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Experimental study on liquefaction-induced large ground deformation

Masakatsu Miyajima & Masaru Kitaura
Kanazawa University, Japan

ABSTRACT: The present paper deals with mechanism of large ground deformation induced by soil liquefaction. Small scale vibration tests were conducted using sloping loose sand stratum. The permanent ground displacement can be obtained from the product of the duration time of ground deformation and its velocity. The relationship between these and other factors was investigated. Based on the test results, the duration time of ground deformation and thickness of the loose sand stratum have a good correlation. The velocity of ground deformation and slope of loose sand stratum also correlate to each other. Furthermore, extent of liquefied area is pointed out as one of the most influential factors in determining the magnitude of large ground deformation.

1 INTRODUCTION

Large ground deformation induced by soil liquefaction depends on many factors such as the thickness, width and slope of liquefied stratum, magnitude and duration time of earthquake and so on. Some research work on the causes of large ground deformation and its effects on civil engineering structures has been undertaken. However, the mechanism of the liquefaction-induced large ground deformation has not been clarified sufficiently.

Vibration tests were conducted in order to evaluate the principal factors affecting the large ground deformation. The permanent ground displacement can be obtained from the product of the duration time of ground deformation and its velocity. The relationship between these two, the duration time and velocity of ground deformation, and other factors was investigated through small scale vibration tests. Moreover, effects of boundary condition of liquefied ground on permanent ground displacement was studied.

2 VELOCITY AND DURATION TIME OF LARGE GROUND DEFORMATION

2.1 Test Procedure

The diagram of test apparatus is shown in Fig. 1. The sand box was 500 mm in width, 1500 mm in length and 350 mm in height. The model sand stratum had a slope of 2 % to 6 %. The sand stratum was made from loose saturated sand, whose physical properties are listed in Table 1. Sixteen pins were installed at the surface of the sand stratum to measure the horizontal deformation of the ground surface. The deformation of the ground surface during excitation was recorded by a video camera. The model sand stratum was covered by an acryl board in order to prevent the dissipation of excess pore water pressure from the ground surface and to lengthen the duration time of soil liquefaction. The model sand stratum was vibrated by a harmonic wave with a frequency of 5 Hz. Target acceleration of the table was 120 cm/s^2 and it took about 5 seconds for the table to reach the given acceleration. The duration of the test was 30 seconds.

2.2 Test Results

Fig. 2 shows the relationship between the duration time of liquefaction and that of ground deformation. The duration of liquefaction is defined as the time when lower response ground acceleration than the input acceleration appears in the accelerograph in this study. This coincides with the time from the accumulation of excess pore water pressure to its dissipation at the site where the accelerometer was installed. It can be seen in Fig. 2 that the duration time of liquefaction and that of ground deformation correlate to each other and the latter is larger than the former. Since the measurement of duration time of liquefaction is more precise and easier to do than the measurement of that of ground deformation, the duration time of liquefaction was used instead of the duration of ground deformation.

Fig. 3 presents the relationship between the thickness of loose sand layer and average displacement. The average displacement increases with an increase in the thickness of loose sand layer. Fig. 4 shows the average displacement in relation to the slope of loose sand layer. The good correlation is shown in each other. These results are in accordance with those of the previous research works (Yasuda et al. 1987, Matsumoto et al. 1990).

The permanent ground displacement is expressed as the product of the duration time of ground deformation and its velocity. First, the duration time of ground deformation was investigated in relation to the other test parameters. Fig. 5 illustrates the relationship between the thickness of loose sand layer and duration time of soil liquefaction. This figure indicates that the duration time of liquefaction seems to be directly proportional to the thickness of loose sand layer. The whole sand layer liquefied at almost the same time because of relatively small thickness of loose sand layer in these tests. Therefore, the greater the thickness of the liquefied layer, the longer the time of dissipation of the excess pore water pressure. Fig. 6 reflects the duration time of liquefaction in relation to the slope of loose sand layer. This figure shows no correlation between the two.

Next, the effects of the velocity of ground deformation on the other test parameters were investigated. Fig. 7 shows that there is no relationship between the thickness of loose sand layer and velocity of ground deformation. Fig. 8 shows the relationship between the velocity of ground deformation and slope of the loose sand layer. Since the whole sand layer was liquefied completely in these tests, the effect of gravity on the deformed ground increases with an increase in the slope, therefore, the velocity of ground deformation increases.

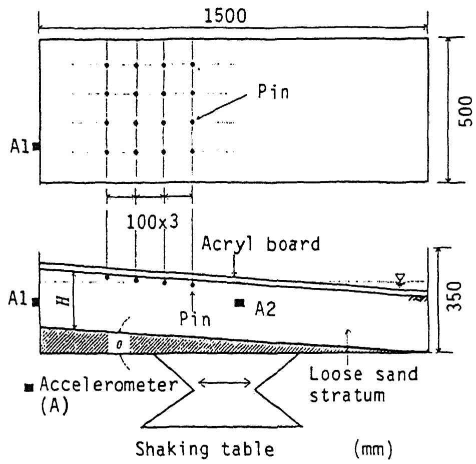

Fig. 1 General view of test apparatus.

