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PRESSURE AND SCOURING AROUND A SPUR DIKE DURING THE SURGE PASS

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Detailed measurements of pressure and scouring depth were performed to improve understanding of the water flow and its influence on the riverbed around a spur dike. Two sets of hydraulic conditions and 20 measuring points located at the spur dike gave an image of how the pressure changes in time when a wave is passing around. The other factor tested was the delay of pressure change at several points on the spur dike structure. After passing the wave, the scouring depth was measured for each flow setup. Those measurements brought doubts in the assumption of the existence of a direct correlation between excess pore water pressure and the scouring of the area near the spur dike.

Key Words: *spur dike, flow measurement, hydrodynamic pressure, excess pore water pressure, scouring*

1. INTRODUCTION

Spur dikes are seen as the best type of the hydro-engineering structures that allow redirecting the flow of water in a river or in a channel. Deflecting the current is very important and advisable in many Cases. The best example is when the flow of the stream should be directed away from the bank to protect the latter from erosion. The usage of a set of several spur dikes is one of the most effective means of stabilizing the river or channel banks.

The phenomenon of surge may occur in different cases. Most of them are like breakdown situations. One example may be the collapse of a weir (see **Photo 1**), which may be the reason for the flow that is never expected upstream and downstream from the damaged structure.

Another example of this type of flow happens when a heavy rain falls in the vicinity of an almost fully filled reservoir so that the operators of the dam have to release big amounts of water. The above situations are unusual and should be considered as emergency cases. It is a good purpose, therefore, to conduct investigations if one breakdown might be a reason for a chain reaction of other breakdowns.

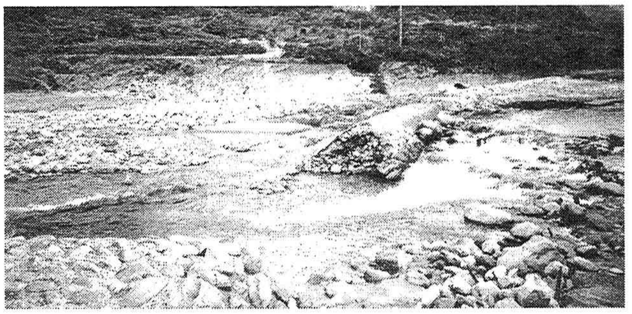

Photo 1 Damaged weir may cause the unpredictable flow

The wave, as a result of such a breakdown, may be observed both upstream and downstream from the damaged structure. The subject of this paper is the influence of a surge upstream from the damaged area on the spur dikes installed in the river.

The flow phenomenon around the spur dike is very complicated and is characterized by 3 dimensional water particle movements. These movements, when coupled with the dynamics of the wave passing and the changes of other parameters, may cause many damages on the spur dike structure and around it. What is more is that it is extremely difficult to describe and to model the changes in all factors.

Measurements of the flow parameters around a spur dike were conducted by many researchers. Most of them focused on the scouring depth[1),2),3),4)] and velocity[1),5)]. It is because the scouring depth is the crucial parameter of stability and safety of the structure and the velocity is considered as the main reason for scouring near an obstacle. During the dynamic flows, like a surge, many parameters, like the pressure of water above and in the sandbed, change very rapidly[1)]. They may also be the factors affecting the scouring depth. In this research project, pressure measurements were conducted to determine the change in characteristics of the pressure with time during a wave passing and to find, if there exists, any correlation between the pressure changes and the depth of the scoured area. Detailed description of the pressure parameter is very helpful in completing the image of scouring phenomena.

