STUDY ON THE LATERAL DYNAMIC RESPONSE OF PILE FOUNDATION IN LIQUEFIABLE SOIL LAYER

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ABSTRACT :

The reasonability of the main computational method of seismic lateral capacity of pile is discussed and the disadvantages of the pseudo-static and coefficient-discounted method are also pointed based on the shaking table test. The p-y curves are got in the paper indicate both the co-efficient-discounted method and using lateral displacement of pile instead of soil-pile relative displacement are not agreeable with the real situation; Fundamental idea of pseudo-static method is not agreeable with mechanism in actual. The pile response can not be obtained simply by discounting lateral stiffness of non-liquefiable soil layer. Calculated results by using pseudo-static method disagree with real situation especially in small displacement range. Calculating results by using pseudo-static method are quite conservative even can not be accepted in engineering practice.

KEYWORDS: Shaking table test; co-efficient-discounted method; soil-pile interaction; pseudo-static method; p-y curve

1. INTRODUCTION

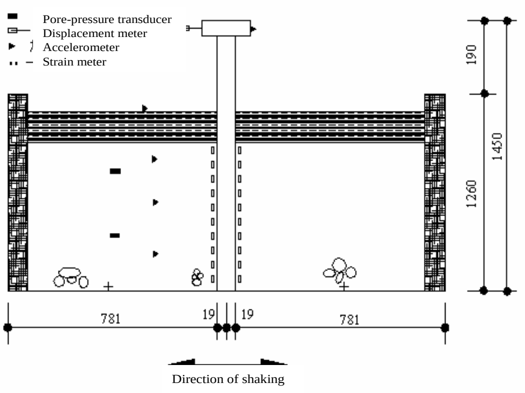
The design method of the pile foundation bearing lateral capacity in liquefiable site is an important question. The simulation using the large-scale finite element analysis method can not be used widely in current engineering practice. The simple method adopted by the pile foundation lateral capacity in the codes is based on the pseudo-static concept. However, there are two questions related to calculating the seismic response of pile foundation in liquefiable site to be answered. One is the reasonability of the simple method under the dynamic loads and the other is the modification of the simple method in the liquefiable conditions. How to confirm the p-y curve in liquefiable site is an impendence research topic at present.

In this paper, the mechanism of interaction of the pile and liquefiable soil is analyzed and the reasonability of coefficient-discounted method is discussed by using the shaking table tests of the liquefiable soil-pile-superstructure models. The testing results indicate the pseudo-static method is not agreeable with the actual behavior of the pile foundation when the liquefaction occurs. The coefficient-discounted method obviously is not suitable for calculating the pile lateral capacity in the liquefied soil layer. For in small displacement range the calculated pile-soil interaction force by using pseudo-static method increases significantly and is much larger than the testing results. As a result, the pseudo-static method is quite conservative and even can not be accepted in engineering practice for the liquefaction cases..

2.MODELING

2.1 Shaking table and model box

The major purpose of the shaking table tests is to gain insight research into SSPSI by analyzing a series of histories to calibrate a numerical model for SSPSI problem. The large SSPSI shaking table tests have been performed in the Institution of Engineering Mechanics, CEA. The shaking table of 5m×5m has a bandwidth of 0-50Hz and can permits many kinds of waves including regular sinusoidal waves and earthquake histories. The model container confined a dimension of 1.6m×0.9m in length×width and 1.26m in height as shown in Fig.1. In order to study the dynamics effects of liquefaction on lateral bearing capacity of pile foundation during different input earthquake motions. A successful container to support the model soil is an important part of the test, which should minimizes the influence of the boundary conditions. Four soil containers are used at the same time to compare the different responses of various cases under the same incidence. The container is modeled with two sponge cushions in two sides of the box as absorbing boundary.



