STATIC FRICTION CHARACTERISTICS OF NEGATIVE SKIN FRICTION ON PILE INDUCED BY A LESS SEISMIC SUBSIDENCE IN LOESS FIELD

Junjie Sun[1,2], Zhijian Wu[1,3], Rendong Qiu[1], Shunhua Xu[1,2] and Lanmin Wang[1]

1. Lanzhou Institute of Seismology, China Earthquake Administration, Lanzhou 730000， China;
2. Civil Engineering and Mechanics Department, Lanzhou University, Lanzhou 730000, China;
3. Cold and Arid Environment and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
Email: sunnjunj@163.com, zhijianlz@163.com

ABSTRACT :

One primary aim of the field testing in this paper is to observe the basic characteristics of negative skin friction (NSF) along pile in seismic subsidence caused by a short delay blasting, simulating an earthquake event. Fortunately, we discover that several results of this in-situ testing could indicate that the characteristic of NSF reported here differs from those before field features of NSF in collapsing loess ground. The first result is that the maximum NSF along pile hits 86kPa and this value is much more than before field NSF data related to the loess settlement by soaking. According to a statistical data of NSF by the effective stress method, this great difference cannot be explained successfully by the varied strength of soil mass and pore water pressure. The second result reveals that during the NSF's increasing process, the position of natural point is almost at the same depth, approximately a 13m depth of pile body or a corresponding depth-buried of 15m, according with the bottom depth of seismic loess layer in the testing field. A fixed phenomenon of natural point is great contrast to the situation in collapsing loess ground evidently, in which the natural point changes its depth along pile with the development of NSF. The third result describes that NSF increases with the depth along pile gradually and there is an extreme value, likely being the maximum value also, of NSF on pile near/at the neutral point. Because position of natural point is relative stable on pile in the field testing, the distribution of NSF along pile merely bears on the weight of loess mass, which increases with the depth. Based on the three results of the field test and some statistical data in this text, the authors believe that this field testing observes a static friction characteristic of NSF, whereas the previous in-situ tests are performance of the NSF's kinetic friction characteristic.

KEYWORDS: Negative skin friction, static friction, kinetic friction, loess, seismic subsidence, settlement by soaking

1. INTRODUCTION

In 1930s, a few engineering accidents take place in soft soil areas of Netherlands, where lots of column piles are applied. For those constructions in the soft soil areas, design bearing capacity of pile foundation is about one-tenth to the in-situ bearing capacity of single pile. In theory, this design is very safety; however, the accidents occur finally. According to accident characteristics of those pile foundations, Terzaghi and Peck provide the concept of negative skin friction (NSF), and they believe that the engineering accident of buildings in Netherlands is a result of NSF (He Yihua et al, 1982).

NSF is a kind of friction, an equivalent force to pull the pile foundation down. There are two types of friction theoretically, i.e. static friction and kinetic friction. Consequently, NSF should include two kinds of friction characteristic also, corresponding static NSF and kinetic NSF respectively. The kinetic friction characteristic of NSF has been proved by a number of field tests of NSF in collapsing loess ground (Johannessen I. J. et al, 1965, Poulos H. G. et al, 1969, Poulos H. G. et al, 1972, Li Guangyu et al, 1988, Li Dazhan et al, 1992, Zhang Houxian, 1994, Li Dazhan et al, 1994, Ma Shidong, 1997, Huang Xuefeng et al, 2002). During a long before period, moreover, researchers take lots of effort to develop various methods to estimate NSF (Walker L. K. et al, 1973, Poulos H. G. et al, 1975, Small J. C, 1988, Zhou Guolin, 1991, Zhao Xihong et al, 1999, Wang Jianhua et al, 2000, Sun Junjie et al, 2003). On the contrary, the static NSF is still a theoretical guess for scientists and engineers, because there is nothing in the in-situ tests to observe a static friction characteristic of NSF.

One primary goal of the field testing in this paper is to research the basic characteristics of NSF along pile in seismic subsidence caused by a short delay blasting, which simulates an earthquake event. Three analysis results of this field testing indicate that NSF caused by a seismic subsidence of loess reported here could be a static NSF, because of some obvious static friction characteristics. In the following text, sequentially, it is described in detail that introduction of this field testing and analysis results to support the static NSF.

2. DESIGN OF THE FIELD TESTING FOR STATIC FRICTION CHARACTERISTIC OF NSF

Considering the loess properties, deposit thickness, safety of surrounding villages and construction condition, the south field of Lijiawan Ping near Lijiawan village of Gansu province, Northwestern China is finally selected as the testing site. Having a flat topography, a proper thickness of collapsible loess deposit and a certain distance away from villages, this site is suitable to carry out the explosion testing on NSF along pile caused by seismic settlement of loess ground.

