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Effect of Displacement Method on Sand Bed Liquefaction under Oscillating Water Pressure

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SYNOPSIS

In this paper the liquefaction of sand bed under oscillating water pressure are treated as a basic study of the prevention works against the scouring around the hydraulic structures. The results of the former resurch show that the occurrence of the liquefaction depends on both properties of the oscillating water pressure and of the sand layer. Considering the latter properties, that is, the resistivity against the liquefaction increases with the increase of the permeability of the sand bed, we propose the displcement method as one of the prevention works, which is a method to displace the upper layer of the sand bed by the sand with large permeability. The effects of this method are investigated theoretically and experimentally.

By the experimental study, it is shown that the proposed displacement method has the apparent effect to prevent the liquefaction.

The experimental results are explained fairly well by the theoretical analysis based on the theory of the flow through the elastic porous media.

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1. INTRODUCTION

Authors have been treating the local scouring mechanism around the hydraulic structures in relation to the liquefaction of the sand bed under the oscillating water pressure. Concerning the liquefaction of the sand bed the theoretical and experimental studies have been carried out about vertically one-dimensional sand layer model [1]. The results show that, as a result of the increase of the excess pore water pressure in the sand layer, the state that the effective stress acting on the grains becomes to be equal to zero, that is, the state of the liquefaction occurs under certain conditions. Moreover, it is also shown that, the more the permeability of the sand layer increases, the more the liquefaction becomes hard to occur.

In this paper, considering this characteristics of the sand layer, we propose a displacement method as a method to prevent the liquefaction, that is a method to displace the upper part of the sand layer with small permeability by the sand with large permeability. In the following the effect of this method on the prevention of the liquefaction is investigated theoretically and experimentally.

2. OUTLINE OF THE THEORETICAL ANALYSIS

In the theoretical analysis we consider the vertically one-dimensional sand layer model as shown in Fig.1.

The fundamental equation for the pore water pressure in the sand layer is as follows [1].

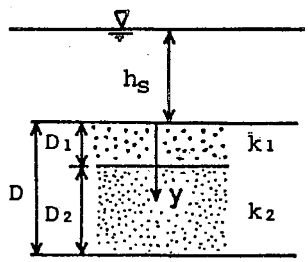

Fig.1 The definition sketch of the two-layered sand bed

$$(\beta\lambda_w + \frac{\lambda a}{\rho g h + p_0} + \alpha)\frac{\partial h'}{\partial t} + (\beta\lambda_w + \frac{\lambda a}{\rho g h + p_0})\frac{\partial hs}{\partial t} = \frac{k}{\rho g}\frac{\partial^2 h'}{\partial y^2} \quad (1)$$

where, α : compressibility of sand layer,

β : compressibility of water,

λ_w: porosity for water part,
λ_a: porosity for air part,
ρ : density of water,
g : acceleration due to gravity,
h : pore water pressure,
h': excess pore water pressure,
h_s: oscillating water pressure acting on the surface of the sand,
p_0: atmospheric pressure,
k : permeability coefficient.

By solving the above equation under the following boundary conditions, the distribution of the pore water pressure and the effective stress in the sand layer are obtained.

$$\left.\begin{aligned} h' &= 0 && \text{at} \quad y = 0 \\ \frac{\partial h'}{\partial y} &= 0 && \text{at} \quad y = D \\ -k_1 \frac{\partial h'}{\partial y} &= -k_2 \frac{\partial h'}{\partial y} && \text{at} \quad y = D_1 \end{aligned}\right\} \qquad (2)$$

The liquefaction occurs under the following condition,

$$\frac{\sigma y}{(\rho_s - \rho) g y (1 - \lambda)} \left(= 1 - \frac{\rho g h'}{(\rho_s - \rho) g y (1 - \lambda)} \right) = 0$$

Eq.(1) is nonlinear differential equation. So, it is difficult to solve this equation analytically. In general it is analyzed numerically.

