World Applied Sciences Journal 23 (Problems of Architecture and Construction): 122-126, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.23.pac.90025

Influence of Seismic Impacts on Foundation Beds Composed of Weak Soils

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Abstract: In many seismically active regions of Central Asia, weak water-saturated sandy and silty-clayed soils are widely spread; industrial and civil facilities of various purposes are built and operated on them. The operating experience, macro-seismic examinations of earthquake consequences and the results of laboratory and field investigations show that the strength and deformational characteristics of soils under seismic impact deteriorate, which means they should be monitored and the soil-bed properties should be evaluated and calculated. In order to decrease the influence of seismic impacts and improve the seismic resistance of structures and facilities, the construction practice provides for a number of methods aimed at improvement of soils properties; pile foundations are also used for such purposes. The present article summarizes on the results of field experimental investigations of the influence of seismic loads simulated by seismic-explosive impacts on the state of natural and artificial basements, as well the influence of pile foundations on weak water-saturated loess soils.

Key words: Seismic and seismic-explosive impacts · Weak water-saturated loess soils · Homogeneous natural basements · Artificial basements · Tightly-compacted bed-plates · Vertical sandy drains · Vibro-formed piles

INTRODUCTION

In seismically active regions of Central Asia, buildings and facilities are often erected on basements composed of weak water-saturated soils [1]. Such basements can be homogeneous or non-homogeneous (double-layer) [2-4]. The experience of operating structures built on such soils indicates a significant decrease in strength and deformational characteristics of soils under seismic impacts. This has to be taken into consideration when calculating basements [5, 6]. In order to increase seismic resistance of structures, pile foundations can be used, or other methods of artificial improvement of the properties of weak water-saturated soils.

Methods: With this task in mind, integrated laboratory and field investigations were carried out on particular features of homogeneous and artificial basements, as well as displacement piles under seismic impacts. In field conditions, imitation of seismic forces is done with the help of seismic-explosive impacts, when an explosion imitates particular parameters of seismic forces in order to solve particular tasks. Seismic-explosive impact can only imitate just a few dynamic characteristics of some types of earthquakes [7-8]. This method is widely used in order to solve geo-technical tasks in difficult engineering-geological and seismic conditions.

Materials: The present article presents the results of experimental investigations on the influence of seismic impacts upon the load-bearing capacity and deformation property of natural and artificial basements, as well as on particular features of vibro-formed displacement piles behavior in weak water-saturated loess soils in Tajikistan.

The Main Part: Investigations of Homogeneous Basements: Field investigations were carried out in an experimental site composed of water-saturated loess soils of high plasticity, with thickness more that 16.0 m.

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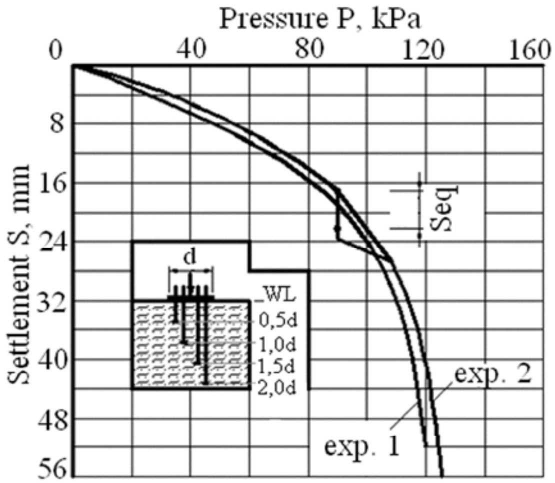

Fig. 1: Dependence of stencils settling on the load

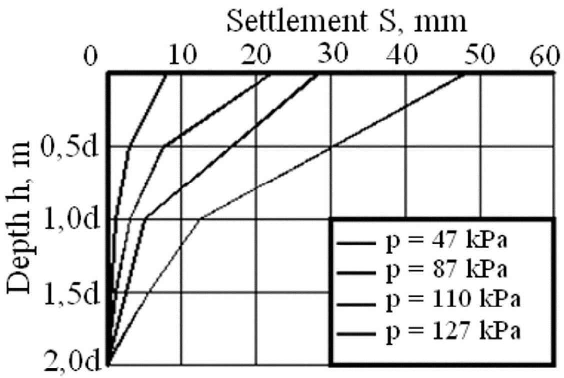

Fig. 2: Development of layer-wise deformations across the depth of basement stencils

Static tests were conducted by simultaneous dipping of two hard round stencils with the area A = 1.0 m^2 [9]; the results were as follows: calculated soil resistance-R ≤ 100 kPa, modulus of deformation-E = 2.7-3.5 MPa (Fig. 1).