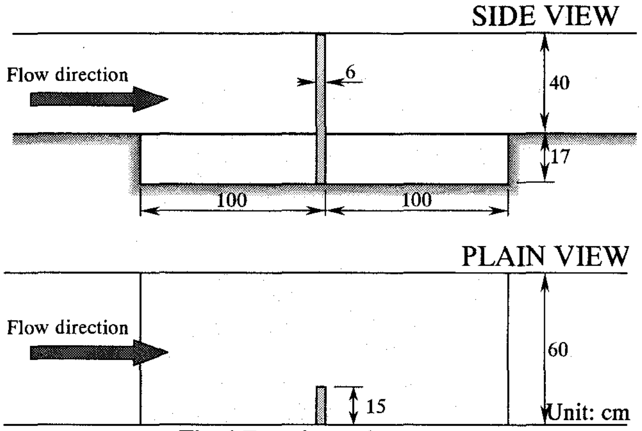

Fig. 1 Experimental setup

2. EXPERIMENTAL SETUP

Experiments were conducted in the laboratory of Okayama University in June 2002. The laboratory flume is a 15 m long, 0.6 m wide and 0.4 m deep steel construction with its front wall made of glass. The channel inclination was 1/500. The pit for experimental installation is located in the middle part of the flume (see **Fig. 1**). The depth of the pit is 17 cm and its length is 200 cm. Its width is equal to the channel width. During the experiment the pit was filled with movable sand. The sand used for this experiment is characterized by an average grain diameter d_{50} = 1.28 mm.

The spur dike was constructed as a full height structure, 6 cm thick and 15 cm wide. As shown in the **Fig. 2** twenty pressure sensors were placed on it: eight on the upstream sidewall, four on the head wall and eight on the downstream sidewall. Pressure sensors were configured into 5 vertical columns and 4 horizontal rows.

The highest level of the sensors during all the experiments was above the ground level. The second and third rows from the top in some cases emerge in the water during the surge while the lowest row of sensors was still in the sand.

All pressure sensors used in the experiment were the transducer type. The sensors were connected to the amplifiers and to the computer to record the data. Sampling frequency was set to 50 Hz. Measurement was performed at 240 s with the first 10 s as the stable flow time without initializing the surge. Those 10 seconds at the time of data analysis were used in adjusting the time scale of all cases and in adjusting the zero value at the beginning of each case and data channel.

3. HYDRAULIC CONDITIONS

The experimental wave came from the downstream side of the dike. The surge was generated by opening the gate located at the end of the experimental channel. Investigations were performed

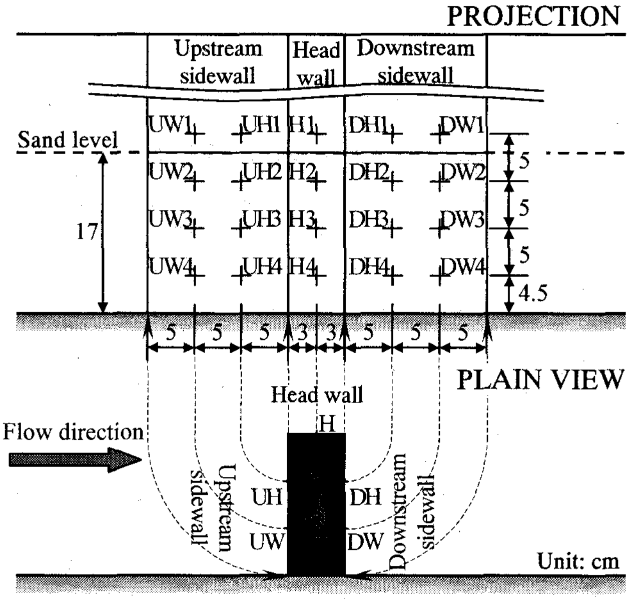

Fig. 2 Pressure sensor location

with two different initial water depths: 20 cm and 30 cm. The depth of the water after the experiment was stabilized at the level of 5 cm.

In both Cases the water discharge was set to the value Q = 0.005 m^3/s. The Froude number of the flow varied from 0.02 to 0.24.

Nomenclature of observation results depends on the initial water depth, and it is as follows:

- initial depth h = 20 cm – Case 1;
- initial depth h = 30 cm – Case 2.

Because of the big number of pressure sensors, each experimental case was conducted several times. The obtained results were fitted with time scales to give a uniform image of the phenomena. For this purpose, each measurement was started with 10 s of stable flow and, after that time, the gate was opened and the wave was initialized.

