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RESEARCH ARTICLE

HYPOTHESIS FOR THE EFFECT OF PILE FOUNDATION ON THE SEISMIC PARAMETERS OF THE GROUND BASE.

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Abstract

After reviewing the dynamic interaction between the soil and structure, it is visible that the piles improve the dynamic characteristics of the weak ground base. A short review of the opportunities to reduce seismic effects on the building project has been made; respectively it decreased the construction cost. The thesis about the increase of the soil stiffness after the construction of the pile foundation has been set out. The principles for evaluation of characteristics improvement and the ways for their experimental determination have been exposed. The outcome highlighted that following the construction of the pile foundation, the improved soil characteristics should be measured again and the results obtained should be used as an input to the dynamic analysis of the entire designed structure.

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Introduction:

The adverse impact of the weak ground base to increase the displacements' amplitude of the seismic load is well - known. The specific seismic study on the construction site for high-rise buildings is evidently very important and obligatory. The information from the study may suggest a number of constructive measures that can reduce the oscillation's amplitude of the building.

The most powerful tool for improving the overall stability of the structure and ground base is the pile foundation. The analyses of the dynamic interaction between the soil and the structure indicate that the piles improve the dynamic characteristics of the weak ground base (Kolev and Toshkov, 2007). Pile foundations increase the density of the medium; they often contribute to the consolidation, change the structure and finally increase the average speed of seismic waves in the area of the pile foundation (Kolev and Perikliiska, b 2010).

And further to the above, the impact of seismic effects on the building project and the possibilities for their reduction has been considered in this report. The ultimate goal is provision of effective measures for reduction of the seismic impact by thoroughly analyzing it and thus finding ways to reduce the construction cost of the project. It is a pretty complex task which is important for the theory and practice, and its solution does not end only with these few pages, but require a deeper multipurpose research whose theses are formulated in this report.

Effect of stratigraphy on seismic intensity

It is known that the cohesive soil filters the high frequency seismic waves and let out those with a longer period. Weak cohesive soil has less density and admission of long period waves leads to large displacements of the field

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points. In such occasions, there is a danger of some solid high-rise buildings that have been founded on such weak soil to tilt or overturn. Even timber structures, which are very flexible could not sustain to large mutual displacements of the ground stations. Experiments have proven (Postoev, 1989) that the frequency period of the body that has been cut increases after the shear of the soil. After the beginning of the new temporary equilibrium state, T is slightly reduced but remains significantly higher than its initial value before shear. Speed of transverse and longitudinal waves' distribution in shear body decreases even when shear occurs in a homogeneous medium. For the same reason the amplitude increases. Consequently, the coefficient for the overall stability of the ground (η) can be expressed by geophysical indicators:

$$\text{If } \eta = \frac{\tau_{zp.}}{\tau} \rightarrow \eta = f(V_p; V_s) \text{ and } \eta = f(A), \quad (1)$$

where:

V_p is the longitudinal wave's distribution speed;

V_s is the transverse wave's distribution speed;

A is the amplitude.

The empiric relation

$$V_s = f(\sigma), \quad (2)$$

where

σ is the normal stresses in the ground which shall also be established experimentally.

According *Sano's investigations* (Zlatanov and Manev, 1984) in ordinary conditions $\varphi > \varphi_{seism}$, i.e.

$$\varphi_c = \varphi - \arctan(k_c/\sqrt{2}). \quad (3)$$

Here k_c is the seismic ratio.

The *Medvedev's* (1962) criterion is very convenient for analysis and evaluation regarding the amplification of seismic impact on weaker geological layers:

$$\Delta n_l = 1,67 \cdot [lg(\rho.V) - lg(\rho_l.V_l)], \quad (4)$$

where:

ρ = bulk density of standard granite;

V = speed of seismic waves for reference granite;

ρ_l = bulk density of the layer researched;

V_l = speed of seismic waves in layer researched.

The conclusion of formula (4) is as follows: the lower the density of the contact soil under the building is, the more seismic impact should be expected. So, the weak soil is worsening the conditions for anti-seismic construction.

The product of $\rho.V$ is called "seismic stiffness" (Pavlov, 1988) of the medium or the material.

The ratio of upper layer seismic stiffness to the one of the soil layer: $\rho_l.V_l/\rho_0.V_0$ is called "seismic contrast". Seismic contrast of the medium impacts the soil level and duration of effects. When the wave rays pass through the boundaries of the different soil layers, they reflect and refract.

Seismic impact on the foundations of buildings:

The quantitative assessment of seismic effect on the foundations of the buildings leads eventually to determination of seismic force S . In Bulgaria, this issue is regulated in the Ordinance on design of buildings and structures in seismic areas (MRD, 2012) but requires clarification of the specific subject and specific source of impact. Clarification of seismic impact can be achieved after micro - seismic investigations.

According to (MRD, 2012) the seismic impact is as follows:

$$E_s = C.R.K_c\beta_r\eta_{ik}Q_k \quad (5)$$

where:

C - structure importance coefficient;

R - the response factor of the structure;

K_c - seismicity ratio;

- β_i - dynamic coefficient for the i -th oscillation form;
 η_{ik} - distribution coefficient for seismic impact on i -th oscillation form in point k .
 Q_k - weight, concentrated in point k .

The most interesting are the meaning and values of the dynamic coefficient β_i of the Ordinance on design of buildings and structures in seismic areas (MRD, 2012) during the calculation of E_s of the same Ordinance. All features of the soil and the construction site reflect in this coefficient. According to the same standards, it is determined by formulas or graphically depending on the period T of the own structure variations and the type of the ground which is classified in the form of tables.

According Article 15 (4) of (MRD, 2012), β_i is defined as weighted average for the soil layers next to the base rock in heterogeneous soil. Therefore, the weak soil is most often from III group and in the best case scenario layers below are from II group.

