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THE FIELD TESTING ON NEGATIVE SKIN FRICTION ALONG PILES CAUSED BY SEISMIC SETTLEMENT IN LOESS

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ABSTRACT

Piles foundation is widely used in the earthquake-prone loess area of China. However, negative skin friction along piles caused by a sudden settlement in loess during strong earthquakes has not been taken account into design of piles foundation due to the lack of data related to the negative skin friction. In order to investigate the negative skin friction along piles in loess during the seismic settlement and develop a method of estimating it, the authors performed a field test at a loess site by means of a series of explosions, where two piles of 20m long were grouted. The ground motion caused by the explosions was strong enough to induce an obvious settlement in the site. There are 40 stress gages to be amounted on the two piles with a certain interval, 2m, to collect the data of negative skin friction with depth during the test. At the same time, the ground motion and settlement of loess site caused by the explosions were respectively observed by accelerographes and a level gauge. The testing data show that the negative skin friction is significant and should not be ignored in design of piles foundation.

Keywords: Negative skin friction, pile, loess, seismic settlement, explosion

INTRODUCTION

Loess is a kind of soil with porous structure and weak cohesion, depositing in different stages of the Quaternary. The compressibility of loess mass is low at natural moisture content as a result of a special microstructure (Miao Tiande, 2001). While the water immerges, however, the strength of loess mass will be reduced obviously, and this could make loess collapse (Gao Guorui, 1980; Yang Yunlai, 1988; Rogers et al., 1994; and Feda, 1996). In China, the acreage of the loess reaches 640,000 km^2, in which collapsible loess acreage is about 500,000 km^2 (Wang Guolie & Ming Wenshan, 2001). Furthermore, the most loess area in China is also the seismic region, in which many strong earthquakes occurred. Under the effect of moderate or strong earthquakes, liquefaction or seismic subsidence of loess is easily induced. Those three kinds of settlement due to collapse, liquefaction and seismic subsidence of loess, which relate to immerging water, additional load or ground shock, could come into being negative skin friction (NSF) on piles, which badly endangers pile foundation.

NSF is a complicated problem and it connects with some other theoretical problems in soil mechanics area. Because in-situ test costs a lot and also needs a long-time period for prepare, existing test data is limited for satisfying the study on NSF. Especially, the research data with regards to the NSF on pile in loess ground caused by seismic subsidence is very rare. Consequently, the NSF along piles caused by a sudden settlement in loess ground during strong earthquakes has not been taken account into the design of piles foundation, while piles foundation is widely used in the earthquake-prone loess area of China at present.

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In order to investigate the NSF along piles in loess ground during the seismic settlement and develop a method to estimate it, the authors performed a field testing at a loess site by means of a series of explosions on September 12, 2006 after one year preparing. In this paper, the field test design, observatory data and preliminary analysis are presented.

DESIGN OF THE FIELD EXPLOSION TESTING

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. A rough landform around the site is shown in Figure 1, where the area circled with dash-dash-dot-dot line is the test site and the area outlined with dash-dash-dot line is observatory field. 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 piles caused by seismic settlement of loess ground.