4. PRESSURE CHARACTERISTIC

The long time pressure graph for column H (Case 1) is presented in **Fig. 3**. In this figure, one will notice that the most rapid changes in pressure are observed at the first 40 s of the experiment. For reasons of good legibility of the next graphs and limited space, the time scale was shortened to 40 seconds.

All graphs in this paper present the alteration of the pressure with time. What one can see on the charts is the change in pressure without considering the value of the pressure at the time before the experiment started. The state of stable water flow was set at a "zero state" when the pressure in all points was set to zero value.

It is easy to see the very big value of oscillating pressure in each graph that registered just after the arrival of the surge. It was supposed to be the effect of the process of opening the gate. The time of these oscillations is about 3 seconds.

Fig. 4 presents the pressure measured at several

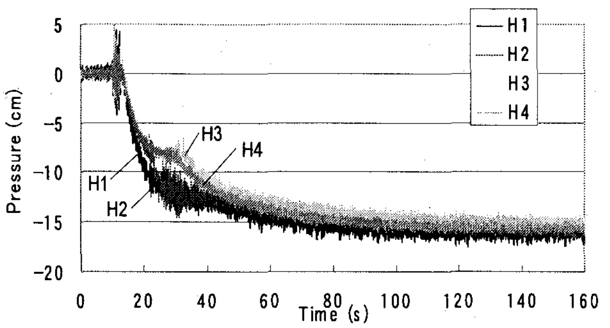

Fig. 3 Pore pressure – Case 1-1, column H

points in the vertical column in Case 1. In those figures, the change in pressure at different levels in the sand bed can be seen. What is obvious is that, in different columns, the pressure was changing in different ways. The pressures measured in the columns located on the upstream sidewall of the dike are changing less rapidly. The lines of pressure on all levels are changing simultaneously. The downstream side pressures look slightly different. Bigger alterations between particular values are also evident. The most rapid changes and the biggest fluctuations are observed in H column located at the head wall of the spur dike. The difference of the pressure in this column is also biggest. Like what has been assumed before, a kind of pressure change delay was observed in the area of rapid changes – the pressure in the lower layers has changed more slowly than in the upper layers. This phenomenon is a reason for the appearance of excess pore water pressure (see **Fig. 5**).

The excess pore water pressure may be defined as an additional pressure value above the sum of hydrostatic and hydrodynamic pressures. In this particular case it was calculated as a difference between the measured pressures – in the sand layer and above sandbed – in the water. Using this method of calculation results in considerably small error, because comparison is done between two pressure values. The pressure above the sand level consist of the hydrostatic and hydrodynamic pressures. As one can see, in H column, the excess pore pressure has the largest value. The area near the head of the dike is the one where the scouring process was the most intense. The excess pore pressure might be seen as a very important factor. On the other hand, the graphs of excess pore pressures measured at the downstream sidewall and upstream sidewall appear to disregard this statement. The scouring in the area of column UH is almost as intense as the one on the head of the spur dike although the excess pore water pressure was oscillating around the zero value. On the contrary, excess pore water pressure is observed in column DH, where scouring did not take place. Maximum values of the excess pore water pressure in that column are about half of those in column H when it was supposed to have an influence on the scouring phenomenon.

The above described phenomenon cannot be understood without the description of mechanism of scouring near the spur dike.

As shown in **Fig. 6** the pressure configuration at the sidewalls and headwall of the spur dike suggests horizontal water flow in the ground. The seepage water flows from the area of the upstream sidewall, and towards upward just in front of the headwall. The seepage force is the main factor in the appearance of the sandbed liquefaction. The effect of liquefaction means that the force maintaining equilibrium state, i.e., effective shear stress is reduced to zero.

The excess pore water pressure and the scouring depth progress with the time are necessary to calculate the effective stress. The first value has been measured. However, the second parameter was not described in a sufficient way. Rough calculations confirm occurrence of the liquefaction phenomena.

The visual observations show that scouring first occurs in the area near the headwall, and afterwards in the upstream sidewall area.

