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Movement of Sand around Revetment under Water Pressure Variation

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SYNOPSIS

Many hydraulic structures are damaged by under flood flow and storm waves year after year. Many cases of dike and breakwater failure are caused by the suck out of sand from behind the revetment. This type of failure will be in close relation to the dynamic behavior of sand bed around the revetment. In this paper, from this point of view, we investigated the basic characteristics of such sand movement by small model tests and tried to explain the hydro- and soil-mechanical mechanism of this phenomenon theoretically.

1. INTRODUCTION

The collapse of hydraulic structures under flood flow and storm waves is closely related to the dynamic behavior of the surrounding sand bed under large variations in water pressure. In this point of view, the authors have investigated the fundamental characteristics of the pore water pressure and effective stress in a highly saturated sand bed under the water pressure variation. In former researches that treated one- and two-dimensional simple models, the reduction of strength of the sand bed evaluated by the behavior of pore water and effective stress in the sand bed has been clarified.[1)-6)]

This paper deals with the suck out problem around revetment under

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water pressure variation. To clarify this phenomenon, the effect of the slope of revetment, the sheet pile attached at the toe of the revetment and the suck out prevention mat are examined experimentally and theoretically.

2. EXPERIMENTAL PROCEDURE AND CONDITION

For the experiment the vertical two-dimensional model as shown in Fig.1 was used. The width of the model is 40cm. It is filled with highly saturated sand (Toyoura standard sand $d_{50} \fallingdotseq 0.25mm$). The water depth over the sand surface is about 100cm. The sinusoidally oscillating air pressure acts on the water surface. Its amplitude is about 40cm in the water head. The frequency is about 1 Hz. The experiments were carried out for the runs shown in Table 1. Run1 is a basic model among them. Three slopes of the revetment are used in the experiments. They are vertical, 1:1 and 1:2. The revetment and the mat are permeable or impermeable. The length of sheet pile and mat are changed. Wire net is attached to both the permeable revetment and the permeable mat. Its mesh size is smaller than the diameter of sand to prevent the suck out of sand through the surface of them. In Fig.1, the size of model given in parentheses were used for the experiments Run9 to Run19. Fig.2 shows the setting procedure of sand-structure model. After the revetment made of iron is fixed, the standard sand is packed. Then, the sand bed is compacted by a vibrator. Furthermore, the water pressure variation is acted on the sand surface until the porosity becomes about 0.38. After that, the sand shown by the oblique line in Fig.2 is removed and the acryl cover plate is set up. The experiments were carried out for 300 minutes for cases Run1 to Run8 and 500 minutes for cases Run9 to Run19. The amount of sand sucked out, that is the height of the sand surface from the initial state, was measured by using point gauge. Measuring points are arranged densely near the revetment and sparsely away from it. The pore water pressure variations around the revetment were measured by using the pressure transducer attached to the side wall of the model (see Fig.2).