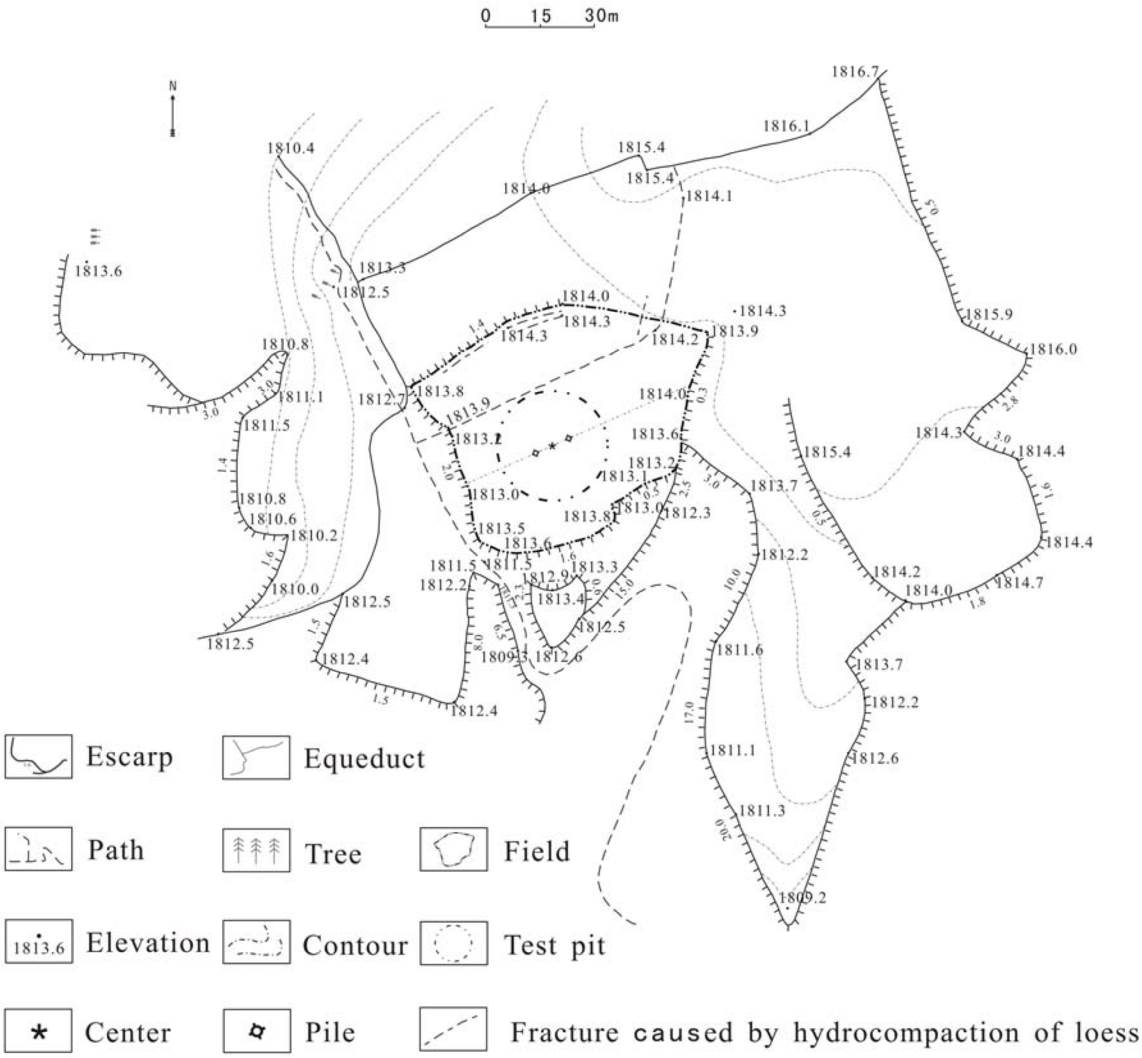


Figure 1. A rough drawing of landform around the test site

Testing Piles

There are two reinforced concrete piles, as shown in Figure 2, to be disposed in the loess ground.