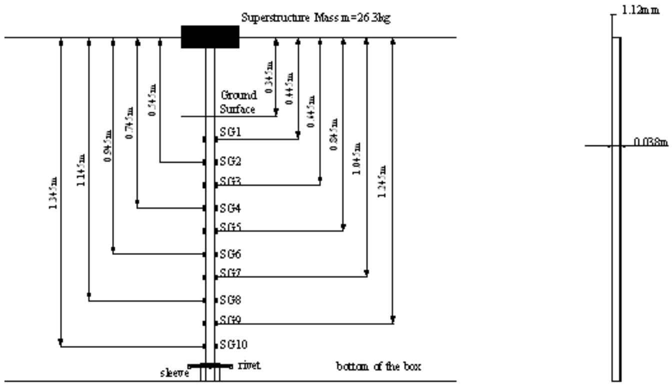


Fig.1 Location chart of model box and model pile Fig.2 Location chart of model pile dimension and strain gauge

2.2 Soils and piles

The aluminum tube with the outer diameter of 38mm and height of 1.12mm is made as the model of the pile. A weight mass of 26.3kg is taken as the superstructure and is located at top of the pile as shown in Fig. 2. A sleeve is welded to bottom of the container and the pile insert in it. Then the pile is fixed in the sleeve by four rivets in different directions. The pile head is fixed to the superstructure. By cantilever beam method, the lateral rigidity of the pile is obtained as 1483.3N-m^2.

Table 1 Material parameter and geometry dimension of model pile

Material	Outer diameter	Inner diameter	Yang' module	Inertia square	Density	Poisson ratio
Rolling aluminum	38mm	35.6mm	6.4e^{10}Pa	2.32e^{-10}m^4	2700kg/m^3	0.3

The harbin sand is used as the saturated sand test, Grading curve of the sand is shown in Fig.3. Based on this we can get d_{10} =0.129mm, d_{30} =0.191mm, d_{60} =0.274mm and asymmetry coefficient C_u =2.124, curvature coefficient C_c =1.032.

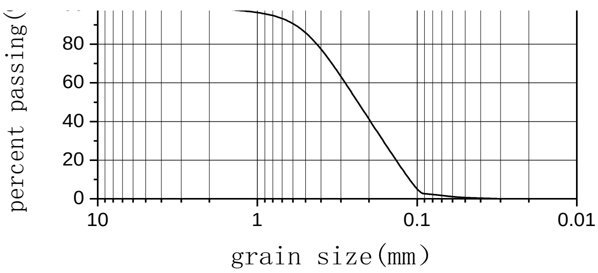


Fig.3 Grading curve of the sand

2.3 Input motions

Sine wave and earthquake wave are both input in this test. The sine wave frequency is 3 Hz and EL-Centro wave acceleration history record got in Imperial Valley America 1940. See in table 2.

Table2 Input motion and the main parameters

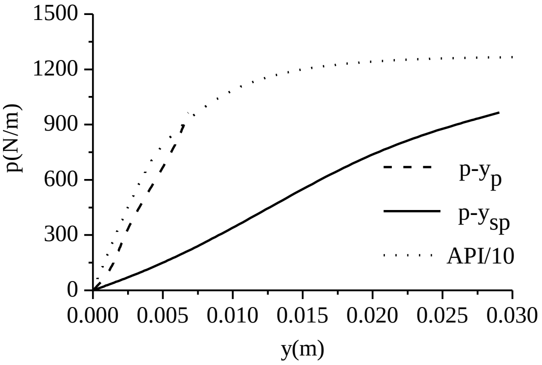
Number	Relative density	Input waves	Input $A_{max}(g)$	Output $A_{max}(g)$	Frequency Hits (Hz)	Directions
SIND1	20%	Sine wave f=3Hz	0.3	0.303	200	South-North
SIND2	30%					
SIND3	40%					
SIND4	50%					
ELD1	20%	EL-Centro	0.4	0.402	200	South-North
ELD2	30%					
ELD3	40%					
ELD4	50%					