During the tests, the character of development of deformations across the depth of the basement under stencils was also measured. Analysis of the curve for the development of layer-wide shifts shows that more than 90% of general deformations take place within the depth limit equal to the diameter of the stencil (Fig. 2).

During the static tests No. 2, a natural earthquake took place, with magnitude 7 and duration about 2 minutes; the average pressure on the stencils' bed was p = 87 kPa ≈ 0.9R (Fig. 1), i.e., it was 90% of the calculated resistance (load-bearing capacity) of the basement. The measured values of additional increments of stencils deformations and depth marks were 27% of the total amount recorded during the static tests. In this case, as well as during the static tests, increments of additional deformations of soils were also detected at the depth equal to the diameter of the stencil and more than 80% of them took place at the depth equal to 0.5 of the stencil diameter.

Before the tests of weak water-saturated soils for seismic-explosive impacts, similarly to static tests, the load on the stencils was increased to p = 80 kPa (0.8R), i.e., it was 80% of the load-bearing capacity of the basement. Imitation of the seismic impact was done with the help of millisecond-delay camouflet explosions of charges, positioned in three concentric circles at the depth of 7.5 m and at the distance of 15, 20 and 25 m from the tested stencils (Fig. 3). As the calculated parameter of seismic-explosive impact intensity, the velocity of soil oscillation was taken; it correlates well with the charge size and epicentral distance [7]. Explosive charges were positioned in specially manufactured explosion columns (Fig. 3) consisting of a metal container for the explosive charge (*4*) with the height h = 1000-1200 mm and a casing pipe welded to it (*1*).

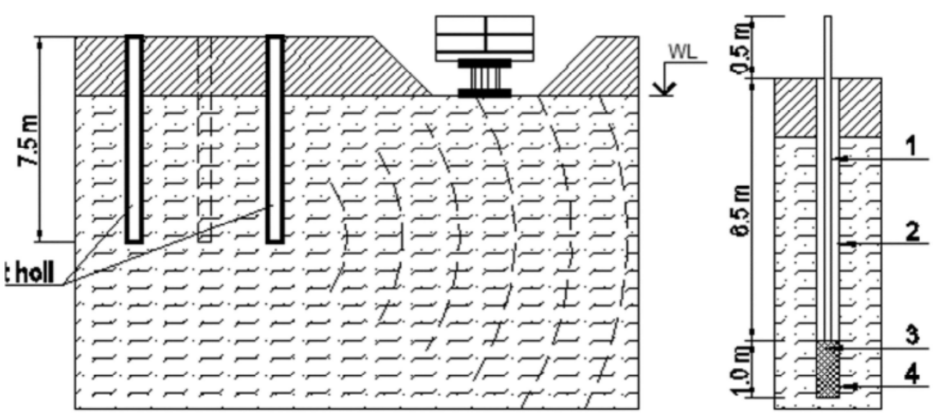

Fig. 3; Cross-section of the experimental site and the layout scheme of the explosion column: *1* is the tube d = 50 mm; *2* is the drilled well d = 220 mm; *3* is the explosive charge; *4* is the tube d = 200 mm

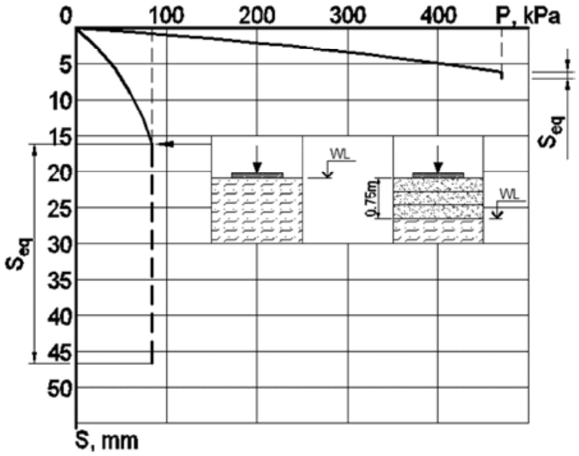

Fig. 4: Results of tests on homogeneous and artificial basements under seismic-explosive impacts

Under seismic-explosive impacts with the magnitude 9 and duration more than 2 minutes, the stencils deformations were constantly increasing until the loss of their resistance (Fig. 4). During the tests, the level of underground water raised above the stencils bed by 0.3-0.4 m, which indicates an increase in the porous pressure in the series of weak water-saturated soils as seismic waves pass through them.