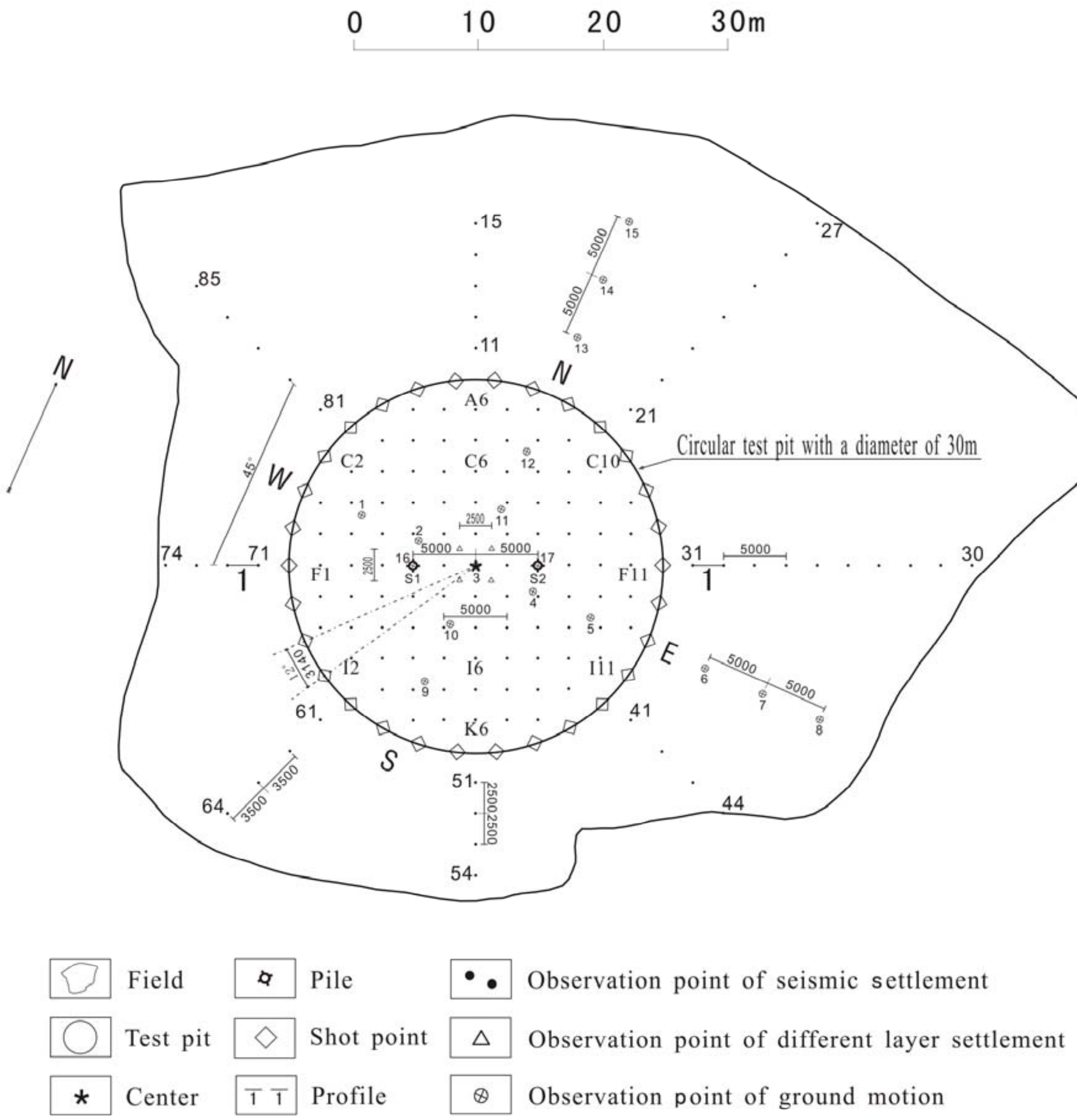


Figure 2. The details of field, test site, and all kinds of observation point

The laboratory test (for details to see Figure 3) shows that the residual strain (coefficient of seismic settlement) of the loess layer with the depth 16m and 20m is mighty lower than the upper soil mass during a moderate or strong dynamic stress. Considering the in-situ test cost and the characteristics of residual strain above-mentioned, the test piles are seated on the soil layer with buried depth of 22m. Seating on a non-seismic settlement layer, each of the two piles with a diameter of 0.8m is 20m long (see Figure 2). In their body, 40 stress gages are embedded in average with an interval of 2m in the direction of depth. For each pile the gages arrange as two symmetrical groups to eliminate the eccentric force and the two axial planes of gages in piles cross cut each other. The design strength of each reinforced concrete pile is C25 (see Figure 4).

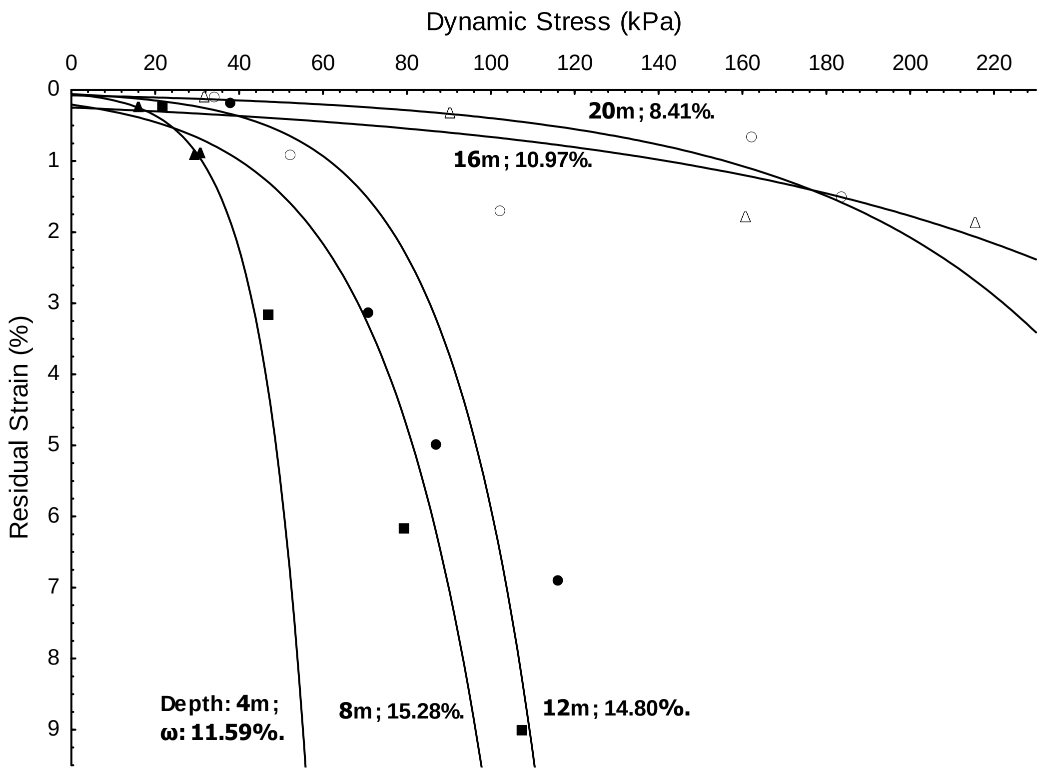


Figure 3. Characteristics of seismic settlement of soil mass with nature water content at different depth in the in-situ test loess field.

Observation Points of Seismic Settlement of loess and Ground Motion

For observation points of seismic settlement of loess as shown in Figure 2, there are 97 points in the test site and 43 points in the field around the site. Furthermore, 4 observation points of different layer settlement are placed near the center of the test site. Moreover, a datum mark is situated at the east of the site with a distance of 220m from the center. The details of all observation points related to seismic settlement of loess are showed in Figure 2.