3.P-Y CURVE RESULTS AND CONTRAST ANALYSIS

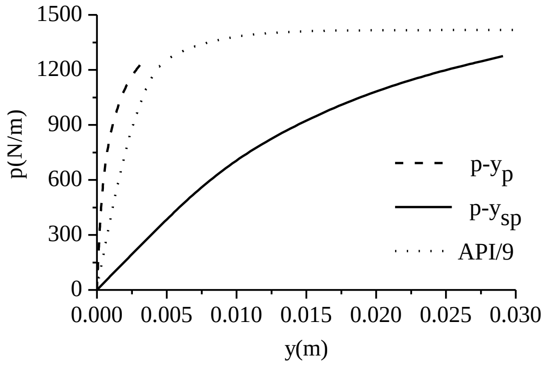
In liquefiable soil layer, the pile-soil interaction p-y curve used is simple means that discount lateral earth pressure，that is, using the existing non-liquefied soil dynamics p-y curve and multiply reduction factor of liquefication. The p-y curve in API code is usually discounted in engineering，and people use pile-soil relative lateral displacement as the pile lateral displacement. That is the basic thought of co-efficient-discounted method。The method to choose reduction factor is choosing 1/10~1/5 in the relative density of 20% to 65% according to the views of some scholars ，the smaller relative denstiny is，the smaller reduction factor is.For the paper, when relative destiny is 20%、30%、40% and 50%，choose reduction factor as 1/10、1/9、1/8 and 1/7。As the results in this paper，in chronic way，selecting pile-soil relative lateral displacement as pile lateral displacement to get p-y curve，that is pseudo-static method。As to the results of the trial in this paper，use pile-soil relative lateral displacement as actural results，not pile lateral displacement，at the same time，compare actural pile-soil interaction p-y curve at mainline form with co-efficient-discounted method and pseudo-static method。P-y curves got by three different methods are contrasted and shown in Figure 4 to Figure 7。In the figure,“API/A”Chart(point line) stands for the results got by co-efficient-discounted method，it is the result got from co-efficient-discounted method of API criterion，standing for the common arithmetic in engineering，and A is reduction factor；“p-y_p” Chart (crossed) stands for the result got from pseudo-static method.Under chronic thought that soil is static，use pile-soil relative lateral displacement as results after piles' lateral displacement and deal with the data of trial，y_p is lateral displacement of pile；“p-y_{sp}”Chart (solid line) stands for the result in actural case，pile-soil relative lateral displacement is actural results after dealing with the data of trial，y_{sp} being actural pile-soil relative lateral displacement。

Figure 4 (a), (b), (c) and (d) to Figure 5 (a), (b), (c) and (d) showed respectively are four p-y curves 40cm and 80cm under the bottom of piles when the sand relative denstiny is saturate under input of sine wave from large-scale shaking table.Through the comparison，the result got from co-efficient-discounted method is close to the pseudo-static method，that is, for liquefaction，the result got by discounting p-y curve in API criterion，is basicly the same with the result got from the chronic thinking of using pile-soil relative displacement as pile lateral displacement。From that point of view，co-efficient-discounted thinking comes from the chronic thinking of static（pseudo-static）method。Where special attention must be paied is the results of co-efficient-discounted thinking and chronic thinking are basically the same，but when both compared with the actual situation,there are considerable variations in the performance of p-y curve。As showed in Figure 4 ~ Figure 5，in the case of small displacement，p from co-efficient-discounted thinking and pseudo-static method grow rapidly，and quickly reached yield limit；but indeed，in case of small displacement,the reaction of p is not very big。

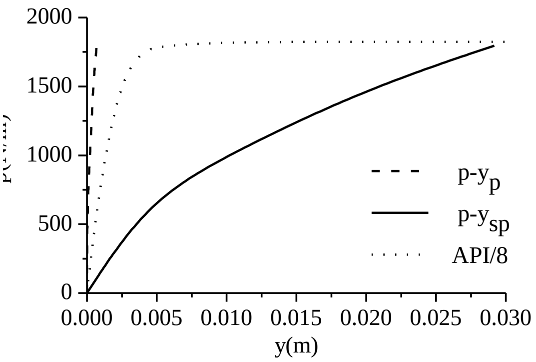
In engineering，the design of lateral capacity p-y curve for piles in liquefiable field used currently is co-efficient-discounted thought。Result of this method would lead to rapid growth of p in the case of small displacement,which is unacceptable in engineering。As the results showed in Figure4 ~ Figure5，co-efficient-discounted method is really conservative，and there is lange difference between the result and practice。Also,it can be seen from the comparision that the limits of the three methods tend to be identical。



