EXPERIMENTAL INVESTIGATION OF HYPORHEIC INTERACTIONS

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Abstract
Research on hyporheic interactions is not new to the present world, but most of the previous research is in the environmental and ecological points of view. This study was to understand the hyporheic interactions by means of engineering perspectives. Several experiments were carried out at laboratory scale to identify the relationships between important non-dimensional river parameters and non-dimensional interaction parameters. Results can be concluded to show some clear relationships among the non-dimensional parameters.

Keywords: Hyporheic interactions; Hele-Shaw model; River Froude number

1. Introduction

River flow and seepage flow interactions are technically called Hyporheic interactions and frequently occurred in mountainous rivers. These interactions can occur either vertically or horizontally. Since these interactions are the governing force of the most biological activities in the vicinity of the river bed, it is very important to maintain the natural balance of river systems. However due to human activities, the natural balances of most of the nature have been disturbed.

The hyporheic zone can be simply defined as an active eco-tone between the surface stream and ground water, which facilitates to exchange water, nutrients and organic mater due to the variations in discharge and bed topography [1], [2], [3], [5], [12], [15]. Two interactions as “up-welling” and “down-welling” can be identified and Up-welling subsurface water supplies river organisms with nutrients while down-welling river water provides dissolved oxygen, inorganic ions and organic matter to microbes and invertebrates in the hyporheic zone [1], [2], [4], [10], [11], [13], [14], [17], [18], [23], [24].

These up-welling and down-welling interactions influence the biogeochemistry of stream ecosystems by increasing solute residence times and more specifically solute contact with substrates in environments with spatial gradients in dissolved oxygen and pH [8].

Literature shows some typical physical parameters about the hyporheic interactions and the hyporheic zone. The hyporheic flow paths can be centimetres to tens of meters in length [7] and the zone can be few centimetres to couple of meters of thick [16]. Some analysis shows that the hyporheic zone is facilitating to exchange at-least 10% of the river water flow [22].

2. Hele-Shaw model experiments

Several experiments were carried out under the laboratory scale at river and watershed engineering laboratory, Hokkaido University, in order to understand the hyporheic interactions and to find out the relationships among non-dimensional parameters. The experimental set up which was used to pursue this research is shown at Figure 1. Seepage layer was modelled using a Hele-Shaw model which is a longitudinal parallel plate model and is shown at Figure 2. Flow above the Hele-Shaw model was considered as the river flow in these experiments.

Hele-Shaw model is a parallel plate model forming a narrow channel and this viscous flow model was first used by Hele-Shaw to study the nature of flow around obstructions of various shapes [21]. In 1936 it was used for the first time in groundwater investigations by Dachler [3]. However later it has widely used to analyze the groundwater flow in a 2-dimensional cross section of an aquifer [3], [6], [9], [19], [20].