3. EXPERIMENTAL RESULTS

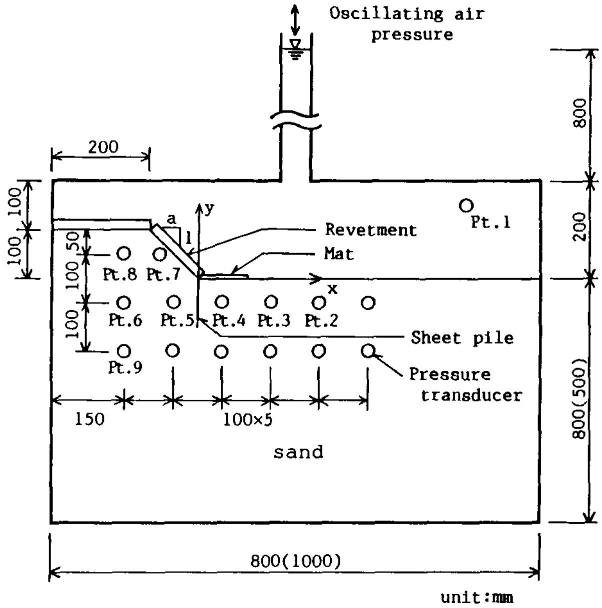


Fig.1 Sand bed model used in the experiment

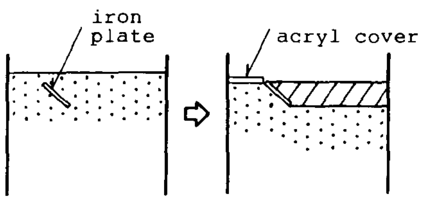


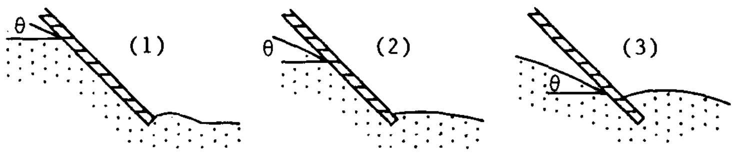
Fig.2 Setting procedure

Table 1 Experimental condition

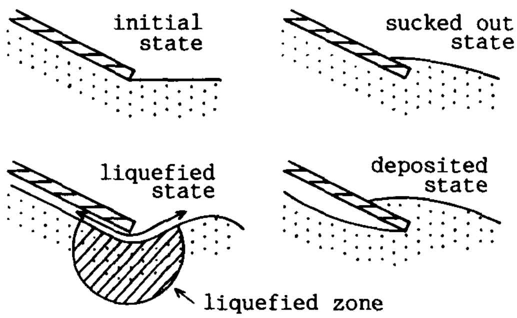
Run	Revetment		Mat		Sheet pile
	slope(1:a)	permeability	permeability	length(cm)	length(cm)
1	1 : 1	impermeable	–	0	0
2	1 : 2	〃	–	0	0
3	1 : 0	〃	–	0	0
4	1 : 1	permeable	–	0	0
5	1 : 2	〃	–	0	0
6	1 : 0	〃	–	0	0
7	1 : 1	impermeable	–	0	5
8	〃	〃	–	0	15
9	〃	〃	–	0	0
10	〃	〃	permeable	5	0
11	〃	〃	〃	10	0
12	〃	〃	〃	20	0
13	〃	〃	impermeable	5	0
14	〃	〃	〃	10	0
15	〃	〃	〃	20	0
16	1 : 0	〃	permeable	10	0
17	〃	〃	impermeable	10	0
18	1 : 2	〃	permeable	10	0
19	〃	〃	impermeable	10	0

3.1 General Characteristics of Sand Movement

In almost all cases a pattern of sand movement as shown in Fig.3-1 was obtained. The sand behind the revetment moves gradually with a nearly constant slope. In some cases the movement pattern shown in Fig.3-2 was obtained. This phenomenon is explained as follows. The water way along the back of the revetment is gradually formed with the progress of the sand movement, and large amount of sand is suddenly blown off by the water pressure directly acting on the sand behind the revetment. During this phenomenon the sand near the toe of the revetment is liquefied and the water goes through freely under the toe. As the time proceeds the blown sand is deposited in front of the revetment, and the flow of sand stopped.



3-1 Pattern 1



3-2 Pattern 2

Fig.3 Patterns of sand movement

3.2 Effect of Slope and Permeability of Revetment

Figs.4, 5 and 6 show the amount of sand sucked out with time for the revetment of different slope. The upper part of each figure shows the result for the impermeable revetment. The lower is for the permeable one. From these figures, the amount of sand sucked out for permeable revetment decreases considerably. This trend is similar in all cases with different slope. Although the difference of the amount of sand sucked out is not clear with the variation in slope of revetment, it is found that the amount is very small in the case of the permeable revetment with its slope 1:2.