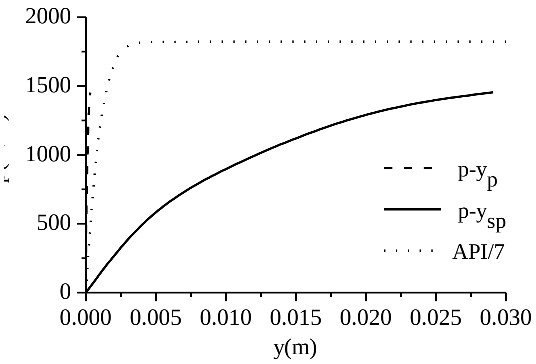
（a）SIND1 test



（b）SIND2 test

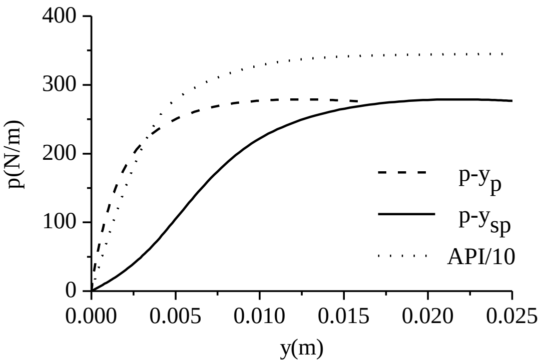


（c）SIND3 test

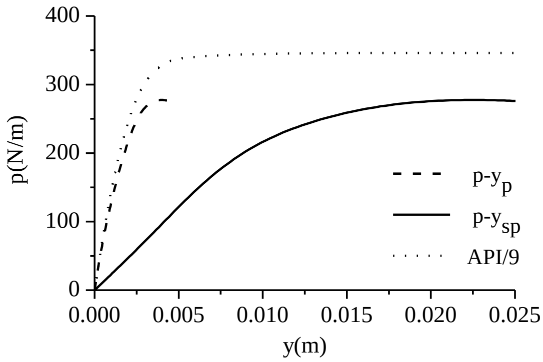


（d）SIND4 test

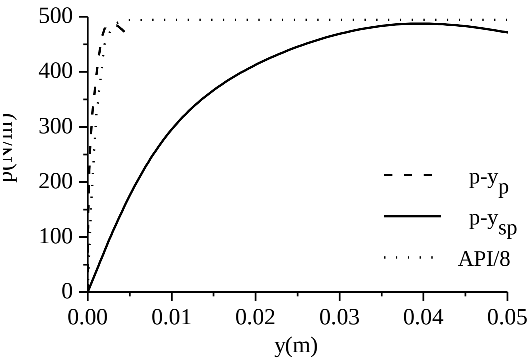
Fig.4 Comparison of p-y curve got through three kinds of method（sine wave input，40cm to the pile bottom）