In Figure 2, there are 23 observation points of ground motion, including 11 points in the test site and 6 points around the site along the direction of E-W and S-N, respectively, and other 7 points scattering in the east of the test site to observe attenuation of ground motion.

Details of Shot Points

With an interval of 3.14m and a burial depth of 23m, the 30 shot points are disposed along a circularity, whose diameter is 30m and centre is the center of the test site. The details of shot points are showed in Figure 5 and Figure 6.

For the expected peak acceleration of around 450gal, 40kg middle-power explosive should be filled in the bottom of every explosion well in this field. Subsequently the well must be backfilled adequately. As shown in Figure 6, during explosion process each shot detonates two shot points at the same time, which are symmetrical against centre. Based on the designed delay time after each shot, the total duration of ground motion could reach 11s.

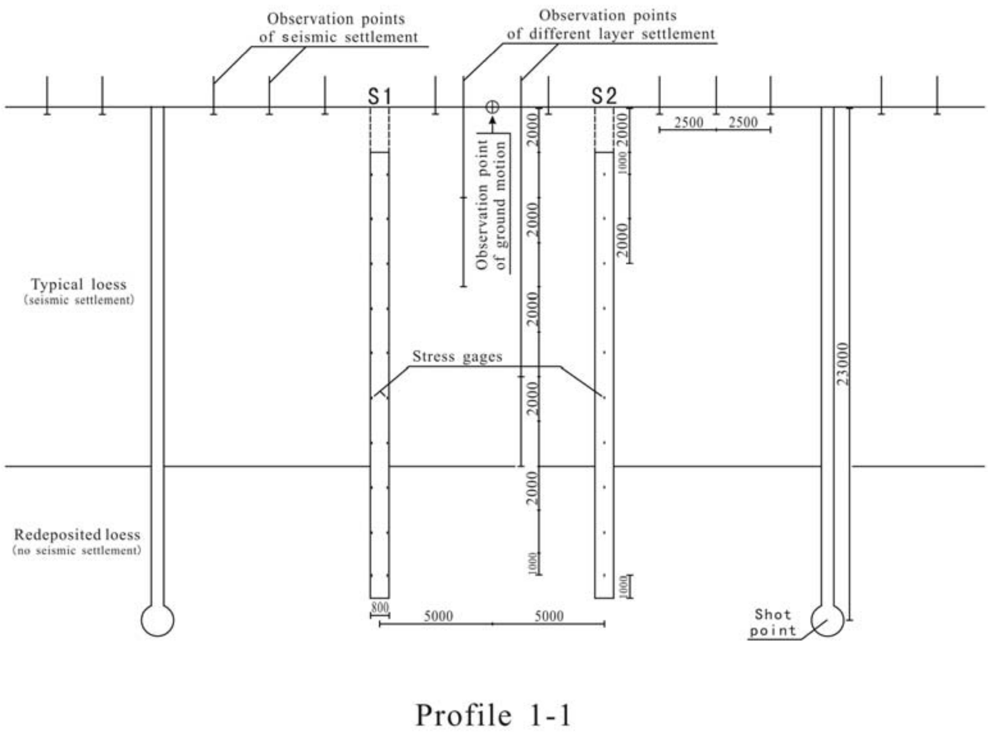


Figure 4. The profile of testing disposal in the field

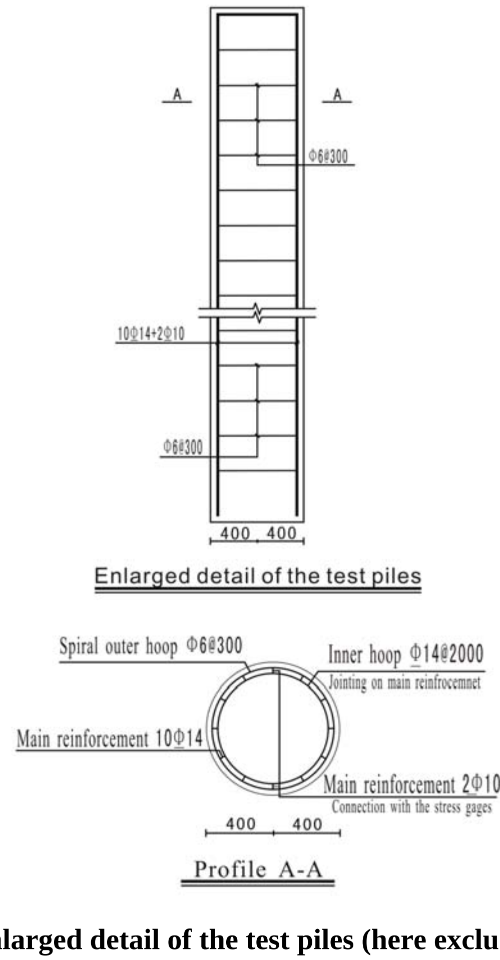


Figure 5. The enlarged detail of the test piles (here excluding stress gages)