2.1. Testing Piles and Gages

There are two reinforced concrete piles to be disposed in the loess ground; the design strength of each reinforced concrete pile is C25.

Seating on a non-seismic settlement layer, each of the two piles with a diameter of 0.8m is 20m long. In their body, 40 stress gages are disposed in average with an interval of 2m along the direction of depth. For each pile the gages arrange as a symmetrical pair to eliminate the eccentric force and the two axial planes of gages in piles cross cut each other.

Signal variation of these gages is recorded by DDS32 dynamic strain instrument, which is produced by Beijing Shijixingyuan Science & Technology Development Company of Limited Liability, with total channels of 40. Before detonating, an adjustment for dynamic strain instrument shows that all gages is in good condition and have a high sensitivity to respond external force.

2.2. A Short Delay Blasting

With an interval of 3.14m, the 30 shot points, which are plotted points of explosives on the field surface, are disposed along a circularity, whose diameter is 30m and centre is situated at the center of the test site.

For the designed/expected peak acceleration of around 450gal, 40kg middle-power explosive is filled in the bottom of each explosion well. Subsequently, all wells are adequately backfilled. During blasting process each shot detonates two explosives at the same time, which are symmetrical against centre. Combining the designed delay time after each shot (655~760ms), expected duration of ground motion should reach 9.8~11.4s.

3. SOME RESULTS OF THE FIELD TESTING

3.1. Distribution of Ground Motion in the Field

Peak ground shock in test site is larger than motion in outside area, which attenuates dramatically with a distance away from the site center. This situation is corresponding with the distribution of loess settlement caused by explosion. In test site, the maximum peak acceleration of ground motion could reach 1G.

3.2. Distribution of Loess Seismic Subsidence and Its Developing Characteristics

After explosion, there is not any ground fracture to be discovered in the field. However, observation data shows that all points reveal an obvious subsidence in the field. During the whole field testing, the maximum seismic settlement of loess is about 33mm, and this maximum point stands at the south of the field. As shown in Fig. 1, seismic settlement of loess decreases from the south to the north. Loess settlement in the test site, furthermore, is distinctly greater than subsidence outside the loess site, and development of loess settlement in the former region is more rapid.

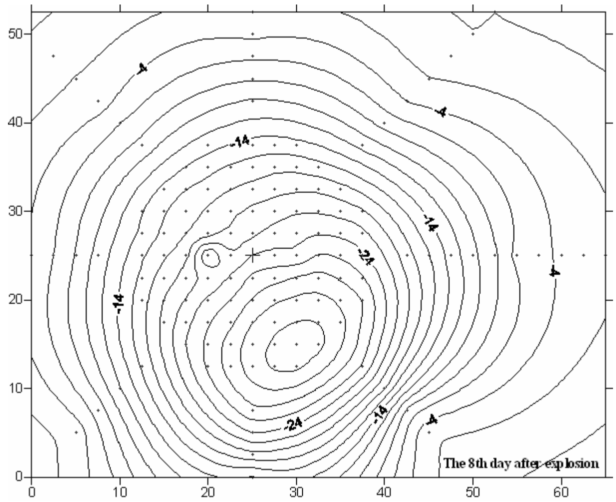

Fig. 1 Isoline map of seismic settlement of loess after 8 days (the dots express the observation points of loess settlement, and the cross is the center; unit is mm)

3.3. Distributional Characteristics of NSF along Pile

Distribution of NSF along pile with depth and its developing process during period of field testing are presented in the Fig. 2. It can be interpreted by actual contribution of effective weight to NSF during seismic settlement of each soil layer that there is no only one extreme value of NSF on pile with depth. By an envelope line for the NSF curves, the situation of several extreme values as shown in Fig. 2 will be able to simplify and this fact will be obvious that NSF increases with the depth along pile gradually.

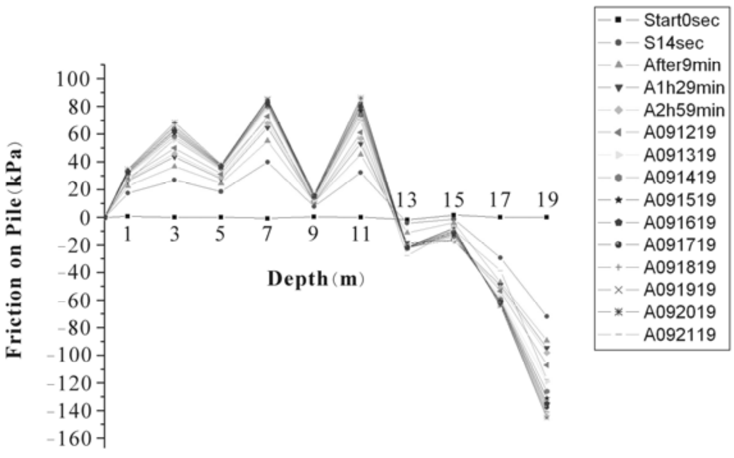

Fig. 2 Distribution of NSF on pile (Start0sec denotes the detonating moment; S14sec expresses the end moment

of explosion; A is an abbreviation from after the explosion test and 091219 figures the month/day/time)