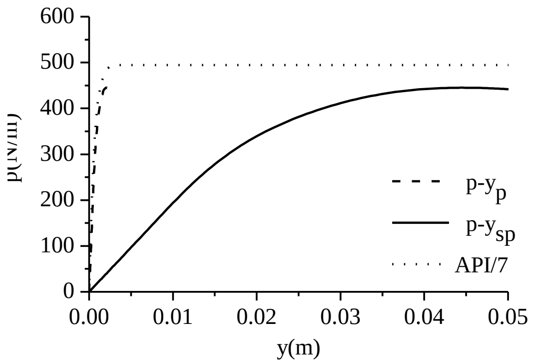
（a）SIND1 test



（b）SIND2 test



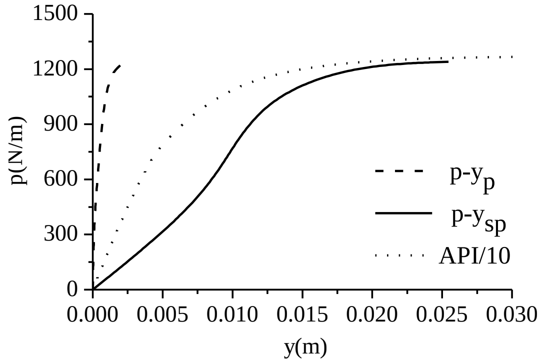
（c）SIND3 test



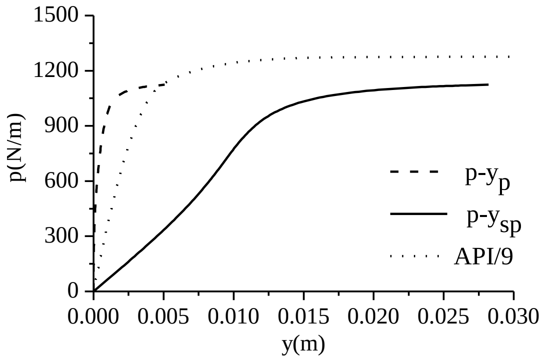
（d）SIND4 test

Fig.4 Comparison of p-y curve got through three kinds of method（sine wave input，80cm to the pile bottom）

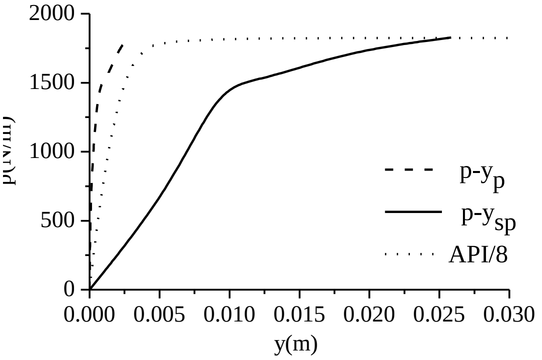
For the case of EL-Centro wave input, comparison of p-y curves got from three kinds of method are presented in Fig.6 (a), (b), (c), (d) and Fig.7 (a), (b), (c), (d). Each one represents 40cm and 80cm to the pile bottom for four relative destiny saturated sand cases respectively. From the comparisons we can see that the results gained from pseudo-static method and co-efficient-discounted method are closely. For seismic wave case，result of co-efficient-discounted method result for p-y curve got from API code is coincide with pseudo-static method. However, there are quite more difference among pseudo-static method and co-efficient-discounted method and actual results. For in small displacement range the calculated pile-soil interaction force by using pseudo-static method and co-efficient-discounted method increases significantly and is much larger than the testing results. In other words, if we accept the thought of co-efficient-discounted method to design lateral capacity of pile foundation p-y curve in engineering for seismic wave input, the result must be quite conservative and even can not be accepted in engineering practice for the liquefaction cases. In addition, the terminal value of three methods is accordant by comparison.