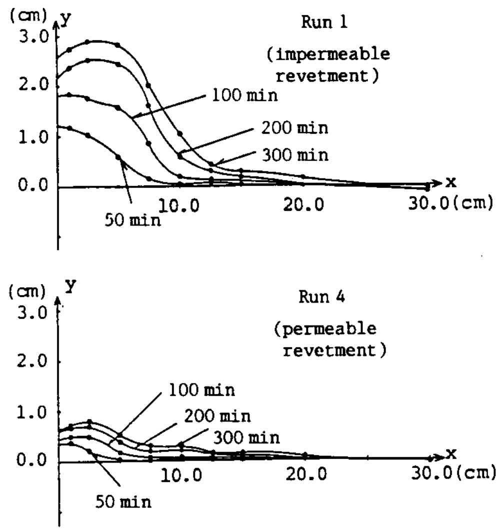


Fig.4 Amount of sand sucked out(slope 1:1)

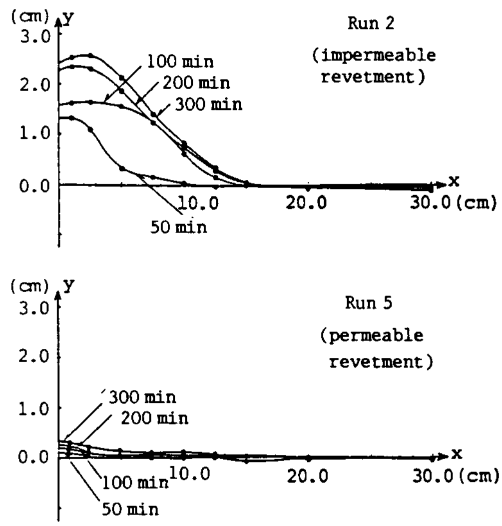


Fig.5 Amount of sand sucked out (slope 1:2)

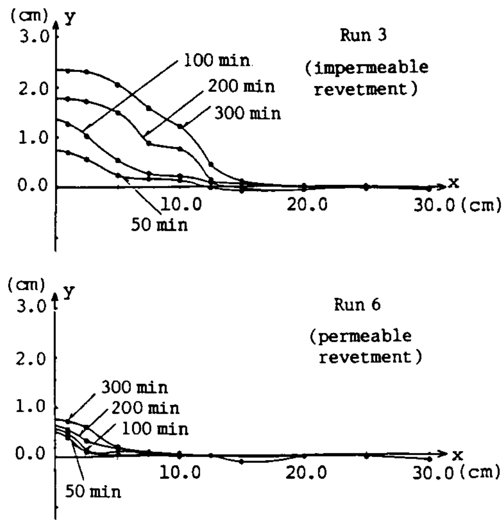


Fig.6 Amount of sand sucked out (slope 1:0)

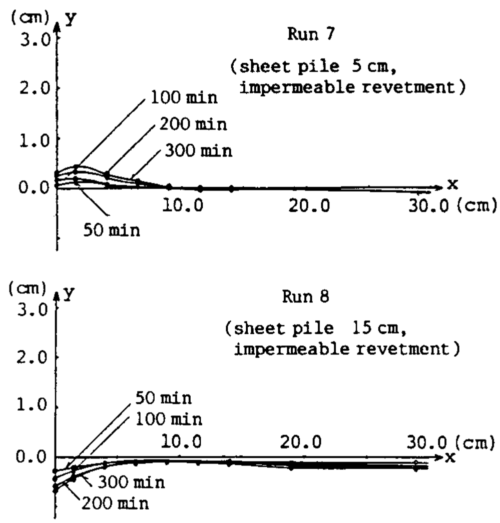


Fig.7 Amount of sand sucked out (slope 1:1)

3.3 Effect of Sheet Pile

Fig.7 shows the variation in the amount of sand sucked out in the cases of the two types of impermeable revetment with a sheet pile. This figure shows that the more the length of sheet pile increases, the more the amount of sand sucked out decreases. Comparing this figure to Fig.4, it is clear that the sheet pile has notable effect in reduction of the amount of sand sucked out even in the case of the impermeable revetment.

3.4 Effect of Mat

Figs.8 and 9 show the amount of sand sucked out at the final stage of each experiments Run9 to Run19. At this stage 500 minutes has passed since the beginning. From these figures, the effect of mat is explained as follows.

In the case of the revetment with a mat, the amount of sand sucked out becomes smaller than that for the revetment without a mat. The permeability of mat has a large effect on the reduction of that amount. The longer the length of the mat increases, the more the amount of sand sucked out decreases. This phenomenon is notable for the impermeable mat as compared with the permeable mat. In the case of permeable mat, the mat with short length is enough to reduce considerably the amount of sand sucked out.