In general, results of numerous experimental investigations and the experience of operating various structures built on weak water-saturated soils show that seismic impacts of magnitudes 7, 8 and 9 cause a decrease in the load-bearing capacity of the foundation basement soils by 10, 20 and 30%, respectively.

Investigations of Tightly-compacted Soil Base Plates: In Tajikistan, one of the most widely used artificial methods for preparing the basement is preparing compacted-sand and gravel-pebbles base plates. This is due to availability of large quantities of natural material, its low cost and high efficiency for use in construction. Numerous investigations and design experience show that the thickness of compacted-soil base plates should not be less than 0.75-1.0 of the stencil diameter or the width of the foundation.

In this respect, experimental investigations of particular features and parameters of tightly-compacted gravel-pebbles and sandy base plates are of great interest (density of dry soil $[rho]_d \geq 2.2$ t/m^3, compacting coefficient $k_{com} > 1.0$) thickness h = 0.5, 0.75 and 1.0 m in weak water-saturated loess soils with the consistency I_L = 0.6-0.8 [10-11]. According to the results of static tests carried out by dipping round hard stencils with the area A = 1.0 m^2, calculated resistance (load-bearing capacity) of all the artificial basements was R $\geq$ 500 kPa, which is by more than 5 times higher than the calculated resistance of naturally-formed weak soil (R = 90 kPa).

Investigation of tightly-compacted base plates under seismic-explosive impacts were carried out in the site, where, at the elevation of the underground water level, a tightly-compacted ($[rho]_d > 2.2$ t/m^3, $k_{com} > 1.1$) gravel-pebbles bed-plate was formed, with the thickness h = 0.75 m on water-saturated loess loams with the consistency I_L = 0.8. In the experimental site, stencils were installed with the area A = 1.0 m^2 (d = 1.13 m); they were dipped according to the method of static tests until the average pressure on the bed p = 480 kPa was achieved (Fig. 3).

During seismic-explosive impacts of the magnitude 9 and duration more than 2 minutes, the maximum increment of stencils deformations was only S_{eq} = 7% from the total settling distance detected during static tests. The obtained data and the construction experience showed high efficiency of using tightly-compacted base plates made of sandy and gravel-pebbles materials.

Investigation of Basements Compacted with Vertical Sandy Drains: Construction sites can often be composed of thick series (more than 15 m) of weak water-saturated loess soils of soft-plastic and liquid consistency ($I_L \geq$ 0.8-1.0). In such conditions, it is good practice to preliminarily compact the soils with sandy drains with using swamp weight on the site [12,13].

The experimental site had water-saturated loess loams to the depth more than 16 m with the consistency I_L = 0.80, calculated resistance R $\leq$ 90 kPa and module of deformation E = 2.0-2.7 MPa. The site was divided into 3 separate sections 10×10 m each. In the first section, vertical sandy drains were not used; in the second section they were arranged in a 2×2 m grid and in the third section they were arranged in a 3×3 m grid, with the length 6.0 m and diameter 0.4 m. The static load was transferred onto the series of the weak soil layer by layer-wise filling of gravel-loamy material.

It was found that the main part of deformations in the series of weak soils takes place during the first 5-6 days after applying each portion of the load (Fig. 5). More than 70% of general deformations were detected within the depth 3.0 m and more than 50% of them are within the depth 1.5 m.

Stencil tests showed that, despite the relatively small value of the compacting static load, the values of the calculated resistance of soils in the compacted sections increased to R $\leq$ 200-250 kPa (by 2.2-2.8 times),