3. EXPERIMENTAL INVESTIGATION

3.1 Experimental Apparatus and Procedure

For the experiment the vertical cylinder as shown in Fig.2 was used. The inside diameter of the cylinder is 8.9cm. It is filled with the highly saturated sand up to 65cm high from the bottom of the container. The water depth over the sand surface is about 80cm.

The periodically oscillating air pressure acts on the water surface. Its amplitude is about 65cm in water head. The frequency is 1.37 Hz. Two kinds of sand with different permeability coefficients were used. That is, the one is nearly uniform sand which 50% grain size is 0.25mm and permeability coefficient is small, and the another used for the displacing materal is field gathered sand which sieved grain size is 2.00 ~ 2.38mm and permeability coefficient is large. Permeability coefficients of each sand are about 2.0×10^{-2}cm/sec and 1.31cm/sec respectively. The experiment was carried out for four cases shown in Table 1. The water pressures in the water and in the sand layer are picked up by the semi-conducter pressure transducer attached to the side of the cylinder.

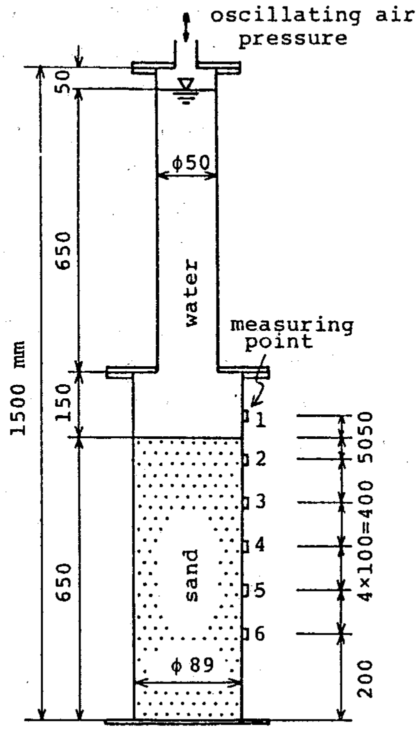

Fig.2 Experimental apparatus

Table 1 Values of k and D in experiments

Run	k_1 (cm/s)	k_2 (cm/s)	D_1 (cm)	D_2 (cm)
1		≒ 0.02	0	65
2	≒1.31	≒ 0.02	10	55
3	≒1.31	≒ 0.02	20	45
4	≒1.31		65	0

3.2 Experimental Results

Experimental results are shown in Figs.3 ~ 14. Figs.3 ~ 6 show the time history of the pore water pressure. Figs.7 ~ 10 show the vertical distribution of the pore water pressure. Figs.11 ~ 14 show the time history of the effective stress.

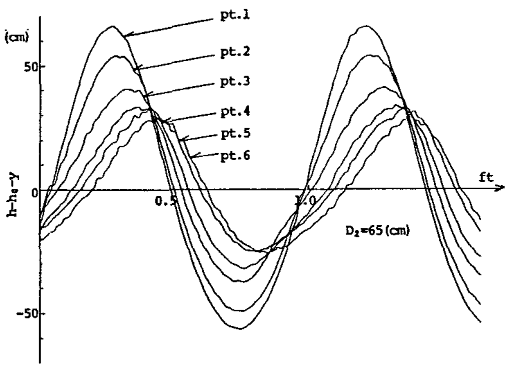

Fig.3 Pore water pressure, Run 1 (observed)

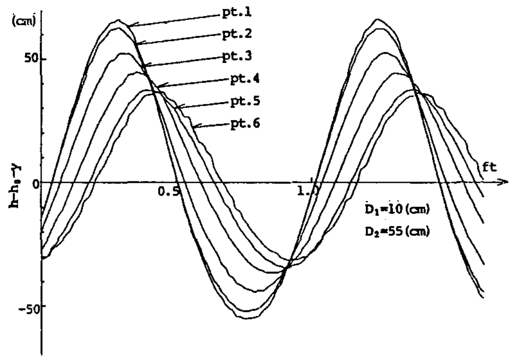

Fig.4 Pore water pressure, Run 2 (observed)