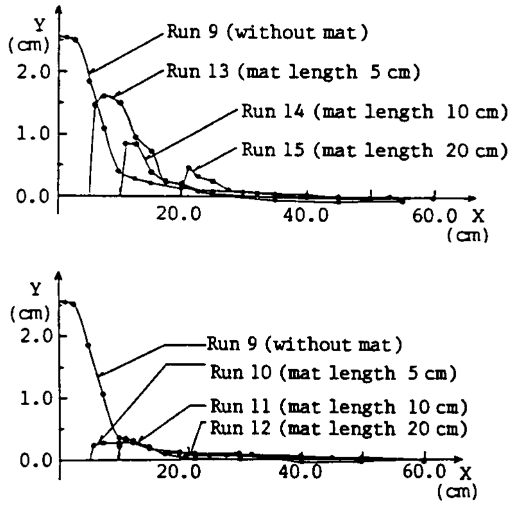


Fig.8 Amount of sand sucked out with or without mat (final stage of the experiments)

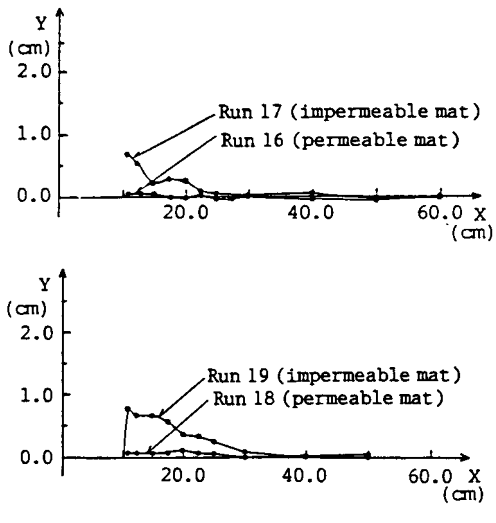


Fig.9 Amount of sand sucked out with variation in slope of revetment (final stage of the experiments)

3.5 Mechanism of Sand Movement

Figs.10 and 11 show the experimental and theoretical results of the pore water pressure with time around the revetment for Run1. The theoretical results are analysed by the same method as the two-dimensional ground water problems in the elastic aquifer.[1),7),8)] It is shown in these figures that the pore water pressure propagates to the sand behind the revetment with the damping in amplitude and the lag in phase. The theoretical results explain fairly well the behavior of the pore water pressure obtained by the experiments.

Figs.12 to 19 show the analytical results of the incremental pore water pressure. The analytical conditions for each figure correspond to experimental conditions for Run1 to Run8 respectively. Although the pore water pressure varies sinusoidally with time, these figures show the pore water pressure distributions at the state that lowest pressure is acting on the sand surface in front of the revetment.

A series of results shown in Figs.12 to 14 are for the impermeable revetment, and these in Figs.15 to 17 are for the permeable revetment. It is found that the notable pore pressure gradient occurs along the impermeable revetment. Contrary to this, the pore water pressure distribution along the permeable revetment is nearly constant. From these results, it is evident that the seepage force will occur along the back of the impermeable revetment and that this force promotes the suck out of sand. In contrast, this force will be very small along the permeable revetment. Thus, it may be concluded that the amount of sand sucked out depends on such pressure distribution along the revetment.

Figs.18 and 19 show the distribution of pore water pressure around the revetment with sheet pile. From these figures, it is apparent that the pore water pressure gradient occurs along the sheet pile. As described above, the sheet pile has the effect of reducing the amount of sand sucked out, even if the seepage force exists along the sheet pile like in the case of the impermeable revetment. In this case it is considered that the weight of sand in front of the sheet pile prevents the sand movement behind the sheet pile.

