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SELECTION OF PARAMETERS AND CALCULATION OF LATERALLY LOADED PILES BY TRADITIONAL METHODS

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1. INTRODUCTION

This paper presents calculation of a laterally loaded pile by traditional analytical method with emphasis on the method of selecting the coefficient of soil reaction, and specific design recommendations.

The most common use for such laterally loaded pilot is horizontal forces appears on the foundation piles in ports - on impact shear force of the ship, at bridge foundation - the horizontal forces in the bridge foundation, and especially at any structure based on the pilots when they appear horizontal force of the earthquake (Figure 1c).

Laterally loaded piles are critical elements in system construction – soil. When a pile can withstand the level of strain that leads to the collapse of the soil, then it is called solid pile, while the situation becomes critical when the pile up to its collapse under the strain comes at a critical environment for the soil, it is called flexible pile. It can be said that the short piles are solid piles, while the long are flexible piles, however, for accurate classification it is necessary to consider rigidity of pile and soil, and the length of the pile.

2. TRADITIONAL ANALYTICAL METHOD ON ONE-PARAMETER MODEL OF SOIL

As one-parametar model of soil most commonly is in use so called Winkler's model for approximation of real soil. This model does not describe the soil properties of soil as a continuum, because the displacement of soil in such a model only occurs at the point where loads are acting. Neighboring points that are not directly loaded is not affected, as opposed to the real behavior of the soil. Also Winkler's coefficient of soil reaction is not soil constant i.e. soil physical property. It depends on the load, the size of the loaded surface area and is only valid for a certain state of stress in the soil. But after all these shortcomings, this model has so far most applied because of its simplicity in terms of mathematical formulation.

The governing differential equation of pile loaded with lateral force and bending moment on one-parameter soil model is:

$$E \cdot I \frac{d^4 u(z)}{dz^4} + p(z) = 0 \qquad (1)$$

General solution of such homogenous differential equation is stated using the unknown function of deformation, i.e.deflection:

$$u(z) = e^{\alpha z}(C_1 \cos \alpha z + C_2 \sin \alpha z) + e^{-\alpha z}(C_3 \cos \alpha z + C_4 \sin \alpha z) \quad (2)$$

Where is:
$$\alpha = \sqrt[4]{\frac{k \cdot d}{4 \cdot E \cdot I}} \quad (3)$$

Integration constants C_1, C_2, C_3, C_4 are determined from the boundary conditions on the head and top of the pile.

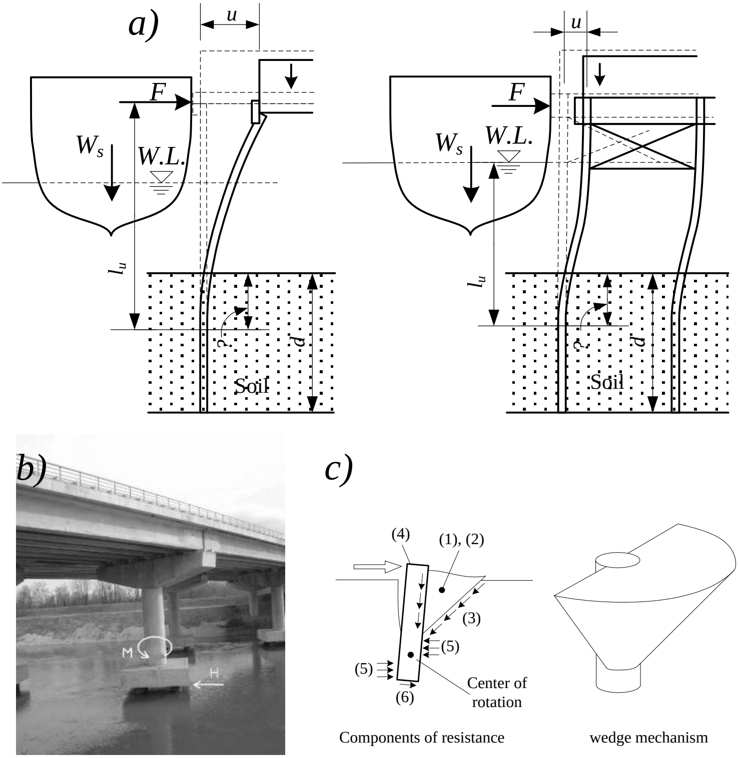

Figure 1. Example of lateraly loaded piles a) in the ports, b) in the construction of the bridge, c) due to earthquake action - 1 deformation of soil within the wedge; 2 work done by the soil weight within the deforming wedge as it moves upward; 3 shear along the wedge-soil interface; 4 shear along the pile-soil interface as the wedge moves upwards;5 flow of soil around the pile below the base of the wedge with a limit pressure of $9c_u$ and 6 shear of soil over the base of the pile.