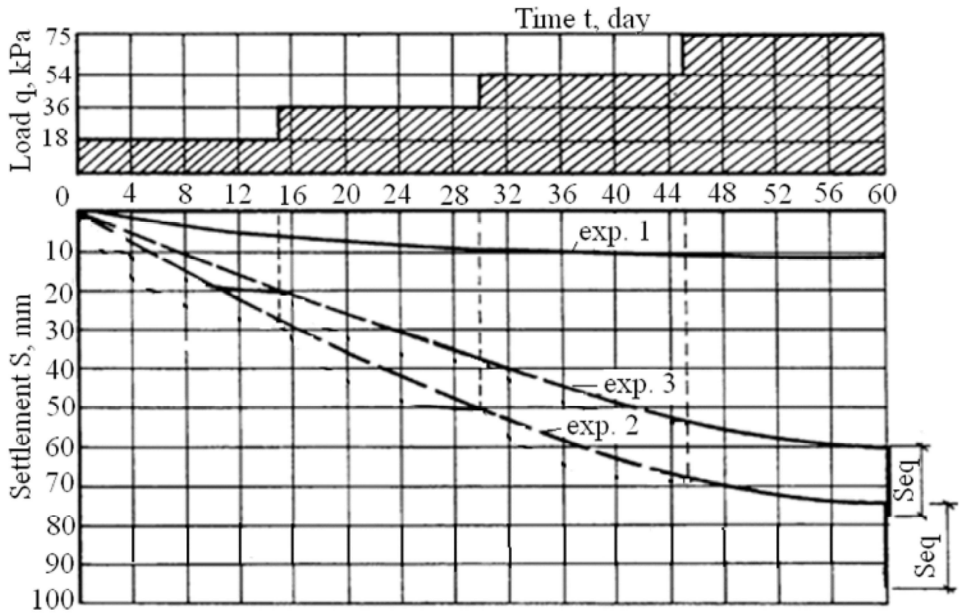

Fig. 5: Layout scheme of dipping and development of deformations in experimental sites across time

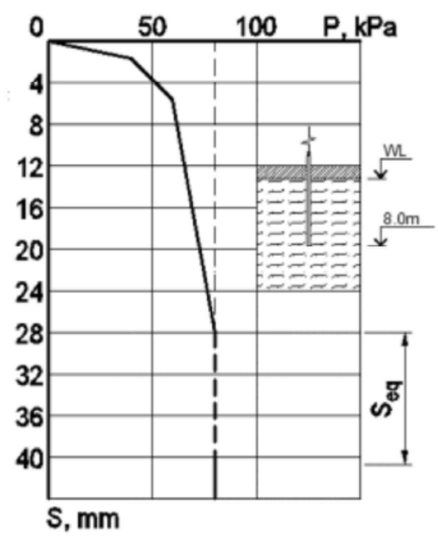

Fig. 6: Dependence of pile deformations on the load under seismic-explosive impacts

the module of deformation increased by 2.4 times and the specific cohesion increased by 1.6-2.0 times (according to the results of static tests).

Investigations of Displacement Piles: Experience of operating buildings and facilities on pile foundations in seismic regions proves their reliability in conditions of weak water-saturated soils. With consideration of this, there were investigated technologies and particular features for reinforced-concrete vibro-formed floating piles with the diameter d = 0.4-0.6 m and the length l = 6.0-8.0 m. According to the results of static tests, the load-bearing capacity of a displacement pile with the diameter d = 0.6 m and the length l = 8.0 m was p = 100 kN.

With consideration of this, for testing a similar pile for seismic-explosive impacts, the magnitude of the static compression load was set at p = 80 kN, i.e., 80% of the load-bearing capacity calculated according to the results of static tests (Fig. 6).

Under a seismic-explosive impact of the magnitude 9 and duration more than 2 minutes, additional increments of settling of the experimental pile was S_{eq} = 13.4 mm, i.e. about 50% from the value of the settling distance under static tests.

The analysis of the results of experimental investigations shows that displacement floating piles are inefficient for both static and seismic-explosive impacts. In the conditions of weak water-saturated soils and high seismic activity, the piles should have the form of column piles, with their lower end dipped into strong and non-compressible soil layers.

CONCLUSIONS

- Experimental investigations showed the decrease of the load-bearing capacity of basements made of weak water-saturated soils within 10-30%;
- tightly-compacted base plates from gravel-pebbles or sandy materials makes it possible to significantly

increase the load-bearing capacity and decrease compactability of artificial basements, both for static tests and for seismic impacts;

- as weak water-saturated loess soils are compacted with vertical sandy drains and the weight of backfilling, seismic impacts help increase porous pressure in the soil series and improving the compaction;
- seismic impacts cause a significant decrease in the load-bearing capacity of displacement floating piles, which indicated inappropriateness of such piles in conditions of weak water-saturated soils and high seismic activity.

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