Case 2 shows a good agreement with Case 1. Pressures measured in Case 2 are shown in **figures 9-12**. Naturally, the pressure change is bigger since the initial water level was also higher. The differences of pressure values in one column are larger as well but the characteristic of the curves remains the same. A higher value of excess pore water pressure is the result of these bigger differences. In this case, the highest excess pore water pressure in column H has also been observed. The excess pore water pressures in columns DH and UH follows the same pattern in Case 1. The pressure gradient shows the same character, but it is much higher.

In the figures, one may observe the pressure change during the appearance of some points in the water (see **Fig. 5** and **10**). In Case 1, point H2 emerged in the water after 23 seconds. In Case 2, the sand near point H2 (after 20 s) and point H3 (after 28 s) is washed out. After the time when the sand is removed, the excess pore water pressure decreased to zero value. It was unable to determine when the points located at the upstream sidewall appeared in the water because, for those points, the excess pore water pressure was not observed.

Figures 7 and **12** (for Cases 1 and 2 respectively) show pressure characteristics at several depths above and below the sand surface. Pressure values may be grouped into 3 classes, i.e., downstream sidewall, head and upstream sidewall classes. In the downstream sidewall class the pressure decreased to the lowest level most rapidly, while it took a longer time in the case of upstream side sensors. In both cases, the points located at the head of the spur dike are the independent class as long as they are below the surface of the sand. After the points appeared in the water, pressure measured at point H2 (Case 1 and 2) and at point H3 (Case 2) rapidly decreased to the values close to those recorded at downstream sidewall. Some similarities between emerged points and points in water were observed in the shape of the pressure curve after their appearance time. Some of