There is an extreme magnitude, likely being the maximum value also, of NSF on pile near/at the neutral point, where NSF is equal to zero due to absence of relative deformation between pile and soil mass. This situation of NSF's extreme value along pile differs from a typical characteristic of NSF related to loess settlement by soaking. In the whole period of this field testing, moreover, the position of neutral point is almost at the same depth, approximately a 13m depth of pile body or a corresponding depth-buried of 15m, which accords with the bottom depth of seismic loess layer in the testing field.

During this field testing, the maximum value of NSF attains to 86kPa at the 11m depth of pile body, with a buried depth of 13m; average NSF reaches 54kPa and the corresponding total NSF is about 1654kN. This observation magnitude along pile in seismic subsiding loess ground is much greater than NSF on pile in collapsing loess field.

After the explosions immediately, the maximum NSF along pile is about 40kPa, with an average value of 24kPa on pile, whereas this value reaches 86kPa at the end of observation, with a 54kPa average value. Therefore, the maximum NSF along pile increases more than one times, and average value on pile enhances a similar factor also (86/40 and 54/24). Compared the increasing rate of NSF with the before-mentioned increment process of loess seismic settlement, it could be revealed that NSF along pile is proportional to seismic settlement of loess. This result is a tangible proof for that subsidence of soil mass around pile should be one of the key factors to influence NSF on pile(Sun Junjie et al, 2006).

4. THE STATIC FRICTION CHARACTERISTIC OF NSF IN THIS FIELD TESTING

4.1. Statistical Analysis of the Maximum NSF along Pile

In a general, the estimating result of NSF by the effective method is greater than an actual value observed in field testing. By the effective method, we obtained the statistical results of NSF in two conditions of water pressure, taking a computing depth of 13m and the water pressure by a product of γ*w*Z, where Z is always 13m (Tab. 1).

Tab. 1 Statistical results of NSF for different loess used by the effective stress method

Gravity Density (kN/m^3)	Water Content (%)	The Maximum Value of NSF along Pile	
		Ignore Water Pressure (kPa)	Considering Water Pressure (kPa)
12.6	3.9	49.2	10.9
	27.9	44.9	10.0
13.7	6.1	53.4	16.5
	26.5	48.2	14.9
14.3	7.0	55.3	19.8
	25.6	50.8	18.1
14.9	7.8	58.1	23.5
	24.4	53.1	21.5
15.4	14.3	60.0	26.7
	26.8	54.1	24.0

Because physical property in the above-mentioned estimation almost covers all kinds of loess, obtaining from the ref. Handbook of Engineering Geology (Editing Committee on Handbook of Engineering Geology, 1992), these results probably represent the maximum NSF, with a kinetic friction characteristic, in one loess field. It is easy to discover that in Tab. 1 the maximum value of NSF is 60.0kPa, which approximately has a one-third less of the field testing NSF along pile, 86kPa.

It can be discovered that this great difference of magnitudes, between NSF here and before NSF related to loess settlement by soaking, could not be explained successfully only by the varied strength of soil mass and pore water pressure. However, introducing that this field testing NSF is a kind of static friction, the above obvious difference should be problem again, because in theory a static friction is markedly greater than a kinetic friction.

3.2. Position of Natural Point

During the whole field testing, position of neutral point is almost at the same depth, approximately a 13m depth of pile body or a corresponding depth-buried of 15m. This fixed phenomenon differs from the variation position of natural point during before field testing of NSF in collapsing loess ground evidently (Fig. 3, Huang Xuefeng et al, 2002).

Relative stable position of natural point reveals that NSF's scope on interface between pile and soil, with the buried depth from 2m to 15m, is fixed and as a result only the one conclusion could be educed that with development of seismic subsidence there is no relative slide between pile surface and soil mass. Consequently, NSF along pile caused by seismic subsidence reported here is a kind of static friction (static NSF), whereas NSF related to typical loess subsidence by soaking should belong to a scope of kinetic friction (kinetic NSF).