Figs.20, 21 and 22 show the distribution of incremental displacement vector for Run1, 4, and 8 respectively. From these figures, the characteristics of displacement are explained as follows. In the case of the impermeable revetment (see Fig.20), the displacement vectors are parallel to the revetment and toward outside of the revetment from

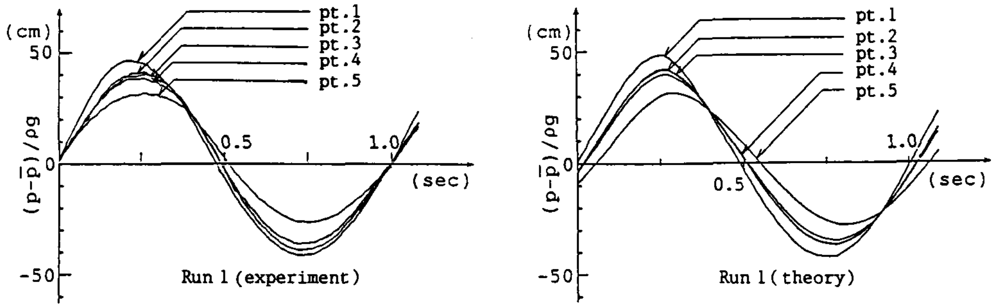


Fig.10 Pore water pressure variation with time

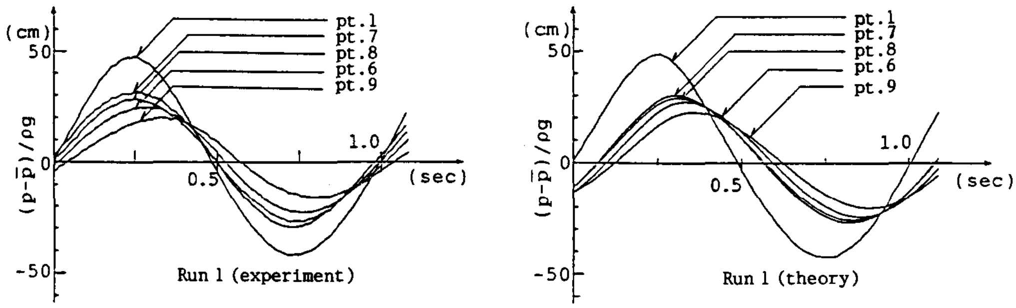


Fig.11 Pore water pressure variation with time

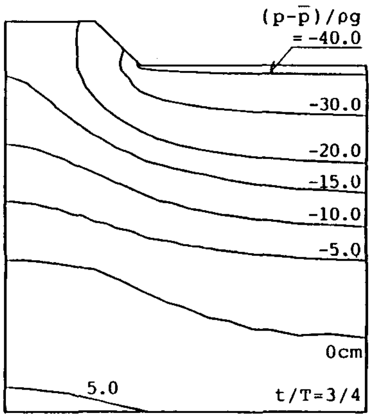


Fig.12 Pore water pressure distribution (Run1)

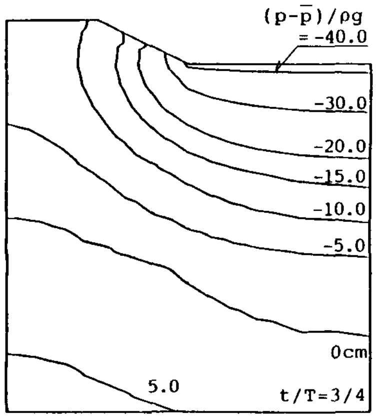


Fig.13 Pore water pressure distribution (Run 2)

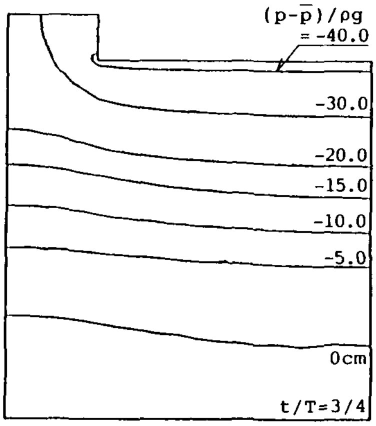


Fig.14 Pore water pressure distribution (Run 3)