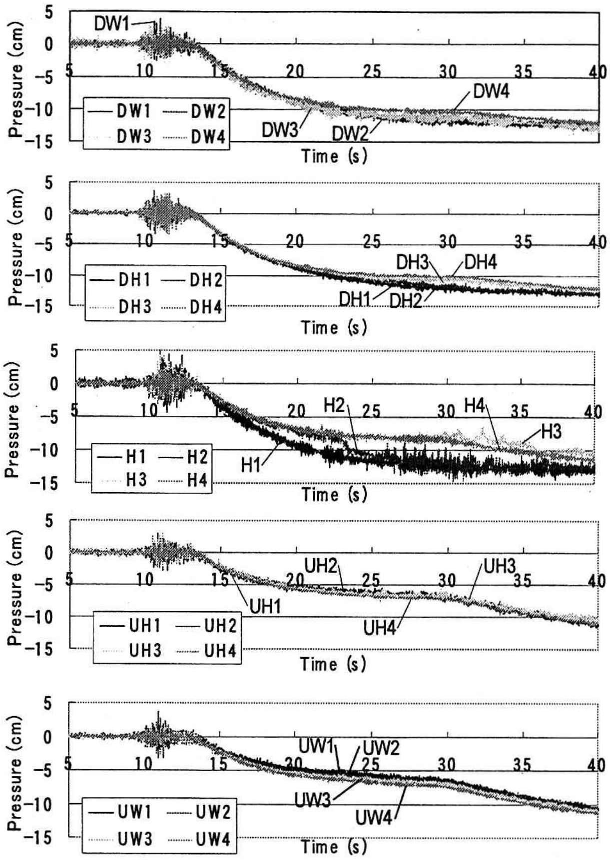

Fig. 4 Pressure in vertical columns – Case 1

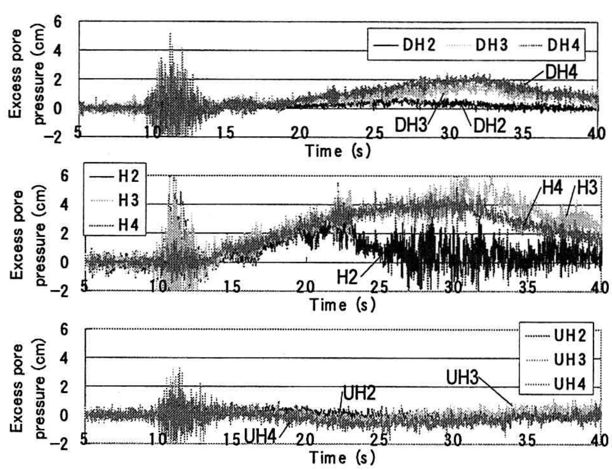

Fig. 5 Excess pore pressure – Case 1

the points are in the sand during the whole experiment (in Case 1 – H3 and H4, in Case 2 – H4). The shape of the pressure line observed in those points is similar with the shape of the pressure line in upstream sidewall points, that is, the line gradually decreased to the stable value.

The pressure fluctuations are visible in all the points of all cases. Frequency characteristics of fluctuations for 3 points, located in one row in Case 1 are presented in **Fig. 8**. The intensity of fluctuations is highest in the points located in column H. That fact may be explained easily by the highest intensity of the water flow near the head of