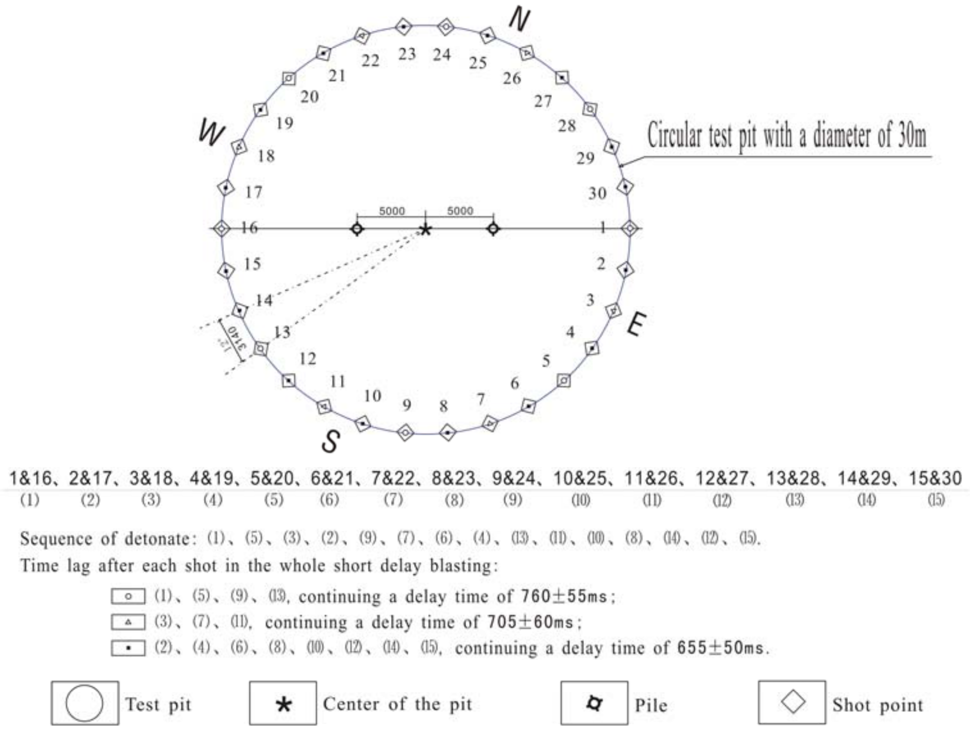


Figure 6. The design of explosion in this field testing

CHARACTERISTICS OF LOESS SETTLEMENT INDUCED BY EXPLOSION

Peak Acceleration of Ground Motion on the Field

From the peak acceleration distribution of ground motion on the field as shown in Figure 7, it can be seen that the peak motion in the test site is larger than the motion in the 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 the test site, the maximum peak acceleration of ground motion could reach 1G.

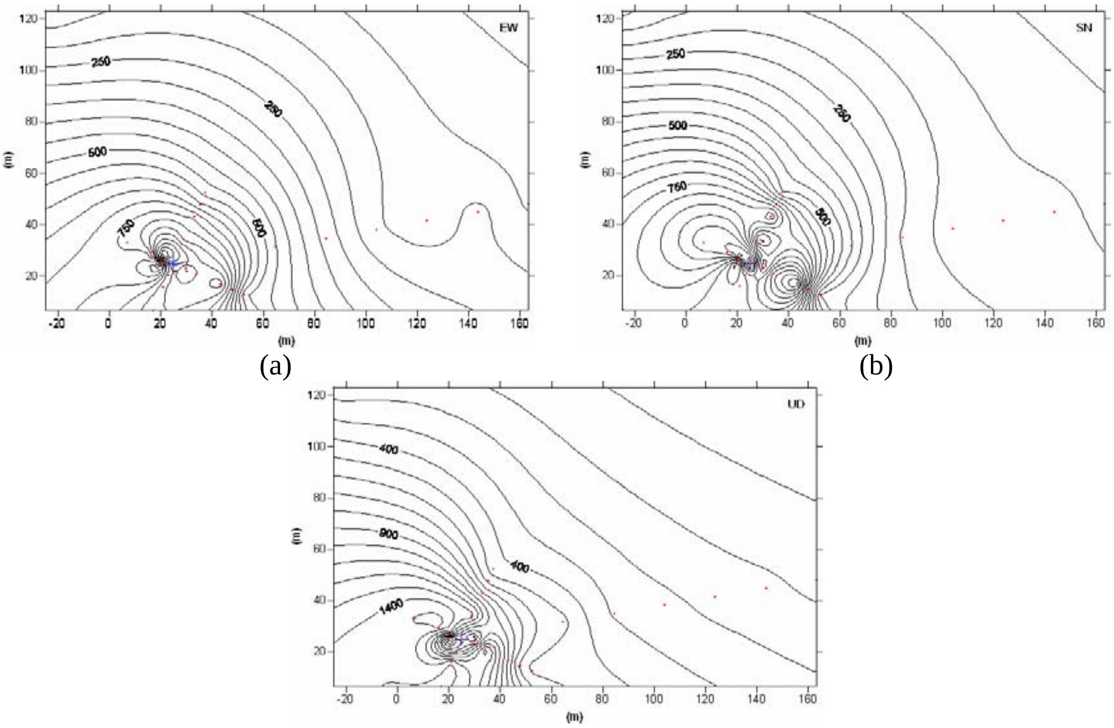
Seismic Settlement of Loess on the Field