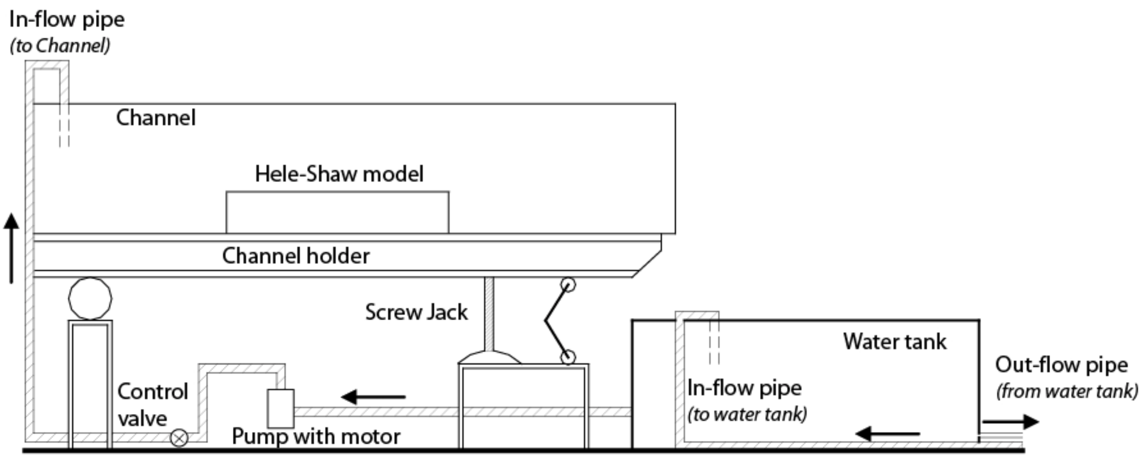

Figure 1 Experimental setup

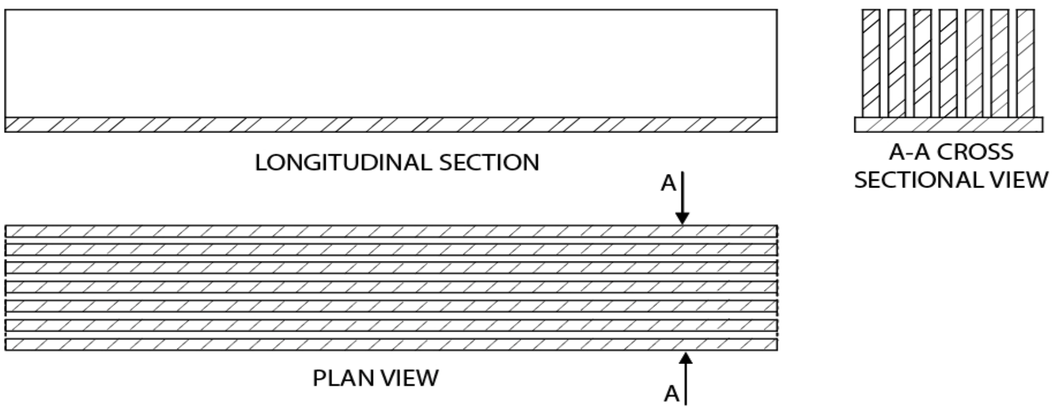

Figure 2 Sectional views of Hele-Shaw model

The re-circulating channel used in this work, has a section of 5 m in length and a channel width of 20 cm. The channel is 40 cm in depth and flexible to change its slope using the screw jack at right edge. It is made up of transparent materials, which allows direct observations of interactions and managed to have digital pictures and digital movies. Let us consider x co-ordinate of the left edge of the channel is to be 0 m and the right edge of the channel is to be 5.0 m respectively. The Hele-Shaw model, where 2.0 m in length, 20 cm in width and 10 cm in height was placed at $x = 2.1$. The porosity; λ of the Hele-Shaw model was 0.3 in the used set up.

Experiments were carried out for two slopes as 0.1%, and 0.2%. Combined channel flow height was controlled using a down-stream weir from 12 cm to 25 cm. Three trials of experiments with same conditions were carried out for the each river height and the discharge of the channel was measured for further calculations.

Methylene blue (blue color dye) was injected just downwards and along the upper boundary of the Hele-Shaw model, in order to visualize the seepage flow and river flow interactions. Continuous pictures were taken at 5 s intervals in each and every experiment. In some cases few videos were taken. Best picture which has the clear interactions was digitized using the commercial package "Bytescout Graph Digitizer Scout 1.2.4". The corresponding wave lengths for S=0.1%, and 0.2% slopes were obtained using these digitized pictures.

Digital pictures at Figure 3 and 4 are here to verify the hyporheic interactions.