Table 1. Boundary conditions for the different conditions on the head and the top of the pile

<table>
<tr><td colspan="2">Strain and internal forces in pile</td><td rowspan="2">$u(z)$ - deflection</td><td rowspan="2">φ_z rotation of pile section</td><td rowspan="2">M_z Bending moment</td><td rowspan="2">T_z Shear force</td></tr>
<tr><td colspan="2">Instalation condition</td></tr>
<tr><td rowspan="2">Head of a pile $z = 0$</td><td>Free</td><td>-</td><td>-</td><td>M</td><td>T</td></tr>
<tr><td>Fixed</td><td>-</td><td>0</td><td>-</td><td>T</td></tr>
<tr><td rowspan="2">Bottom of a pile $z = L$</td><td>Free</td><td>-</td><td>-</td><td>0</td><td>0</td></tr>
<tr><td>Fixed</td><td>0</td><td>0</td><td>-</td><td>-</td></tr>
</table>

Rotation of pile section φ_z, bending moment M_z, and shear force T_z obtained by derivation of pile deflection $u(z)$:

$$\varphi_z = \left(\frac{du}{dz}\right)_z, \; M_z = -EI\left(\frac{d^2u}{d^2z}\right)_z, \; T_z = -EI\left(\frac{d^3u}{d^3z}\right)_z \tag{4}$$

Substituting obtained integration constants in the solution of differential equations we obtain solutions of pile deflection, rotation and pile internal forces.

3. SELECTION OF THE COEFFICIENT OF SOIL REACTION

When pile is laterally loaded it comes to contact between pile and soil as elastic media i.e. supporting system which basic property is rigidity which relate stress and consequences of stress - strain.

By definition the coefficient of soil reaction is rigidity of the soil per unit area. Basic characteristic of Winkler model is the exchange of soil with the infinite group of parallel - joined elastic springs.

When it is about soil it is called specific soil rigidity or coefficient of soil reaction k_s, similarly force is stress p [kN/m^2] and straine is defelction y [m] and so we have the following expression:

$$k_s = \frac{p}{y}\left[\frac{kN}{m^3}\right] \tag{5}$$

When using Winkler model it is very important to keep in mind that it is approximate model of soil and it approximately represents deformation characteristics of foundation soil. That is the reason why it should pay particular attention to the selection of coefficient of soil reaction under certain conditions of the ground, therefore we should take into calculation experimental results of soil testing in situ in correlation with the analytical and numerical results. The literature mentions several ways to calculate the coefficient of soil reaction, specifically to laterally loaded piles, some of them are: Winkler 1867, Terzaghi 1955, Vesić 1961, Davisson 1970, Frisch 1973. and others. More about the coefficient of soil reaction and its influence on the results of bending laterally loaded piles can be found in the literature, for example, as noted in the literature [4].

4. RELATION BETWEEN EXPEREMENTAL RESULTS AND SELECTION OF COEFFICIENT OF SOIL REACTION

As it can be seen in the literature. ([1]) it can be estimated ultimate bearing capacity of laterally loaded piles based on pile size (diameter and length) and soil conditions, cohesive and non cohesive by using various diagrams.

In each analytical method it is very important comparison with the results of experimental data. In figures 2 and 3 is shown the diagrams that are derived from data taken from the book "Soil Engineering, Testing, Design and Remediation" by Fu Hua Chen. Diagrams are based using tables from that book.

Based on the given diagram can be estimated ultimate bearing capacity laterally loaded piles in relation to the diameter and length of piles and certain conditions in the soil. When we compare the results with analytical calculation we can choose an appropriate formula to calculate the coefficient of soil reaction.

5. CTION SHOCK TO SHIP CONSTRUCTION OF COSTAL

When lightning boat on coastal construction is necessary to calculate the kinetic energy of his work. Expression (6) shows the method of determining the values E_{kin} of kinetic energy caused by the action of the ship on the coastal construction:

$$E_{kin} = \frac{mv^2}{2}\alpha_m \alpha_s \alpha_r \tag{6}$$

where: m - mass of the vessel [kg], v - velocity of motion of the ship at the moment of impact on coastal construction [m/s], α_m - the coefficient of the impact of turbulence on the water movement of the ship, α_s - impact stiffness coefficient buffers, α_r - coefficient of gravity distance of the ship from point kontankta with the bumper.

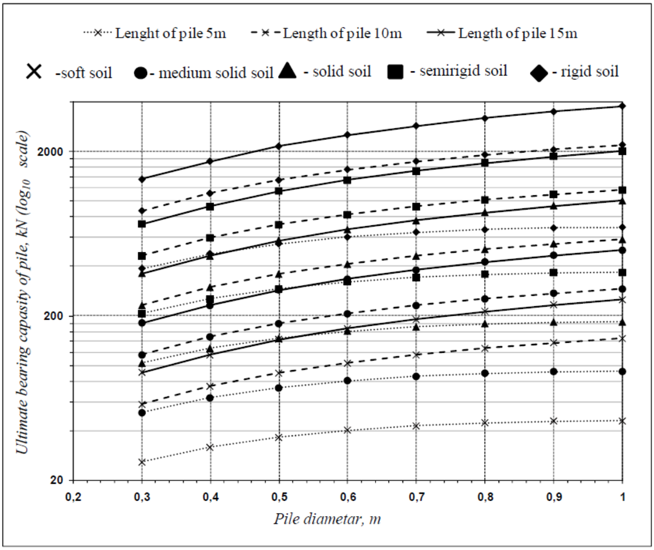

Figure 2. Diagram of the relation of ultimate lateral bearing capacity of a bored pile in cohesive soil to the diameter and length of pile