After explosion, there is not any ground fracture to be discovered on the field. However, the observation shows that all points reveal an obvious subsidence in testing site. In the whole period of this 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 the Figure 8, the seismic settlement of loess decreases from the south to the north. On the other hand, the loess subsidence in the test site is distinctly more than settlement outside the site, and the development of loess settlement in the former place is more rapid.

Development of Loess Settlement with Time

From the Figure 9(a), it could be disclosed that just after explosion the settlement value of loess is about 50 percent to the maximum observation value of loess subsidence. That is to say, during the explosion process the seismic settlement of loess increases quickly.

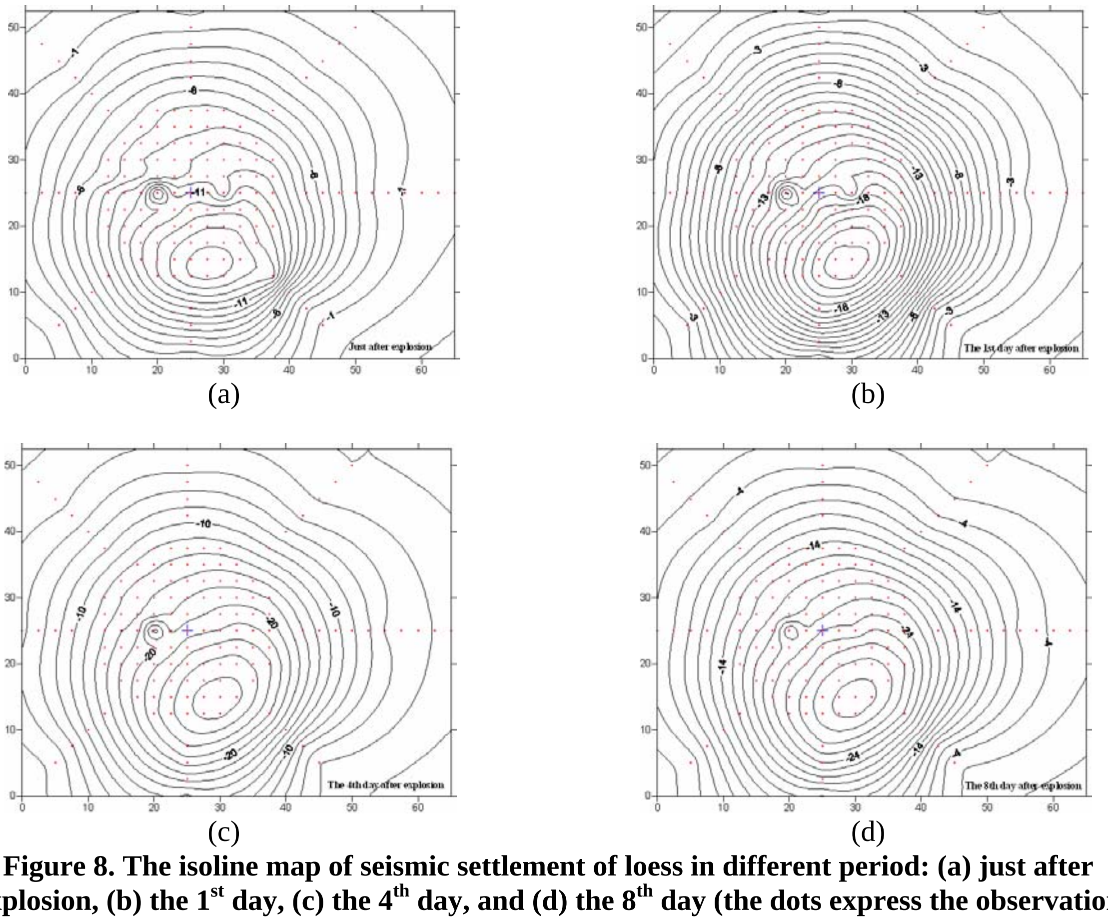
After the explosion, however, development of loess settlement becomes slow and slow. The curve of seismic subsidence versus time as shown in Figure 9(a) indicates that the development of settlement submits an exponential function. While the seismic settlement of non-saturated loess is induced, its developing process for soil mass at different position desponds on the local landform.