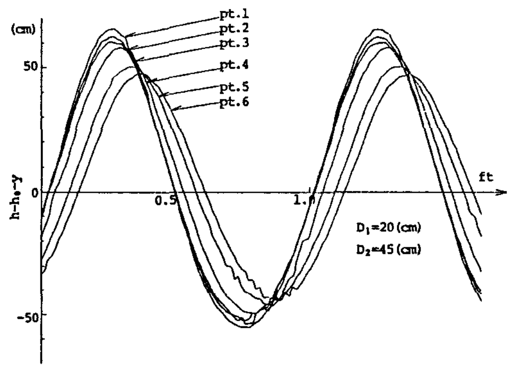

Fig.5 Pore water pressure, Run 3 (observed)

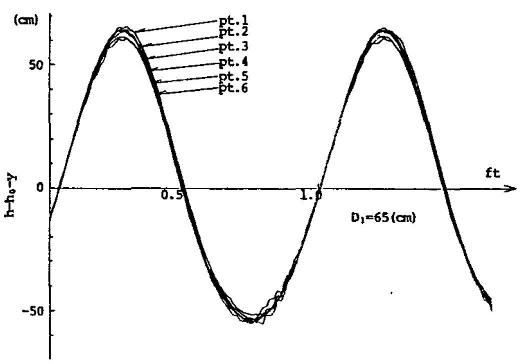

Fig.6 Pore water pressure, Run 4 (observed)

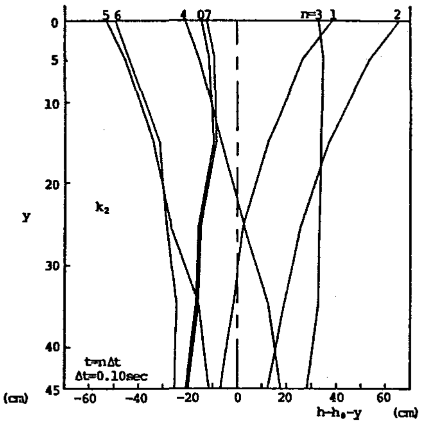

Fig.7 Pore water pressure,Run 1 (observed)

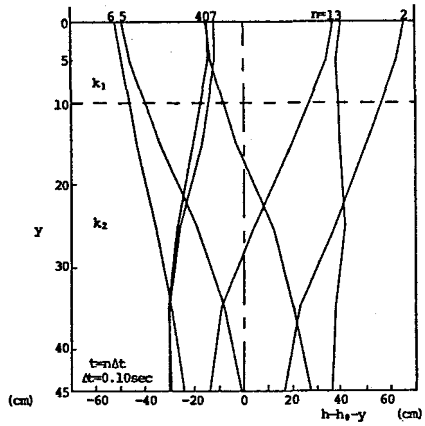

Fig.8 Pore water pressure,Run 2 (observed)

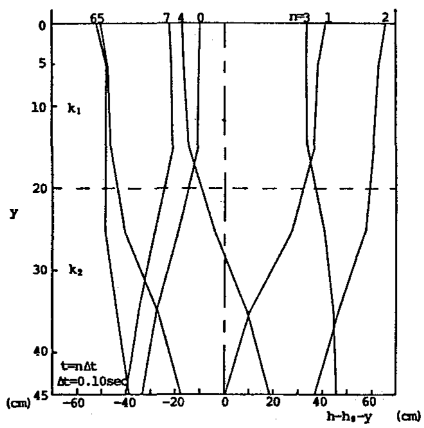

Fig.9 Pore water pressure,Run 3 (observed)

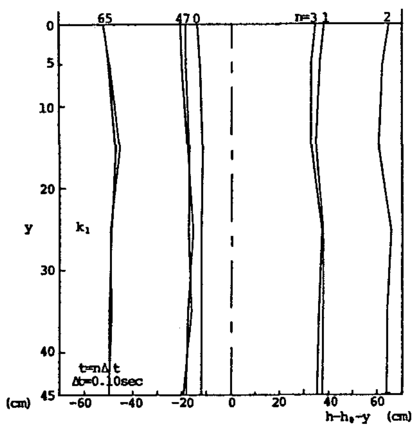

Fig.10 Pore water pressure,Run 4 (observed)