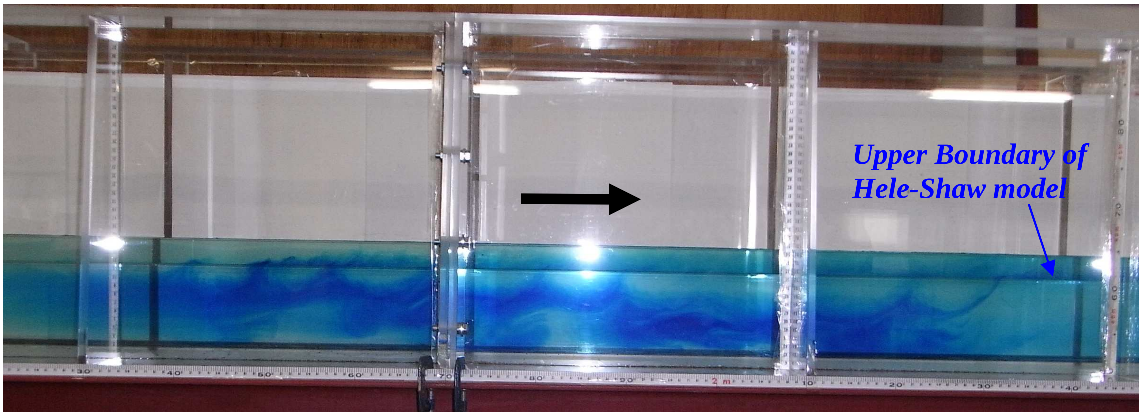

Figure 3 Interactions at 0.1% slope when the river height is 3 cm

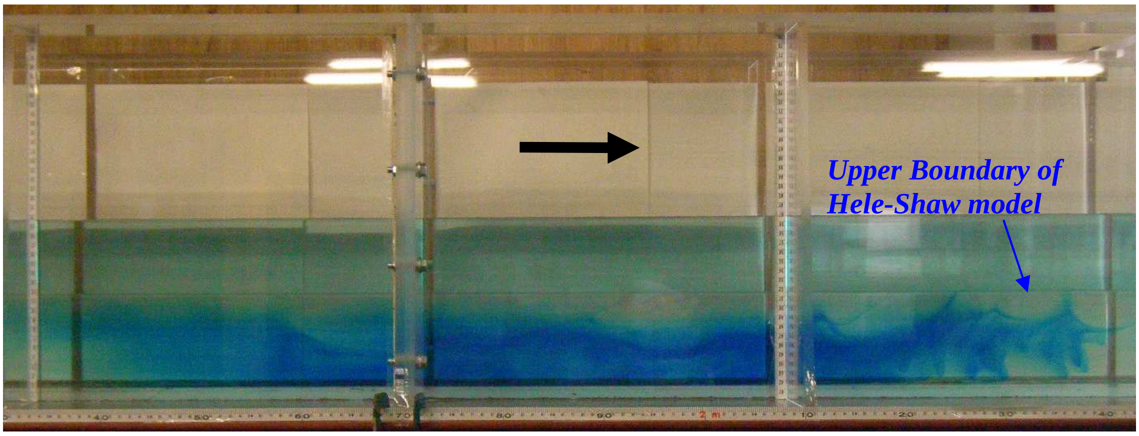

Figure 4 Interactions at 0.2% slope when the river height is 8.0 cm

3. Results of the experiments

Froude number for the river / open channel flow was calculated using the discharge measurements and obtained wave lengths are non-dimensionalized using the height of the river layer to obtain the non-dimensional wave numbers which are also know as the dominant wave numbers for interactions. The calculated Froude numbers are plotted against the dimensionless dominant wave number and shown in the Figure 5 and Figure 6. Also the same data are plotted in the one diagram in order to compare the results against the slope of the combined system in Figure 7.