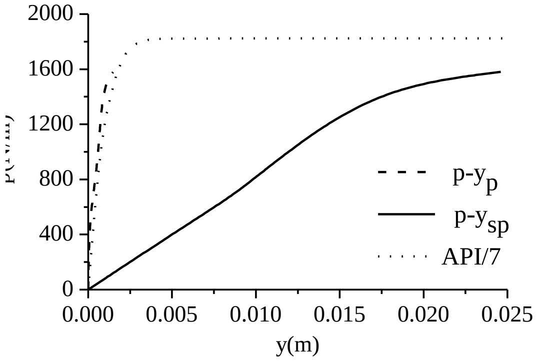
（a）ELD1 test



（b）ELD2 test

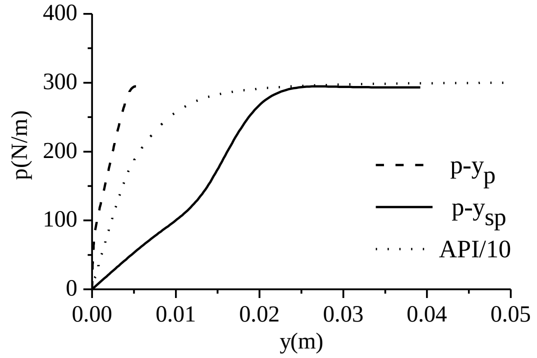


（c）ELD3 test

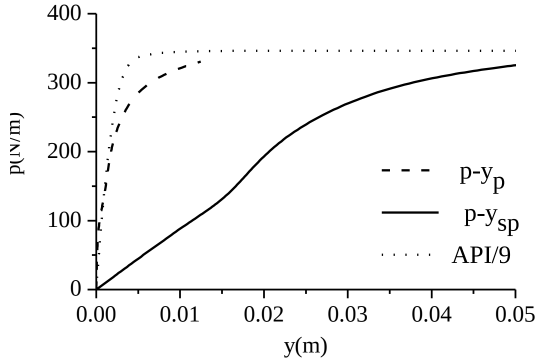


（d）ELD4 test

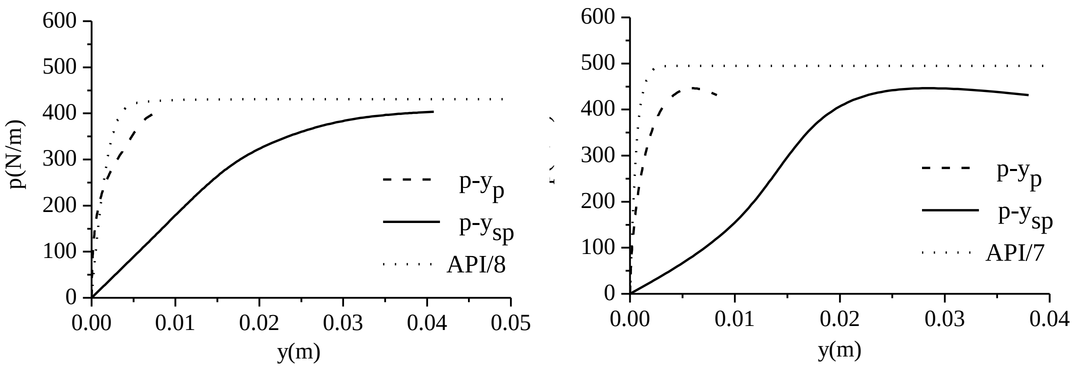
Fig.6 Comparison of p-y curve got through three kinds of method（earthquake wave input，40cm to the pile bottom）



（a）ELD1 test



（b）ELD2 test



（c）ELD3 test （d）ELD4 test

Fig.7 Comparison of p-y curve got through three kinds of method（earthquake wave input，40cm to the pile bottom）

4.CONCLUSION

Pile-liquefiable soil interaction p-y curve is studied through shaking table test in this paper and the illogicality of co-efficient-discounted method commonly used in engineering is pointed out.The test analysis results indicate：

(1)The test result indicated that p-y curve truck line present anti-hyperbolic form and coincides with the API code. Also，the slope of p-y curve near to the soil surface is small. The p-y curve distribute rule is coincide with API code standardization curve after liquefaction.

(2)Based on the test，the pseudo-static, co-efficient-discounted method and the testing results are analyzed by comparison. The testing results indicate the pseudo-static method and co-efficient-discounted method are both not agreeable with the actual behavior of the pile foundation when the liquefaction occurs. However, the terminal value of three methods is to be accordant. For in small displacement range the calculated pile-soil interaction force by using pseudo-static method increases significantly and is much larger than the testing results.

(3)At present, thought of co-efficient-discounted method is used to obtain the lateral capacity p-y curve of pile foundation in liquefiable site in engineering practice. As a result, the pseudo-static method is quite conservative and even can not be accepted in engineering practice for the liquefaction cases.

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