(a) (b)

(c)

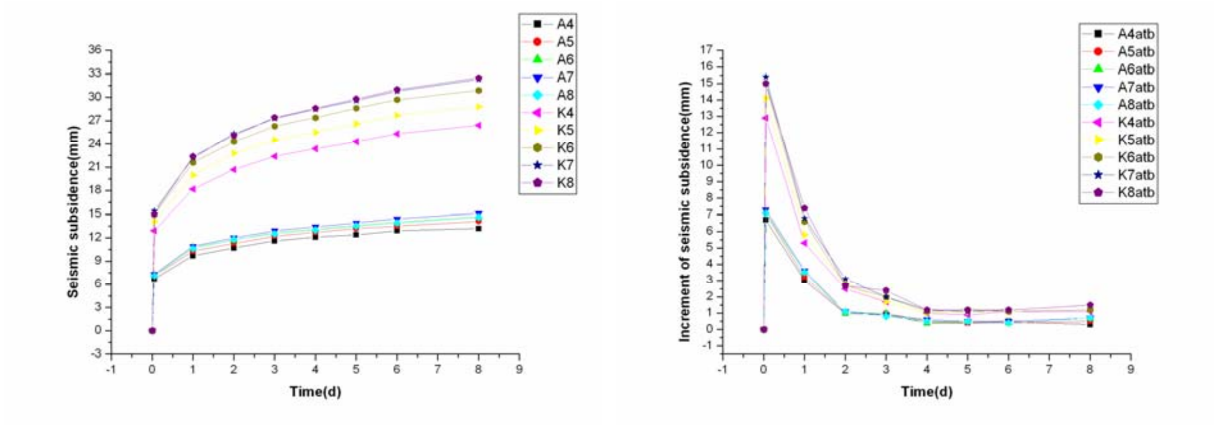
Figure 7. The isoline map for (a) EW component, (b) SN component, and (c) UD component of peak ground acceleration induced by explosion (the dots express the observation points of ground motion, and the cross is the position of the center of the test site; unit is gal)



(a) (b)

(c) (d)

Figure 8. The isoline map of seismic settlement of loess in different period: (a) just after explosion, (b) the 1st day, (c) the 4th day, and (d) the 8th day (the dots express the observation points of loess settlement, and the cross is the center; settlement unit is mm)



(a) (b)

Figure 9. The developing process of seismic settlement of loess with time (A4~A8 and K4~K8 express the northmost and southmost observation points, respectively; A4atb expresses the increment of loess settlement at point A4 during one day)

THE DEVELOPING PROCESS OF NSF ON PILE AFTER EXPLOSION

The Distribution of NSF on Pile in Different depths

The distribution of NSF on pile with depth and its developing process in field testing are presented in the Figure 10. There is an extreme value of NSF on pile above the neutral point, where the NSF is equal to zero due to the absence of relative displacement between pile and soil mass. For this situation, the NSFs related to both seismic settlement and hydrocompaction of loess are similar.

During the field testing, the average NSF along pile in seismic subsiding loess ground could reach 54kPa (the corresponding total NSF is about 1654kN). This value is much greater than the NSF on pile in collapsing loess ground.

As shown in Figure 11, the NSF and positive skin friction (PSF) have a similar process during the explosion testing. In Figure 10, it is could be interpreted by the difference of actual effective settlement between 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 Figure 10 will be able to simplify.

The Developing Process of NSF with Time

The developing process of NSF along pile related to seismic settlement is coincident with development of settlement submitting an exponential function. The maximum value of NSF on pile represents the characteristics of different settlement curves of soil mass with depth.

Figure 10 describes that during the period of explosion and a short time after it, NSF along pile increases rapidly caused by seismic settlement by means of explosion. In the other time stages after, the above-mentioned development of NSF on pile becomes slow.

The Relationship between NSF and Seismic Settlement of Loess

Seismic subsidence of loess is an abrupt settlement of loess ground due to seismic loading in the non-saturated and low moisture condition (Wang Lanmin, 2002). The observation on seismic settlement of loess in this field testing proves the abrupt progress of soil subsidence. However, contrasted to the short time of explosion, the developing process of loess settlement is a slow-motion.

Lost gravitational potential energy of subsiding soil mass and shear strength of soil mass are the dominating factors to generate NSF on pile. It is not the key factors that why and how settlement of soil mass takes place (Sun Junjie & Wang Lanmin, 2006). Compared Figure 9(a) with Figure 11, it is obvious that the change of loess settlement and NSF on pile with time have a similar characteristic.