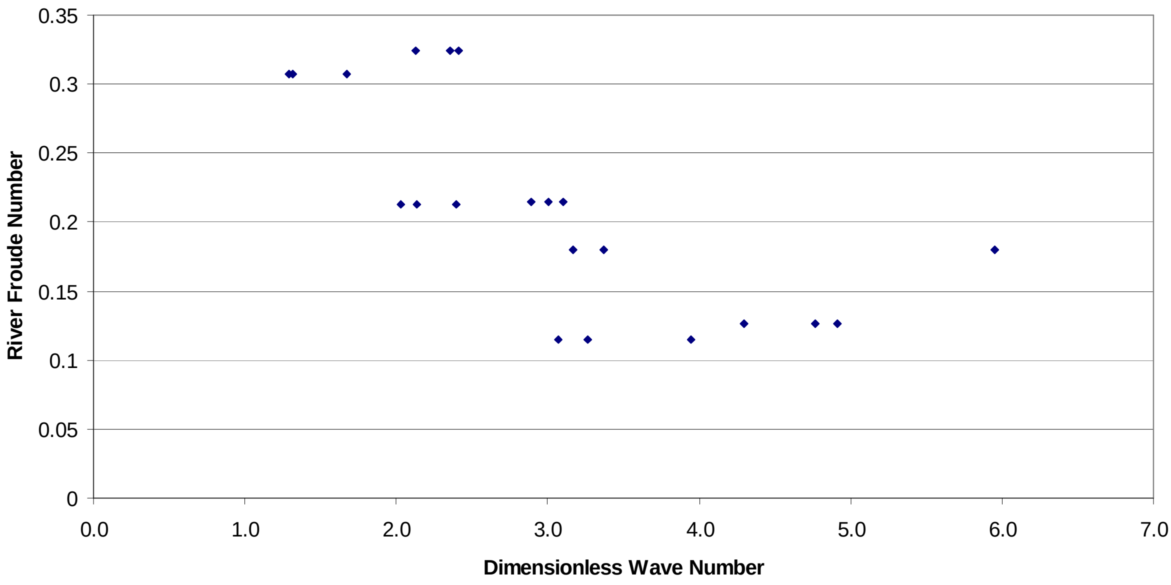

Figure 5 Froude numbers vs. Dimensionless Dominant Wave Numbers for S=0.1%

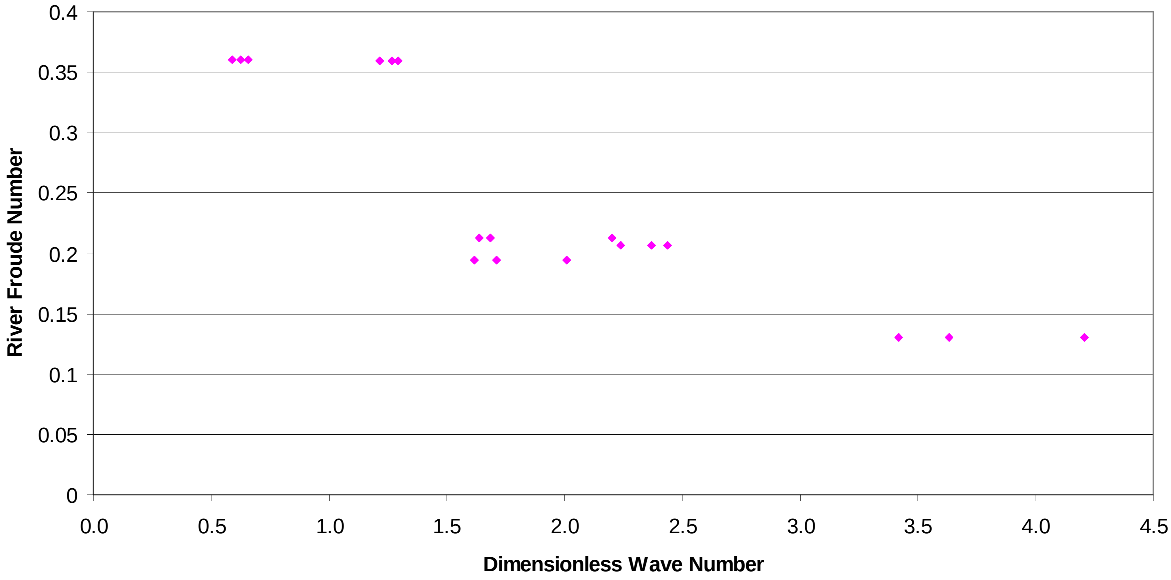

Figure 6 Froude Numbers vs. Dimensionless Dominant Wave Numbers for S=0.2%

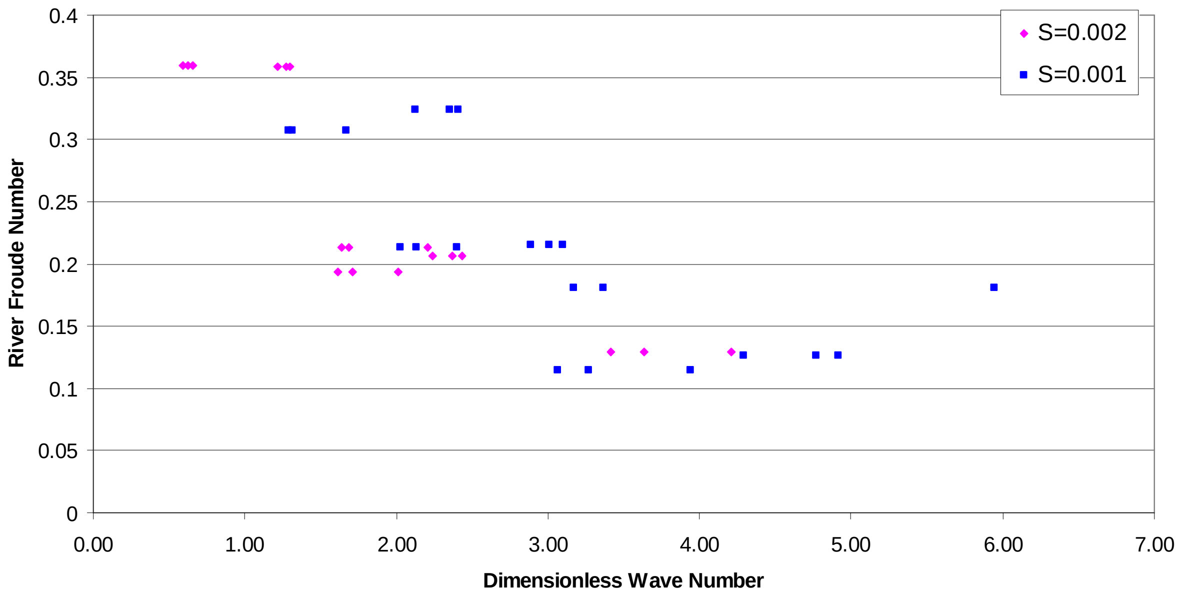

Figure 7 Froude Number vs. Dimensionless Dominant Wave Number for both slopes

4. Discussion and Conclusions

From the observations it can be clearly visualized the river flow and seepage flow interactions. However by examining Figures 5 and 6, it can be clearly understood a relationship between the Froude number of the river flow and the non-dimensional dominant wave numbers. This can be concluded that the non-dimensional dominant wave numbers for the interactions are increased with the decrease of the Froude number of the river flow. This means that the non-dimensional wave lengths of the interactions increase with the Froude number.

In addition, it can be seen that the dimensionless dominant wave numbers have an effect on the combined channel slope from the Figure 7. With the slope it can be concluded that the dimensionless dominant wave numbers are reached to the Froude number axis, or else the value of the dimensionless dominant wave numbers are decreased. This means that the non-dimensional wave lengths of the interactions increase with the combined slope of the river and the hyporheic zone.

From the experiments there are some observational conclusions and presented them as follows. Quick river flow and seepage flow interactions were occurred, when the height of the river layer is comparably small with the Hele-Shaw model, whereas slow river flow and seepage flow interactions were occurred, when the height of the river layer was comparably large with the Hele-Shaw model. With this observation, it can be concluded that the residence time of hyporheic interactions are increased with the height of the river layer.