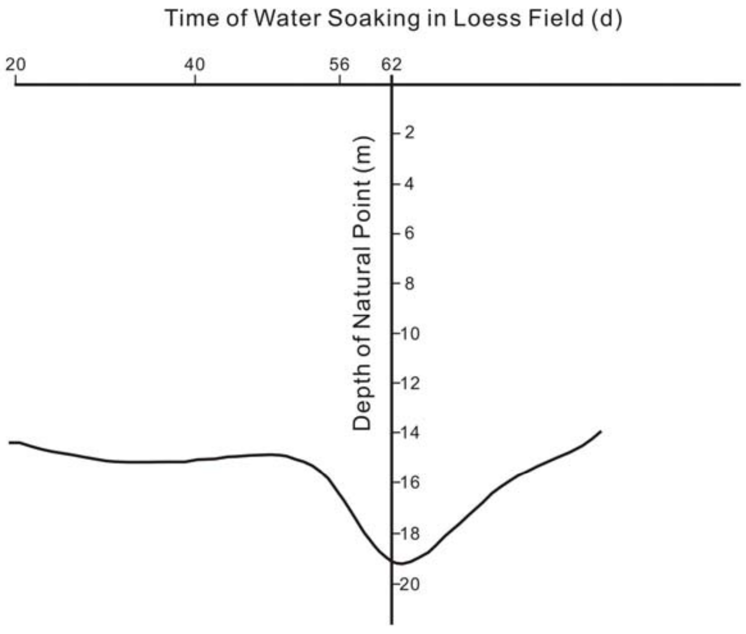

Fig. 3 Variation characteristic of the depth of natural point with the time by water soaking in loess field.

4.3. Distribution of NSF along Pile

As shown in Fig. 2, by an envelope line for the NSF curves, the situation of several extreme values will be able to simplify and one fact will be obvious that NSF increases with the depth along pile gradually. Consequently, there is an extreme magnitude, likely being the maximum value also, of NSF on pile near/at the neutral point.

This NSF's extreme value along pile differs from a typical characteristic of NSF by water soaking.

On a view of energy, lost gravitational potential energy (GPE) of subsiding soil mass around pile in a certain range is the source of energy to generate NSF. Recent researching work shows that NSF always could be regarded as a force on pile due to lost GPE and limited by shear strength of soil (Sun Junjie et al, 2006). GPE is a dot product between gravitation and displacement; therefore, lost GPE could be also described as a dot product between effective weight of soil mass above certain depth and settlement of soil mass around the pile at that depth. According to above analysis of position of natural point during the whole testing, it is obvious that there is no relative slide between pile surface and soil mass with the development of seismic subsidence. This means the NSF discussed here just bear on the weight and shear strength of loess mass. It well known that self-weight stress of soil increases with depth; this characteristic accords with the distribution of NSF along pile in the field testing.

5 CONCLUSIONS

Although for a long time the static friction characteristics of NSF cannot be observed in before field testing, researchers and engineers still believe the existing of static NSF. Here the authors introduce a field testing, which could prove the static NSF is an existing thing.

Three results of the testing could state the NSF induced by this less seismic subsidence has a static friction characteristic. The great difference of magnitudes, between NSF here and before NSF related to loess settlement by soaking, could not be explained successfully only by the varied strength of soil mass and pore water pressure. However, introducing that this field testing NSF is a kind of static friction, the above obvious difference should be problem again, because in theory a static friction is markedly greater than a kinetic friction. Relative stable position of natural point reveals that NSF's scope on interface between pile and soil, with the buried depth from 2m to 15m, is fixed and as a result only the one conclusion could be educed that with development of seismic subsidence there is no relative slide between pile surface and soil mass. Consequently, NSF along pile caused by seismic subsidence reported here is a kind of static friction (static NSF). According to this analysis of fixed position of natural point, it is obvious that there is no relative slide between pile surface and soil mass with the development of seismic subsidence. The fact means the NSF in the field testing provided by authors just bear on the weight and shear strength of loess mass. It well known that self-weight stress of soil increases with depth; this characteristic accords with the distribution of NSF along pile caused by a less seismic settlement.

In our opinion, during the whole field testing, less seismic subsidence of loess field, e.g. observation points in the test site with an average subsidence of 22mm, is necessary for generating the static NSF. On the contrary, in the field testing of NSF in collapsing loess ground, it could be only observed that the kinetic NSF because of the higher water content and water pressure, the lesser strength of loess mass, the much greater loess settlement by soaking, and the longer time interval between observations. However, in a closed condition of loess settlement, it is still a doubt that the two characteristics of NSF induced by seismic subsidence or settlement by soaking of loess respectively are consistent or not.

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