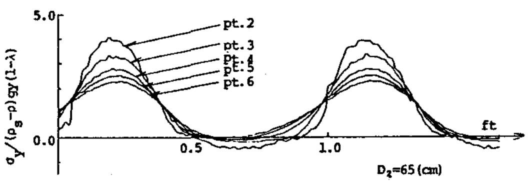

Fig.11 Effective stress,Run 1 (observed)

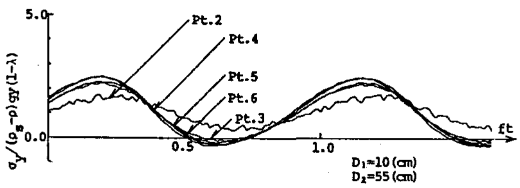

Fig.12 Effective stress,Run 2 (observed)

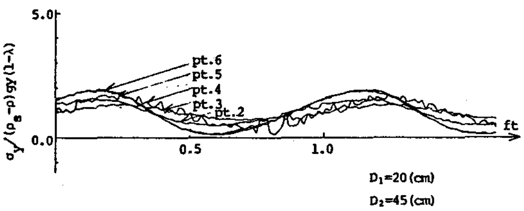

Fig.13 Effective stress,Run 3 (observed)

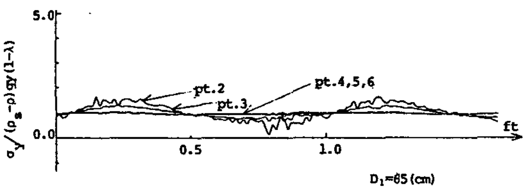

Fig.14 Effective stress,Run 4 (observed)

Run 1 (see Fig.3,Fig.7 and Fig.11) is an experiment for the case that the sand layer is wholly filled with the small permeability sand. In this case both the damping in amplitude and the lag in phase, which are the main factors influencing on the liquefaction, are considerably large. As is shown in Fig.11, the state of the liquefaction occurs in the whole layer of the sand. Run 4 (see Fig.6,Fig.10 and Fig.14) is an experiment for the case that the sand layer is wholly filled with the large permeability sand. In this case both of them are small, and the state of liquefaction does not occur. Run 2 (see Fig.4, Fig.8 and Fig.12) and Run 3 (see Fig.5, Fig.9 and Fig.13) are experiments for the cases that the upper part of the sand layer used for the experiment Run 1 are displaced by the sand with large permeability used for the experiment Run 4. The thicknesses of the displaced sand layer are 10cm and 20cm for each case. In these cases, in the displaced sand layer, both the damping and the lag are very small similar to Run 4,and in the lower layer with small permeability, both of them are notable as is seen in Run 1. Although in these cases the damping and the lag in the lower layer are notable, the lowest value of the effective stress increases comparing with that for Run 1. This shows that the displaced sand layer makes the liquefaction to be hard to occur. The more the thickness of displaced sand layer increases, the more the liquefaction becomes hard to occur.

3.3 Results of Theoretical Analysis

We can obtain theoretically the pore water pressure in the sand layer by use of Eq. (1). Here, the theoretical results which are obtained for the four cases shown above are compared with the experimental results. In the calculations permeability coefficients k_1=1.31cm/sec and k_2=0.02cm/sec are used. As the oscillating water pressure h_s acting on the surface of the sand layer, the values obtained by the experiment is used. Other conditions adopted to the calculations are as follows : $\overline{\lambda}_a$=0.003 ; λ_w= 0.4 ; α=5.17×10^{-4}/atm ; β=4.38×10^{-5}/atm.

Figs.15 ~ 26 show the results of the numerical simulation corresponding to Figs.3 ~ 14 respectively.