Table 1 Physical properties of sand.

Specific Gravity	2.67	
Uniformity Coefficient	2.96	
Maximum Void Ratio	1.030	
Minimum Void Ratio	0.721	
50 Percent Diameter	0.2	(mm)
Coefficient of Permeability	1.92×10^{-2}	(cm/s)

2.3 Discussion

Based on the test results obtained here, the duration time of ground deformation and thickness of loose sand layer showed a good correlation. The velocity of ground deformation and slope of loose sand layer also correlate well. Since the permanent ground displacement is expressed as the product of the duration time of ground deformation and its velocity, the average displacement of ground deformation shows a good correlation to the product of the thickness and slope of loose sand layer.

This suggests that it is reasonable to divide the ground displacement into the duration time and velocity of the ground deformation in the establishment of a prediction model. The duration time of ground deformation depends mainly on the duration of liquefaction. The liquefaction potential, strength and duration of earthquake, etc. seem to be influential factors of the duration of liquefaction. The velocity of ground deformation depends on the slope of liquefied layer, degree of liquefaction, that is, softness of the ground, etc. Furthermore, boundary condition of large ground deformation is also one of the crucial factors, that is, the extent of the liquefied ground. This will be discussed in the next chapter.

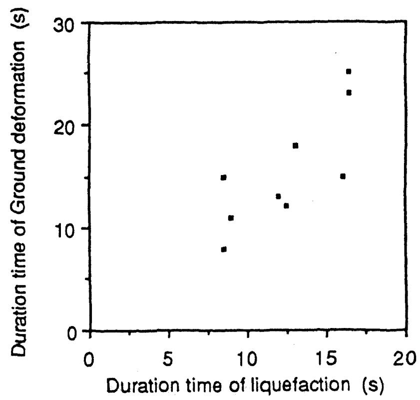

Fig. 2 Relationship between duration time of liquefaction and ground deformation.

3 EFFECTS OF AREA OF LIQUEFIED GROUND

3.1 Test Procedure

Fig. 9 shows test apparatus used in this chapter. The sand box and sand used in this chapter were the same as those in the previous chapter. Since the sand stratum was constructed in water in this case, whole sand stratum was saturated and the ground water table depth did not vary for each case. Therefore, the effects of the ground water table depth were negligible in these experiments. Forty six pins were installed at the surface of the sand stratum to measure horizontal deformation of the ground surface. Target acceleration

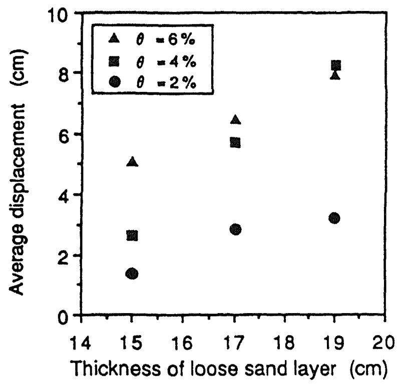

Fig. 3 Relationship between thickness of loose sand layer and average displacement.

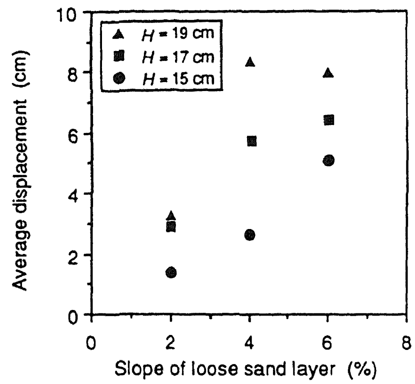

Fig. 4 Relationship between slope of loose sand layer and average displacement.

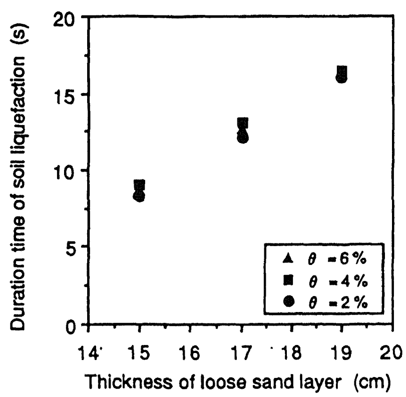

Fig. 5 Relationship between thickness of loose sand layer and duration time of soil liquefaction.

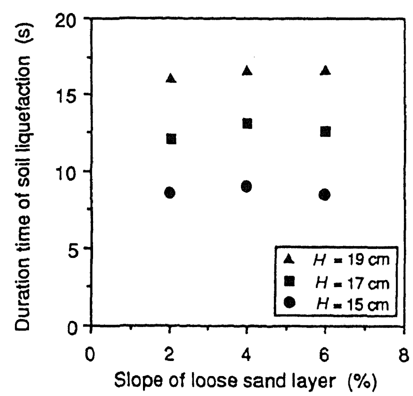

Fig. 6 Relationship between slope of loose sand layer and duration time of soil liquefaction.