When the river layer height was less than or equal to the Hele-Shaw model height, wavy form of the hyporheic interactions were clearly visualized, whereas the wavy form of hyporheic interactions were not clearly visualized, when the river layer height was higher than the Hele-Shaw model height. At the second stage the author was able to see the sudden pop up of dye as shown in Figures 8 and 9.

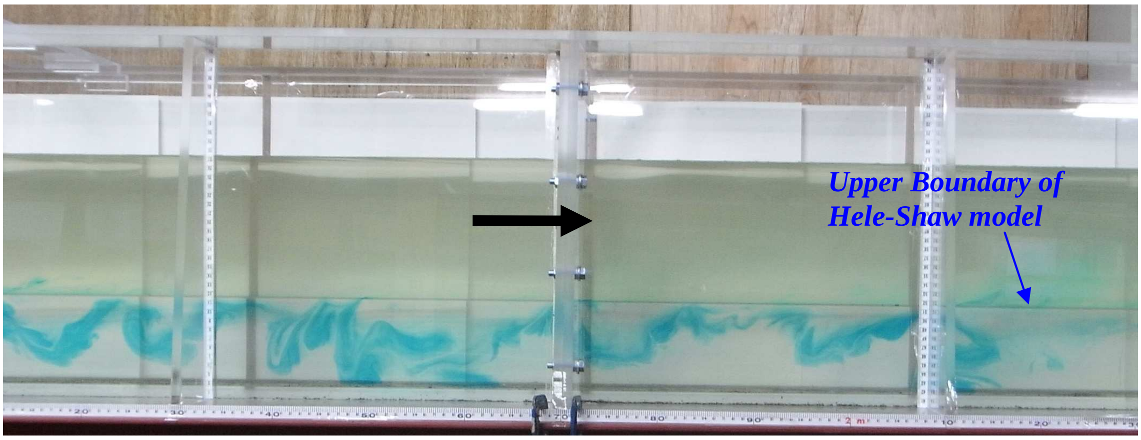

Figure 8 Interactions at 0.1% slope when the river height is 15.9 cm

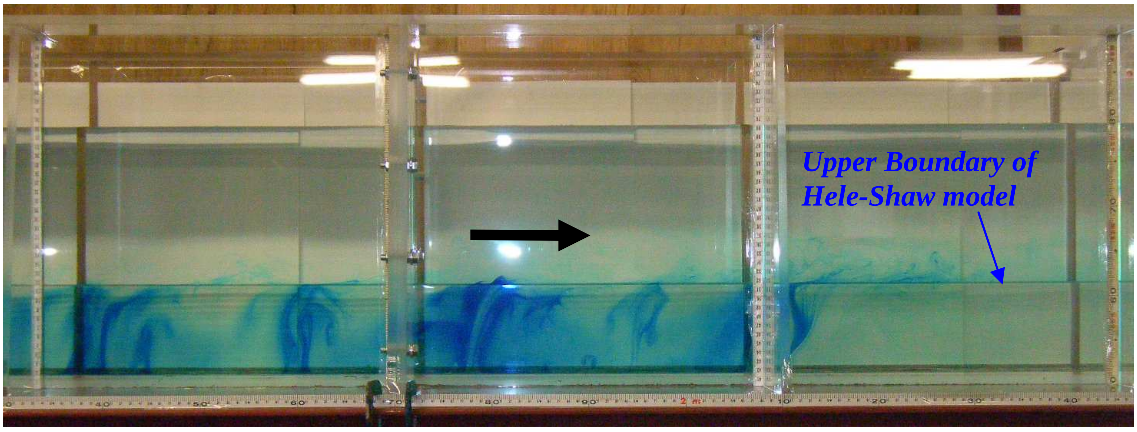

Figure 9 Interactions at 0.2% slope when the river height is 17.6 cm

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