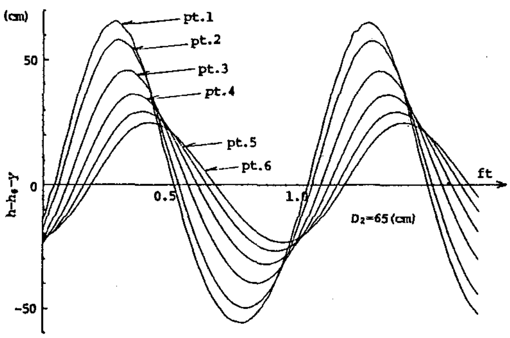

Fig.15 Pore water pressure,Run 1 (calculated)

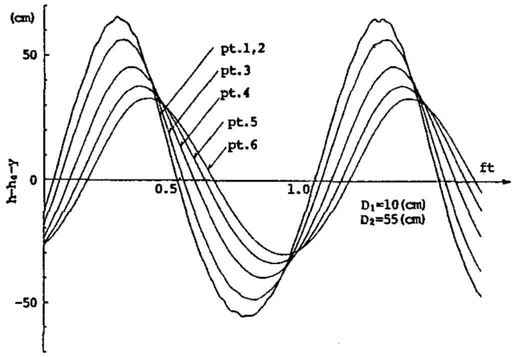

Fig.16 Pore water pressure,Run 2 (calculated)

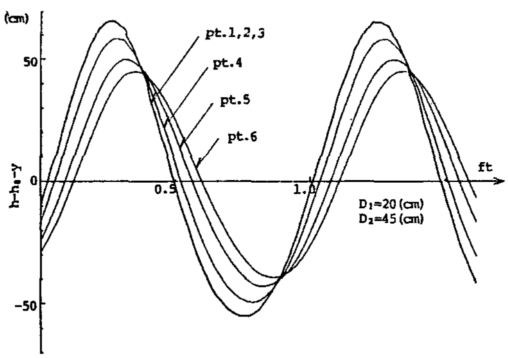

Fig.17 Pore water pressure,Run 3 (calculated)

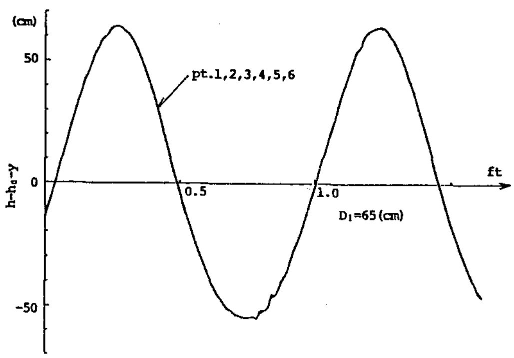

Fig.18 Pore water pressure,Run 4 (calculated)

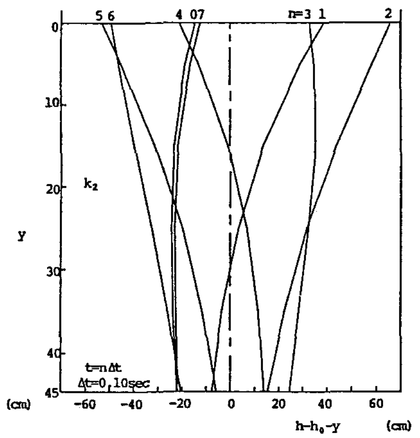

Fig.19 Pore water pressure,Run 1 (calculated)

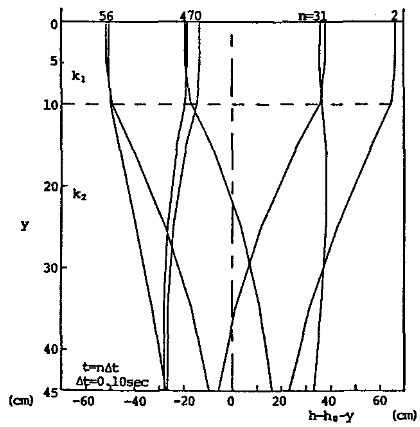

Fig.20 Pore water pressure,Run 2 (calculated)