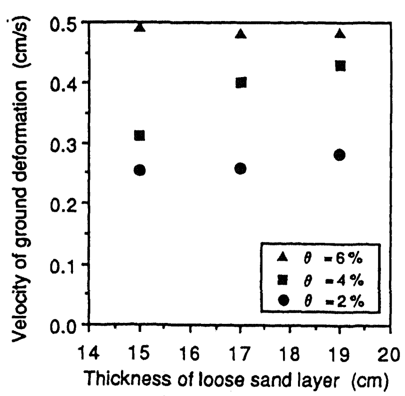

Fig. 7 Relationship between thickness of loose sand layer and velocity of ground deformation.

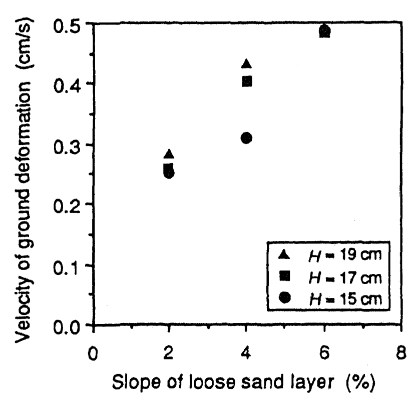

Fig. 8 Relationship between slope of loose sand layer and velocity of ground deformation.

of the table was 100 cm/s^2 in this case.

3.2 Test Results and Discussion

Fig. 10 shows distribution of the permanent ground displacement. It is interesting to note that the ground displacement in the middle of the loose sand stratum was greater than that at the sides and the dense sand stratum did not deform. Since the wall of the sand box was against deformation of the sand stratum, the ground displacement in the loose sand stratum near the wall was also small. Fig. 11 shows the relationship between the width of the loose sand layer and the maximum value of the permanent ground displacement. The maximum value seems to be directly proportional to the width of the loose sand layer.

The tests results suggest that the width of liquefiable area is one of the influential factors in determining the magnitude of the ground displacements. Evaluation of the extent of liquefiable areas is indispensable for predicting the permanent ground displacement. Although several practical methods to evaluate the liquefaction potential of a soil deposit have been developed, little work has been done on evaluation of the extent of liquefiable areas. Therefore, methods must be sought for predicting the extent of liquefiable areas in the future.

CONCLUDING REMARKS

This paper experimentally investigated large ground deformation induced by liquefaction. The small scale vibration tests were conducted in order to establish the prediction method of permanent ground displacement. As the permanent ground displacement can be expressed as the product of the duration of ground deformation and its velocity, the relationship between these two and other factors. The duration of ground deformation and thickness of loose sand stratum have a good correlation. The velocity of ground deformation and slope of loose sand stratum also correlate to each other. Further studies on quantitative evaluation of these two major factors in relation to the other factors are needed.

Moreover, the maximum value of the permanent ground displacement is directly proportional to the width of loose sand deposit. The findings suggest that the width of the liquefied area is one of the most influential factors in determining the magnitude of the permanent ground displacement.

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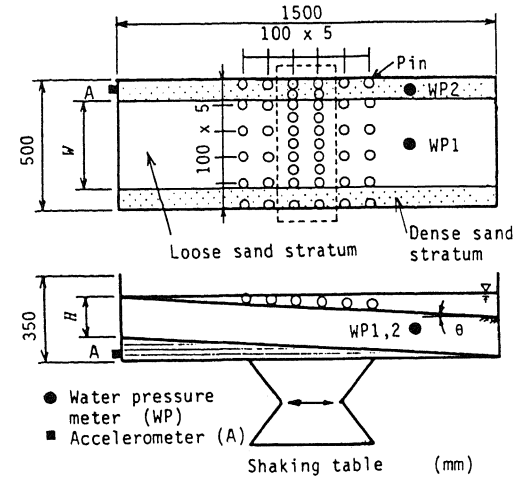

Fig. 9 General view of test apparatus.

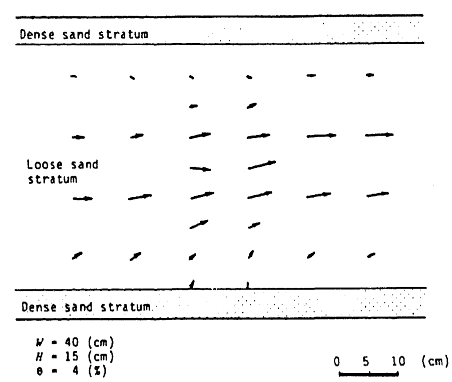

Fig. 10 Distribution of permanent ground displacement.

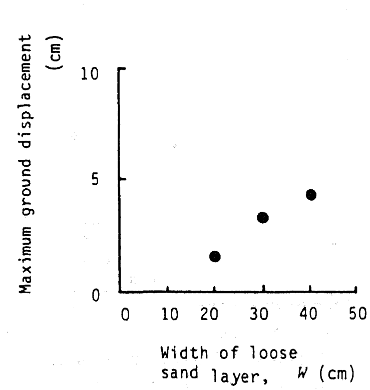

Fig. 11 Relationship between width of loose sand layer and maximum ground displacement.