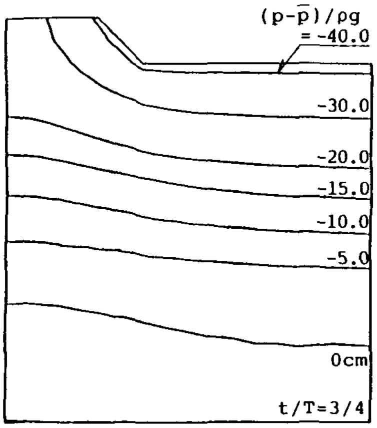


Fig.15 Pore water pressure distribution (Run 4)

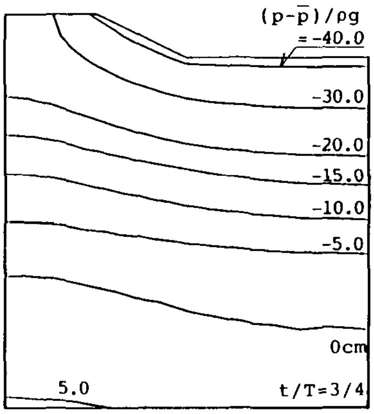


Fig.16 Pore water pressure distribution (Run 5)

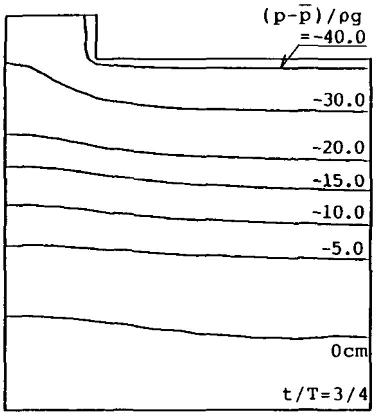


Fig.17 Pore water pressure distribution (Run 6)

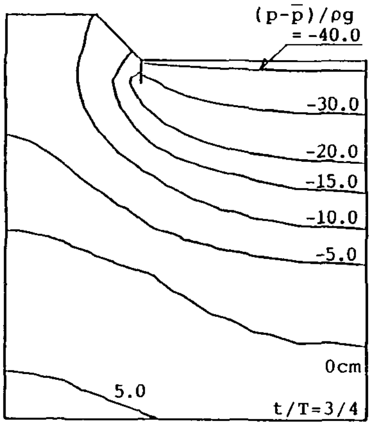


Fig.18 Pore water pressure distribution (Run 7)

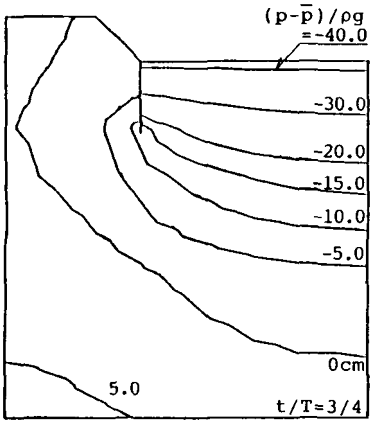


Fig.19 Pore water pressure distribution (Run 8)

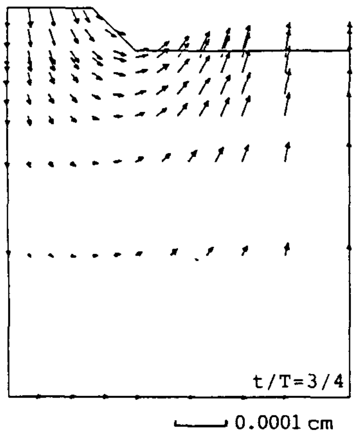


Fig.20 Displacement vector (Run 1)

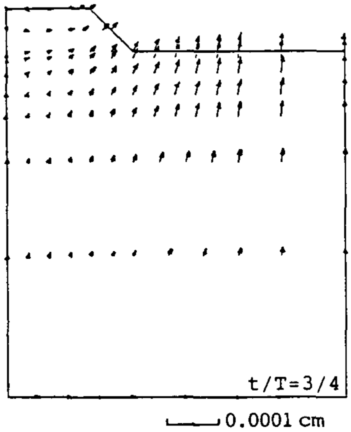


Fig.21 Displacement vector (Run 4)

