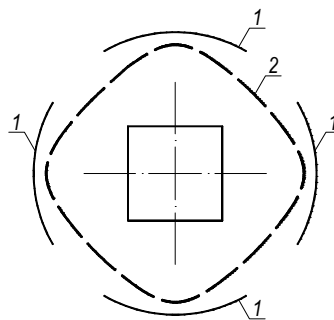


Figure 2 – Compaction (1) and deformation (2) zones of ground around experienced piles determined in field conditions

To construct ground compaction zones around the square cross-section pile the following algorithm is used:

1. Separate calculated elements are allocated in the piles cross-section (Fig. 3).

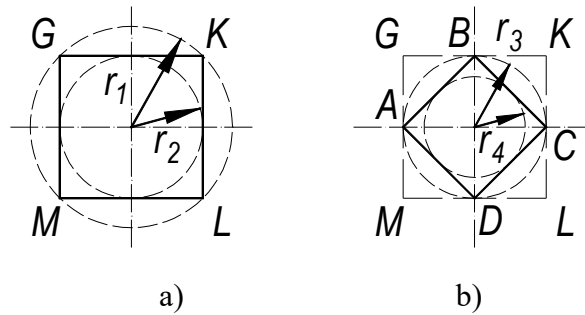


Figure 3 – Calculated elements for determining average radii r_I (a) and r_{II} (b)

2. Average radius r_I is defined for each element as the average between the described and inscribed radius.
3. Compaction radius of ground $R_{i,j}$ is determined according to formulas (1), (2), (3) with a help of average radius r_I .
4. Line segments $R_{i,j}$ are plotted from the each element center of gravity (Fig. 4).
5. The tips of all radii $R_{i,j}$ are connected. Zone of compacted ground around the piles lateral surface is obtained as a result.

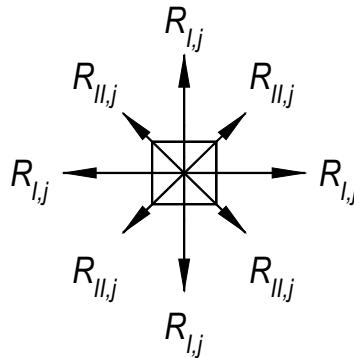


Figure 4 – Compaction zone radius directions around square cross-section pile

Using presented algorithm and formulas (1), (2), (3) there is ground compaction zones around square cross-section pile constructed and compare the obtained results with the experimental data compared given in [8].

Output data: a square cross-section pile with a side size of 300 mm. Pile was driven on a depth of 4m in medium density fine sands, low degree of water saturation with the following characteristics: $\rho = 16.28 \text{ kN/m}^3$, $\rho_d = 15.6 \text{ kN/m}^3$, $e = 0.671$, $W = 0.043$.

The radii of ground compaction zones around a square cross-section pile in directions shown in fig. 4 are determined. Two clearing elements are allocated in the pile cross-section. The first is square GKLM element (Fig. 3, a) with a side of 300 mm. The second is square ABCD element (Fig. 3, b) which vertices match with each side centers of square GKLM. For the first element the reduced radius r_I was calculated as the arithmetic mean of the described and inscribed radius (r_1, r_2) around the square GKLM (Fig. 3, a). Then the values of the compacted zone radii are calculated by the expressions (1), (2), (3): $R_{I,1} = 56 \text{ cm}$, $R_{I,2} = 47 \text{ cm}$, $R_{I,3} = 40.4 \text{ cm}$.

Also define reduced radius r_{II} is defined as arithmetic mean of the described and inscribed radius (r_3, r_4) of ABCD element (Fig. 3, b) and compaction zones radii are $R_{II,1} = 39.6 \text{ cm}$, $R_{II,2} = 33.3 \text{ cm}$, $R_{II,3} = 28.6 \text{ cm}$.

Ground compaction zones around square cross-section pile in horizontal direction are shown in fig. 5.

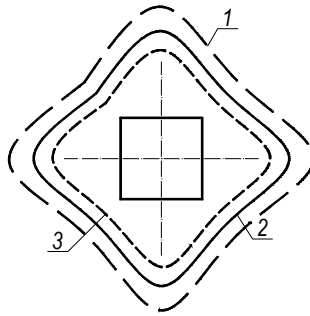


Figure 5 – Compaction ground zones (1, 2, 3) around square cross-section pile determined by the corresponding formulas

In order to compare the analytical calculations values with the experimental data, the compaction zones constructed analytically (Fig. 5) on zones of movements and compactions of a ground based on field investigation results were imposed (Fig. 2). These zones were determined around the lateral surface of the square pile with the help of dynamic probing tests, cone penetration tests, cutting ring and visually after the digging [8]. The overlay results are presented in Fig. 6.

Analyzing Fig. 6 it is possible to note that the character of ground compaction zones constructed analytically are similar to the displacement zones obtained experimentally in field tests. The dimensions of the compacted ground zones determined experimentally are less than analytical ones determined by the formula (1) up to 26%. The radius of the compacted soil zone determined experimentally coincides with the analytical determined by the formula (2), which at the diagonal points coincides with the experimental deformation zones and is by 7% higher than the experimental deformations in the normal direction of the pile side. Expression (3) allows determining the maximum values of the ground deformation zone in the pile side normal direction, coinciding with the experimental data, but they are smaller than experimental compaction and deformation zone of a ground at diagonal points up to 20%.

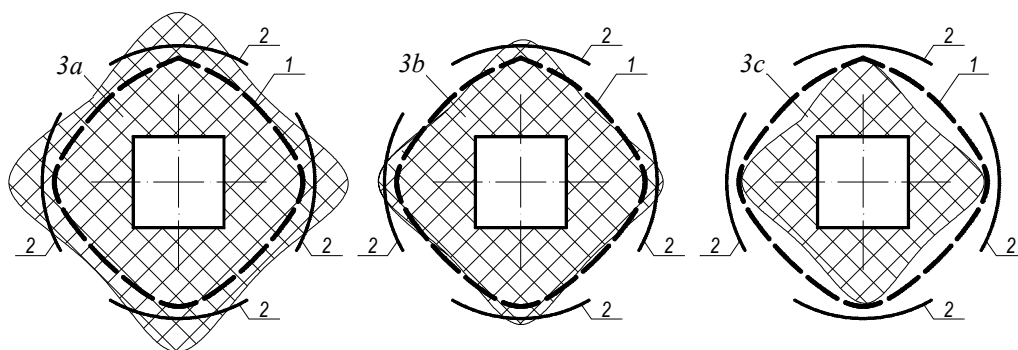


Figure 6 – Comparison of analytical calculations and experimental data:
 1 – deformation and 2 – compaction zones defined in field conditions;
 3a, 3b 3c– analytically constructed compaction ground zones
 with a help of formulas (1), (2), (3) respectively

Conclusions

1. The analytical method of a ground compaction and deformation zone sizes determination around the lateral surface of square cross-section pile was developed. Its use allows obtaining analytical results close to the experimental ones.

2. Analytical values of the ground compaction zone radius around the piles lateral surface in a comparison with the practical results show their satisfactory convergence with maximum deviation increase to 26% using formula (1) and minimum deviation to 7% using formula (2).

3. Comparison of existing analytical methods with experimental data shows the possibility of their employment for analytical compaction or deformation ground zone radius determination around the square pile lateral surface.

4. Compaction zones construction in soils with different porosity coefficient allows placing piles more efficiently in pile foundation, improving analytical method for determining the stresses type distribution around jacked or driven piles with square cross-section, improving their calculation method by the second group of boundary states and increasing their efficiency.

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