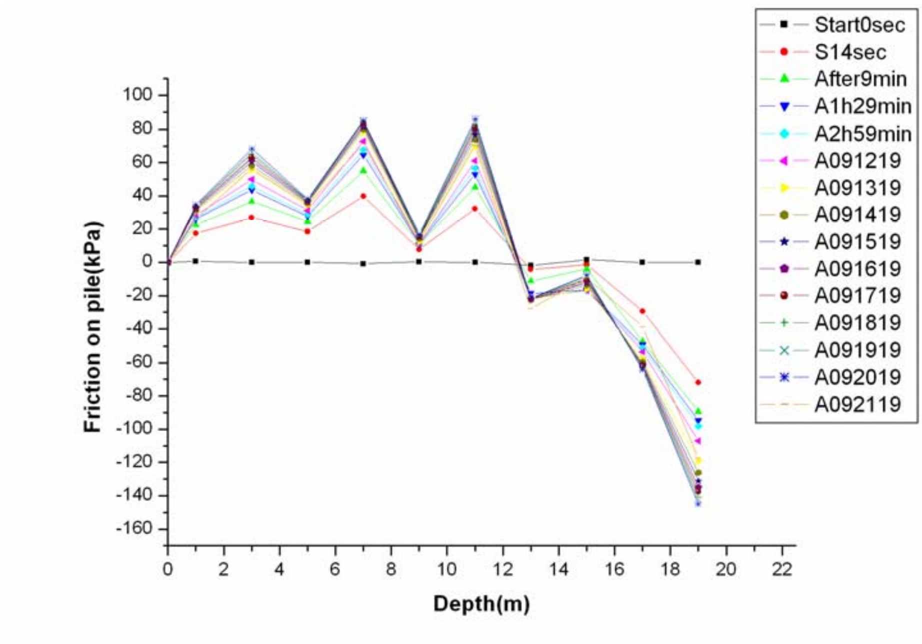


Figure 10. The distribution of NSF on pile and its developing process with time (Start0sec denotes the detonating moment; S14sec expresses the end moment of explosion; A is an abbreviation from after the explosion test and 091219 figures the month/day/time)

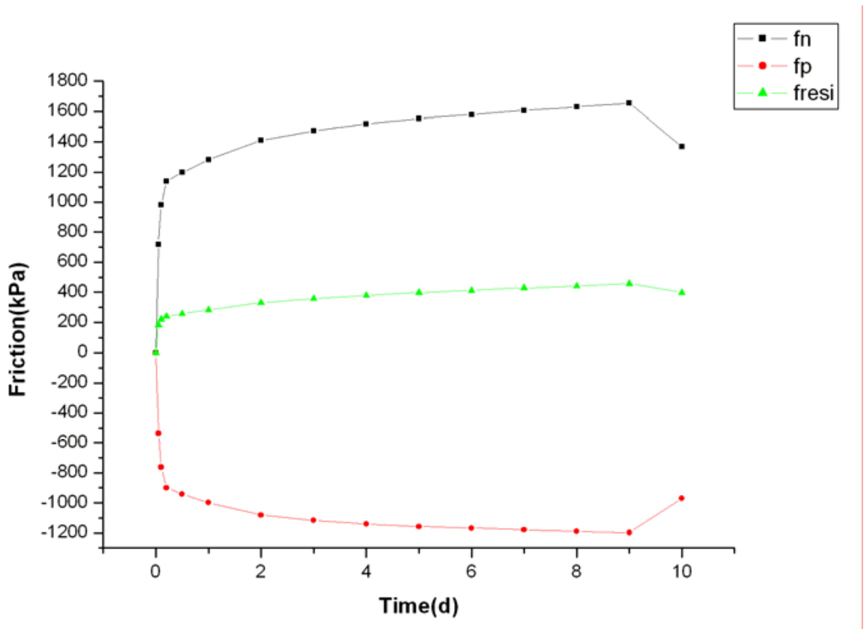


Figure 11. The change of total friction on pile with time (fn, fp, and fresi express the total NSF, the total positive skin friction (PSF), and the difference between the NSF and PSF, respectively)

CONCLUSIONS

Seismic subsidence of loess ground indeed may generate a negative skin friction (NFS) along piles, which has been recorded by stress gages with 2m interval disposed in the piles. The testing data shows that the average NSF and total NSF along pile in seismic subsiding loess ground is ~54kPa and ~1654kN respectively, which is much greater than the NSF on pile in collapsing loess ground. It could be explained by the differences in loess strength and development of loess settlement for unsaturated and saturated soil deposits. Therefore, NFS should be accounted into design of piles foundation in loess area.

During the observation on the testing field, the seismic settlement is not symmetric distribution for different points of the field. This is probably due to the landform around this field, whose south is the escarp with a drop height of about 10m. Here soil mass has more freedom for settlement. In this field testing, the maximum settlement of loess is just 33mm, which is much lower than in a collapsing loess ground. But the former caused stronger NSF than the latter. For the aim to observation NSF along pile caused by seismic settlement, this in-situ test is successful completely.

The recorded peak ground acceleration on the field is much stronger than expected value by empirical formula. This discrepancy could help us to improve understanding on the attenuation of peak acceleration in near loess site of explosion. Furthermore, corresponding recorded settlement data of ground indicate that the effect on failure of loess mass by explosion differs from that by earthquake predominantly. It may be supported by the fact that the intensity degree of the site should be greater than Ⅸ for peak acceleration, whereas the degree of the site is Ⅶ for seismic settlement of loess.

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