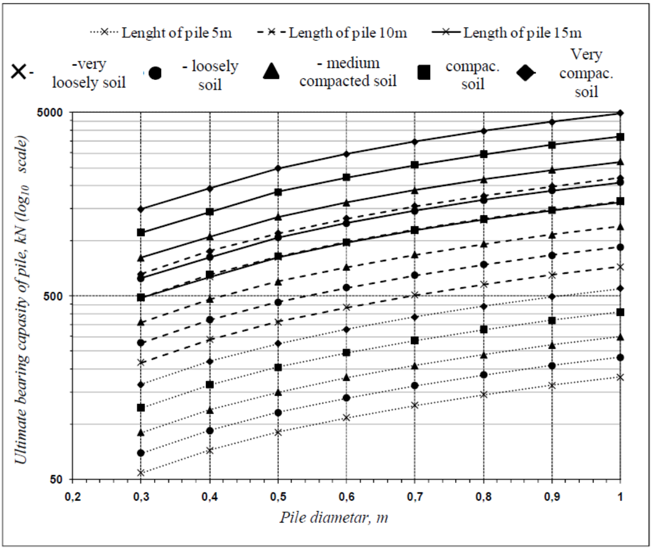

Figure 3. Diagram of the relation of ultimate lateral bearing capacity of a bored pile in non cohesive soil to the diameter and length of pile

For the calculated value of the kinetic energy of the ship is determined by the equivalent static force, to which will be designed coastal structures.

Said force is calculated on the basis of the characteristics of elastic buffers (dimensions, materials from which they are made, the value obtained by the tests, etc.). In Figure 2, for example šupljeg elastic rubber bumper (Figure 4).

Figure 4 An example of an elastic hollow rubber bumper

Input parameter in analysis of the kinetic energy of the ship, that ship operates on a frame. One of the possible ways of solving such problems is to set up an elastic buffer to the structure, which will amortize its strain energy attack ship. The total kinetic energy of the ship then takes only the bumper, while the structure is treated as absolutely rigid.

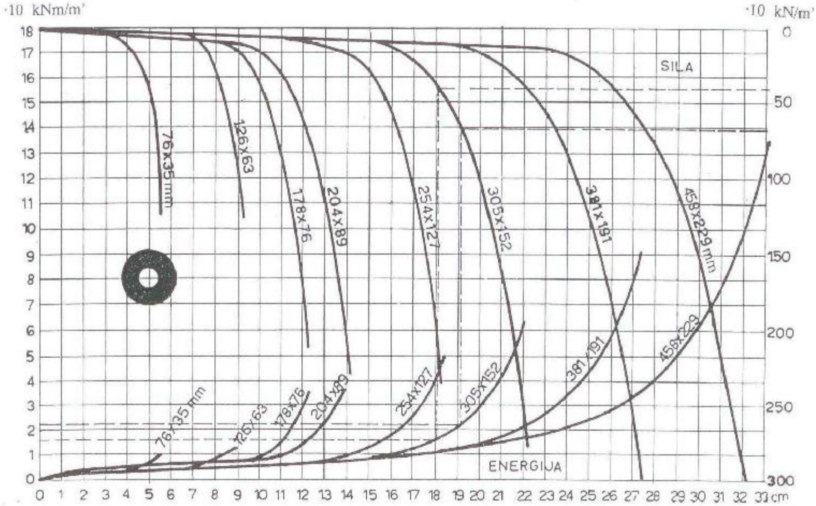

Figure 5 Characteristic diagram of the energy-equivalent force-deformation elastic buffers [13]

Manufacturers provide specifications bumper bumper that is equivalent to the force and deformation that will provide energy equal to the kinetic energy applied to the tested bumper. In the current analysis, it is assumed absolute rigidity planar structure of the ship at the time of impact. Energy balance is achieved only by balancing the kinetic energy of the ship and the elastic strain energy buffers.

6. CONCLUSION

From the above presentation it can be concluded that when i comes to calculation of laterally loaded piles with analytical and numerical methods, special attention should be paid to the selection of coefficient reaction k_s on the comparison of results obtained by field testing, and only then estimate wich results or procedures will be used in the in the pile design.

It is particularly important to emphasize that in Eurocode 7, there are no detailed guidelines for the design of laterally loaded piles, it is mentioned that it is acceptable Winkler's soil model and is mentioned p - y method (Reese and Van Impe, 2001). So the designer has some freedom of selection procedures for the calculation of these piles by their own experience and knowledge from practice. In designing it is recommended to use multiple methods of calculation and experimental data, and than decide wich way is appropriate.

Summary

In addition to numerical software programs for the calculation of lateraly loaded piles it is good to keep in mind the traditional analytical methods. Using analytical methods often appears the choice of input parameters as a significant obstacle. Here is primarily the coefficient of soil reaction, which is often selected in several ways. This paper contains methods of selecting input parameters, calculation of lateral loaded piles, and the conclusions and recommendations for designing.

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