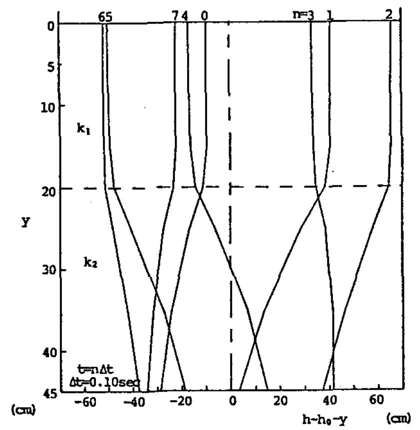

Fig.21 Pore water pressure,Run 3 (calculated)

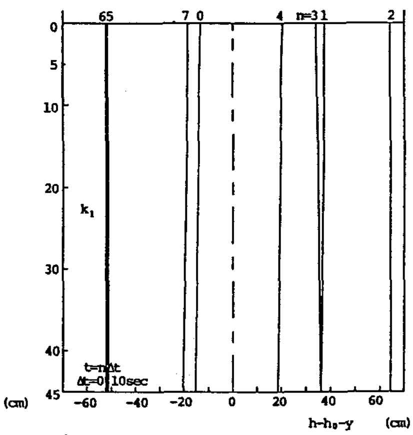

Fig.22 Pore water pressure,Run 4 (calculated)

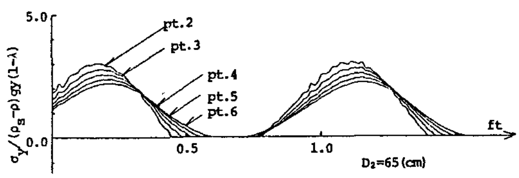

Fig.23 Effective stress,Run 1 (calculated)

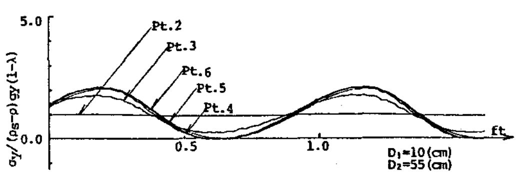

Fig.24 Effective stress,Run 2 (calculated)

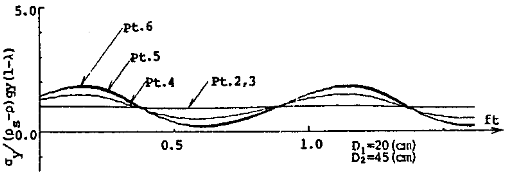

Fig.25 Effective stress,Run 3 (calculated)

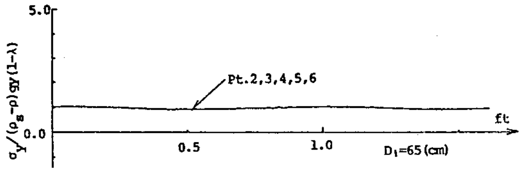

Fig.26 Effective stress,Run 4 (calculated)

From these figures it is shown that the theoretical results explain fairly well characteristics of the pore water pressure and the effective stress obtained by experiments.

4. CONCLUDING REMARKS

In this paper as one of the prevention works against the liquefaction of the sand bed we proposed the displacement method which is the method to displace the upper part of sand layer by the sand with large permeability. The effect of this method on the prevention of the liquefaction was investigated theoretically and analytically.

By the experiments it is clarified that the displacement method proposed in this paper is effective to prevent the liquefaction of the sand bed.

Experimental results are explained fairly well by the theoretical analysis based on the theory of the flow through the elastic porous media.

As described above the effect of the displacement method is clarified in this study theoretically and experimentally. The applications of such principle and the method to the practical problems of the prevention works against the scouring, for example, the design of river bed protection works and so on, are the subject for a future study.

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REFERENCE

[1] Hiroshi Nagō : Liquefaction of Highly Saturated Sand Layer under Oscillating Water Pressure, Memoirs of the School of Engineering, Okayama Univ., Vol.16, No.1, 1981, p.p.91-104.