In such cases, we recommend to comply with Article 15 (9) of (MRD, 2012) and to take measurements by means of geophysical equipment with regard to the distribution speed of seismic waves V_p and V_s , and the periods of their fluctuations T_i and to optimize construction decision at the highest degree.

Opportunities to reduce seismic impact on the construction of high-rise buildings on weak soil:

The construction of high-rise buildings on weak soil is done by deep foundation. It is possible, that some reduction of seismic impact due to hardening of the ground to be taken into account. And also, the velocity of seismic waves V_p and V_s distribution will be increased; part of higher-frequency waves in the range above 5Hz will be let out; the horizontal displacements at the level of the foundation will be decreased and the need of rigid partitions in the superstructure will be reduced.

Seismic load is assumed through deep foundation and provides a horizontal displacement of the level of the raft foundation up to 2 cm. Under these circumstances the foundation of a building, which has 7 ÷ 8 or more floors is being secured.

Still, if we do pile foundation, it is more important to take into account that the dynamic coefficient β is determined as weighted average for the layers of the ground, which the piles are placed into. The pile foundation itself improves the bearing capacity and density of the weak soil and decreases its own period T . Moreover, the stiffness of the ground could be increased by different technologies: Jet - grouting, micro - piles, crush stone piles, soil partly replacement with rock or sand, lime columns, impulse consolidation and others. The structure of the soil will be changed after the strengthening and hence its dynamic parameters will be improved.

Medvedev (1962) suggests quantitative criterion for assessing the effectiveness of soil improvement and corresponding reduction of seismic intensity. This criterion is known in our country and has the following form:

$$\Delta n = \Delta n_1 - \Delta n_2 = 1,67 \cdot [\lg(\rho_2 V_2) - \lg(\rho_1 V_1)], \quad (6)$$

where:

- ρ_2 - higher volume density of the improved medium;
 V_2 - higher speed of seismic waves for improved medium;
 ρ_1 - volume density of the studied layer;
 V_1 - speed of seismic waves for the studied layer;
 Δn_2 - increase of the seismic degree;
 Δn - reduction of the seismic intensity.

Obviously, the relative flat foundation, i.e. the piles and soil pyramids placed around them, create higher density and elasticity of the medium under the raft foundation. Thus, the seismic intensity of the soil below the building is lowered.

There are three additional important factors for soil improvement and the first of them is the **Shear strength of the water-saturated cohesive soil**. This strength decreases abruptly under dynamic effects. Pore pressure in the massif

reduces the effective stresses and decreases the boundary resistance of soil shear in accordance with the *Terzaghi's* principle of the effective stresses. **Geometrical and physical-mechanical characteristics of the ground and the external load** are the other two important factors. They represent the limit conditions of the task. This kind of tension could lead to loss of local stability of the ground. The typical fast non-drained soil shear occurs when the pore pressure from seismic forces increases.

The behavior of water-saturated cohesive soil during seismic effects continues to be an object of study all over the world. Prakash's (1981) publications can be considered as fundamental in this respect. The determination of the dynamic shear strength in water-saturated soil is the most essential in such studies.

Cancelli and Romani (1991) state categorically after they have made a dynamic analysis of a natural research that the well-developed drainage network is the most efficient counteraction to the seismic load.

An integrated assessment for decrease of soil seismic activity could be made by measuring the velocity of distribution of the seismic waves before and after the improvements (Kolev, 2007).

According to Eurocode 8.5, the main parameter for soil stiffness at earthquake is the *G* Shear model:

$$G = \frac{\gamma}{g} \cdot V_s^2, \quad (7)$$

Where γ - volumetric weight of the soil;

g - acceleration of gravity;

V_s - velocity of the transverse waves.

In fact, it is the so called [7] density of elastic energy (I):

$$I = I_{cyn} + I_{pot}, \quad (8)$$

where

I_{cyn} - kinetic energy;

I_{pot} - potential energy.

The role of consolidated medium for the increased velocity of the waves and improvement of the ground is clear by the mathematical expression (7) (Kolev and Perikliiska, 1 2010).

Demonstration of the effect of the soil strengthening:

The effect of soil strengthening by improving its seismic parameters while building-up pile foundation could be proved in three ways: theoretically, by means of models and field measurements:

Theoretical evidence

The theoretical evidence follows directly equations (6) and (7). It is enough to replace soil values characteristics inwith the new improved ones in the equations. A new improved soil layer in the zone of the pile foundation is formed.

Model study

It is necessary, the soil and pile foundation to be modelled in an the appropriate scale according to the capabilities of the respective laboratory. The results of the model study could be used to complete the theoretical solution and create a mathematical model according to the Finite Element Model (FEM)

Field measurements

Seismic researches based on drillings at the construction site could be done to measure the distribution velocity of seismic waves in different layers before and after piles'driving and other soil improvements. Using this velocity calculations according to equation (6) and (7) could be made and an analysis of the design structure could follow. The results could be compared with those from the theoretical and model study. The most appropriate geophysical study for this purpose is *The Cross Hole Test*.

After the construction of the pile foundation, a new measurement of seismic waves' velocity could be made and using thereafter we can use its values in the dynamic analysis of the entire structure. The later will lead to a more economical construction solution.

Conclusions:-

1. Pile foundation is effective soil strengthening and improvement of its reaction to an earthquake.
2. Various technologies for soil strengthening also contribute to reduction of seismic contrast.
3. Direct measurement of seismic waves' distribution velocity in the layers of the construction site is the best study on the effect of the strengthening.
4. After an assessment on the effect of soil consolidation as a result of pile foundation, a new dynamic analysis of the entire structure should be made.

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