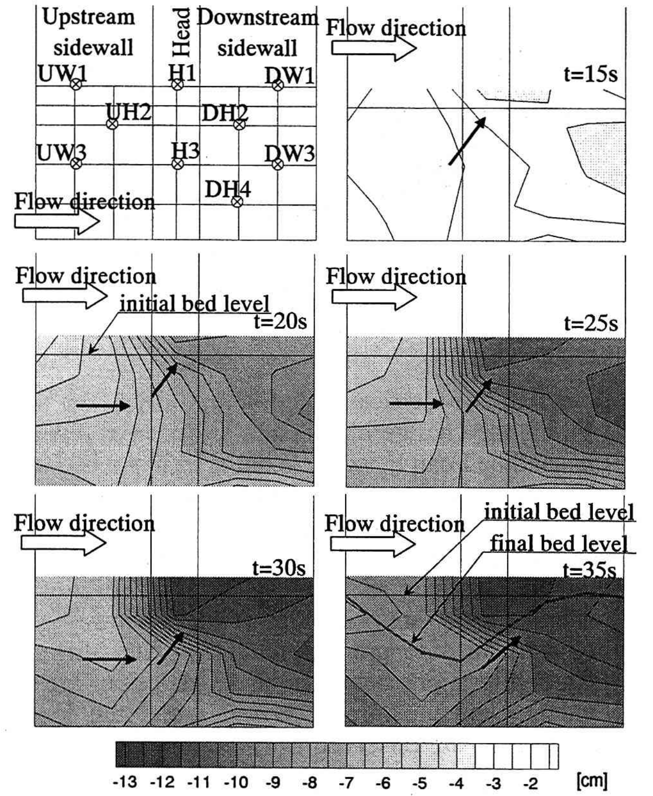

Fig. 6 Pressure on the spur dike walls – Case 1

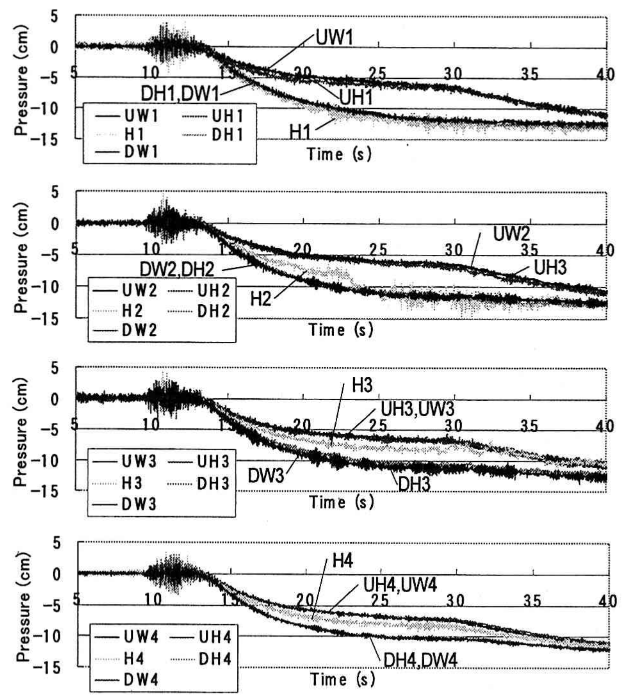

Fig. 7 Pressure in rows – Case 1

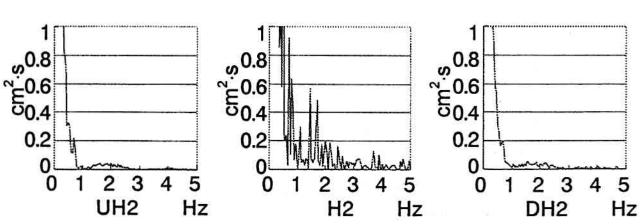

Fig. 8 Frequency characteristics – Case 1

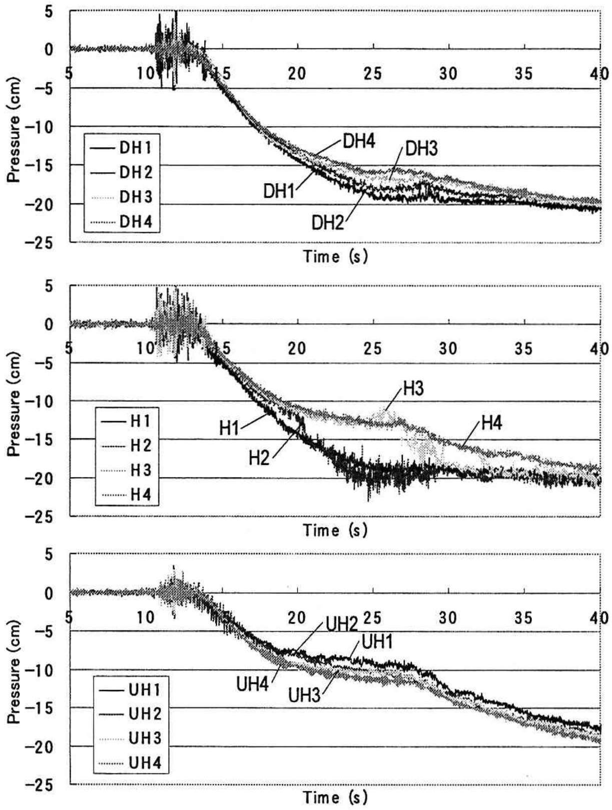

Fig. 9 Pressure in vertical columns – Case 2

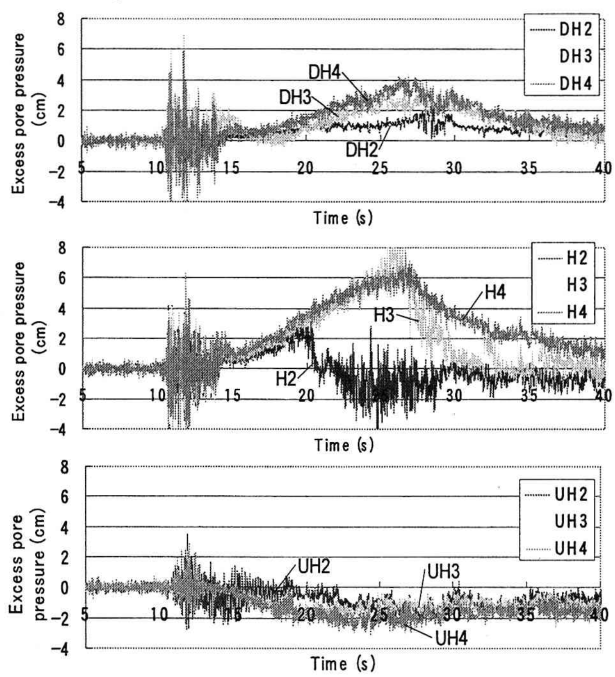

Fig. 10 Excess pore pressure – Case 2

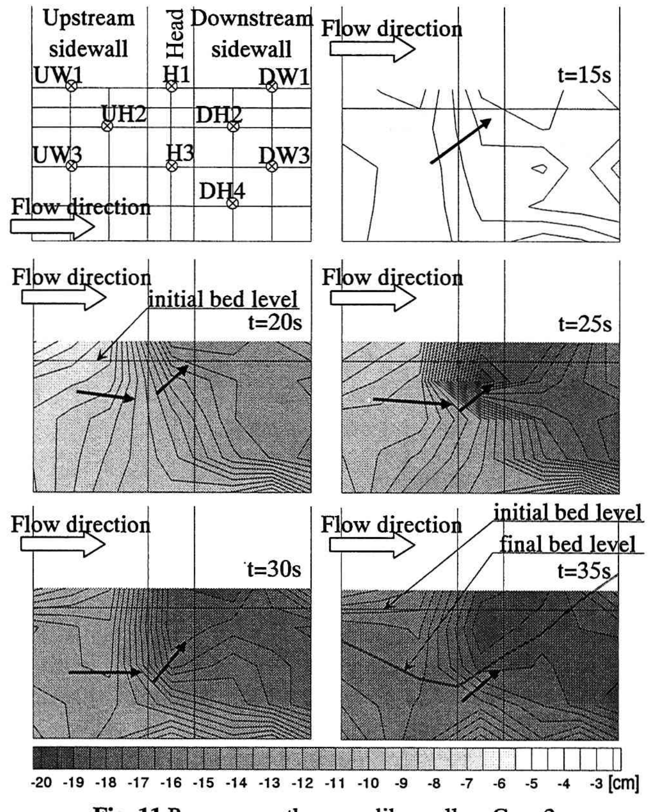

Fig. 11 Pressure on the spur dike walls – Case 2

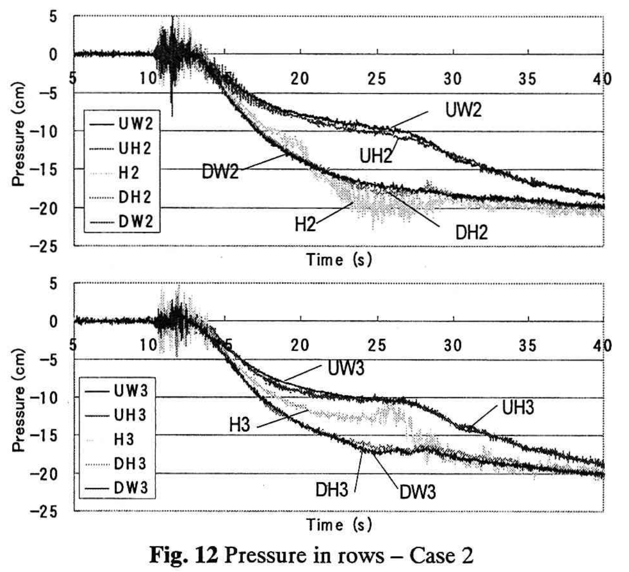

Fig. 12 Pressure in rows – Case 2

the spur dike. Although the similar frequency characteristics at the upstream side and downstream side seem to prove that the pressure is not a deciding factor in the scouring process, the experiment is not conclusive enough to deny that the pressure facilitates the scouring process either.

Generally speaking, the value of fluctuation frequency in all points is below 0.8 Hz. In point H2, especially when the sand is washed out, the pressure has the greatest fluctuations. The probable reason for this is the very complex water particle movements inside the scour hole, which has been created during the experiment.

5. SCOURING DEPTH

The effects of the scouring process are presented in **Figures 13** and **14** (for Cases 1 and 2 respectively). Many researchers who conducted different experiments and simulations proved that the scouring process hits the corner of the upstream sidewall and the head wall and that the intensity of scouring is highest in the area where the highest