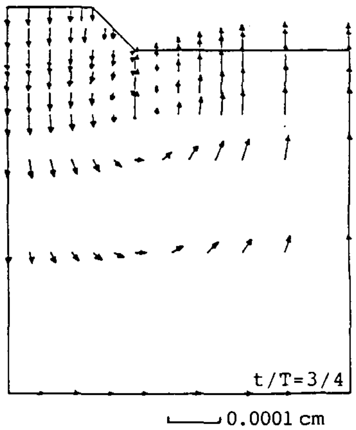


Fig.22 Displacement vector (Run 8)

inside of it. Whereas, in the case of the permeable revetment (see Fig.21), the displacement vectors are perpendicular to revetment, and they are smaller compared with those for the impermeable revetment. Fig.23 is for the case with sheet pile. In this case, displacement vectors are placed along the sheet pile and they are small. From this point of view, it is clear that the displacement vectors show a similar tendency to the direction of seepage force.

Fig.23 shows the incremental pore water pressures for Runs 11, 12, 14 and 15. From these figures the effects of mats are explained as follows. In the case of a permeable mat, the length of the mat doesn't influence pore water pressure variations. Whereas, in the case of impermeable mat, the damping in amplitude and the lag in phase of the pore water pressure behind the revetment become larger according to the increase of the length of mat. The pore water pressure has to propagate around the mat if the mat is impermeable. That is, the direction of the displacement of sand for the impermeable mat will be parallel to the mat. Contrary to this, that for the permeable mat will be perpendicular to the mat. But there is a mat to prevent the sand movement. That seems to be the reason why the amount of sand sucked out will be reduced considerably when the permeable mat is used.

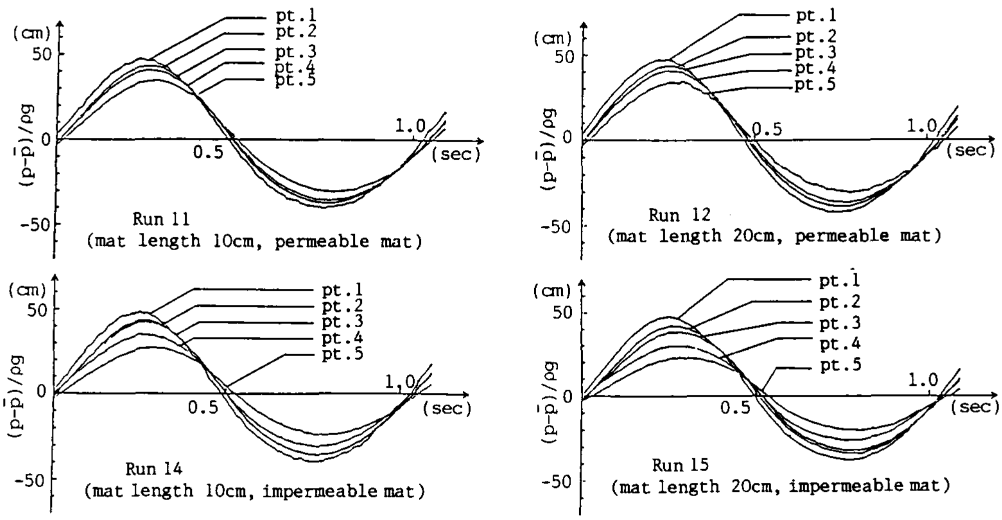


Fig.23 Pore water pressure variation with time

4. CONCLUDING REMARKS

In this paper the basic characteristic of the sand movement around the revetment under pressure variations was investigated experimentally and theoretically. Main conclusions are as follows.

(1) The sand behind the revetment moves and is sucked out under the water pressure variation.

(2) The permeability of the revetment reduces the amount of sand sucked out.

(3) The sheet pile and mat also have the effect of reducing the amount of sand sucked out.

(4) These phenomena are explained to some extent by a seepage flow analysis.

In future studies, on the basis of the present results, it is necessary to investigate the more practical problems for engineering use.

ACKNOWLEDGEMENT

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