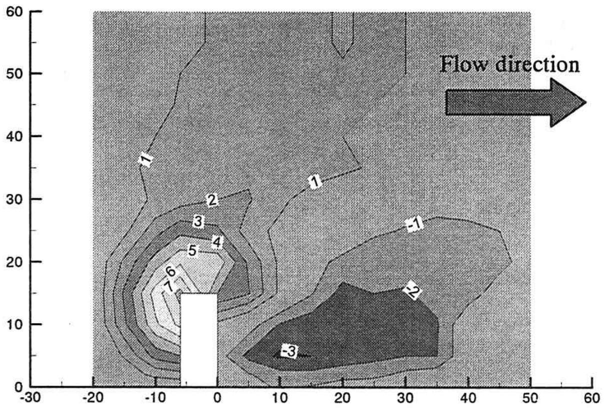

Fig. 13 Scouring depth (Case 1)

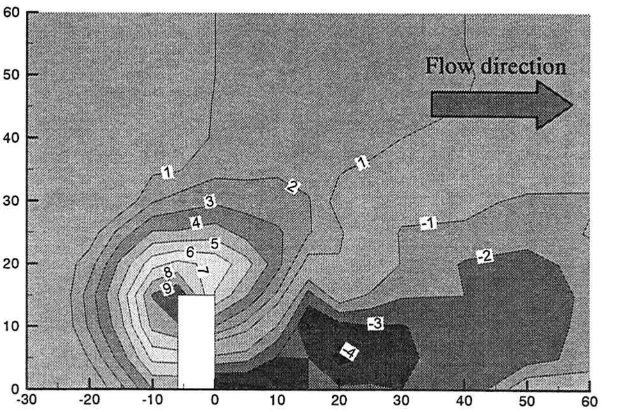

Fig. 14 Scouring depth (Case 2)

velocities had been observed[3),4)]. The cone shaped scour hole was also observed in many investigations. In this study, the shape of the scour hole produced in a short time of intense scouring seems to follow the previous descriptions[3)]. The expansion of the scouring hole is very difficult to observe during the surge. The similarity in the final shape of the scour hole does not allow drawing a conlusion of scouring development during the surge. This part of the phenomena will be investigated in the future study of our work group.

During the experiment velocities were measured to calculate the dimensionless shear stress.Because of lack of space only the shear stress will be described in this article. The critical shear stress for the bed load was estimated at 0.0356 and 0.0367 for the Case 1 and 2 respectively. For the initial flow 5 l/s, the shear stress was 0.0002 (Case 1) and 0.0006 (Case 2). Because of rapid change of the velocity at the beginning of the surge, the shear stress exceeds the critical value almost in the same moment as the surge flow begins.

Scouring process starts at the same time when the surge which is about 3 - 4 seconds after opening the gate. The scouring process lasts about 35 seconds (Case 1) and 37 seconds (Case 2). Maximum value of the shear stress calculated for the highest velocities evaluates at 0.3273 (Case 1) and 0.4750 (Case 2) and occurs after about 15 second of surge in both cases. Firstly scouring concentrates in the area near the head wall. The area near the upstream sidewall is scoured later. What is natural is that in Case 2, the scouring area and depth was bigger than the one in Case 1. The biggest scouring depth observed after the experiment was 8.4 cm (in Case 1) and 9.9 cm (in Case 2).

The area of the scouring process in Case 1 reached 18 cm upstream from the zero point set at the downstream sidewall of the structure, and 30 cm downstream. The width was limited by the experimental channel width. The area of the very intense scouring was limited to 18 cm upstream, 8 cm downstream and 15 cm from the head in a crosswise direction (the total width of scouring was 30 cm). In Case 2 the area was much bigger. The scouring reached 24 cm upstream and 42 cm downstream. The cone shaped scour hole reached 24 cm upstream, 16 cm downstream and 20 cm, from the head, crosswise.

The sand washed out in the spur dike area deposited in the region sheltered by the spur dike.

6. CONCLUSIONS

The conducted experiment brought many doubts if indeed a direct correlation between excess pore water pressure and the scouring process exists. The obtained results suggest that scouring may occur according to different mechanisms. Some of those mechanisms may be strongly influenced and facilitated by high excess pore water pressure. To investigate this phenomenon in a future study, it is necessary to conduct a combined experiment with measurements of the progress of scouring and of the pressure change.

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