The Piping Erosion of subsurface Flow using a Laboratory Experiment

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ABSTRACT

Generally speaking, the landslide is triggered by the fast rising of groundwater level. For the understanding of the relationship between groundwater level and landslide, this study develops the laboratory experiment of landslide. The embedded system is applied to build the measurement system of groundwater level and real-time video record. Three section design of sand box is also used to ensure the efficient water level difference between the top/bottom of hillslope, which is the guarantee for the occurrence of landslide. Experimental outcomes show that the seepage flow initiates soil loss, which can be regarded as the warning signs of hillslope failure. After the seepage flow occurs, if the groundwater level rises sustainable to reach the critical value, the landslide may occur by piping erosion.

INTRODUCTION

Generally speaking, torrential rainfall usually induces the landslide due to the rising the groundwater level and the internal friction reduction of soil. For example, Caris & Van Asch (1991) revealed that a groundwater level of 4 m below the ground surface is the critical threshold for reactivating the landslide. Van Asch et al., (1999) found that deeper landslides 5–20 m depth is in most cases triggered by positive pore pressures on the slip plane induced by a rising ground water level. Chigira (2002) thought that permeable surface materials overlie impermeable materials that prohibit the downward infiltration of groundwater, may concentrate the groundwater and become an important focus of landslides that are triggered by intense rainfall. In conclusion, the rise of groundwater level usually is the one of the important factors for a landslide.

On the other hand, heavy rainfall also upraises the stream water level, increases the pore water pressure of bank, and usually erodes the stream bank. Erosion of stream banks and shorelines by exfiltrating seepage is called sapping or piping (Hagerty, 1991). The piping erosion of stream bank (Hagerty, 1991) is that seepage flow out of a sandy layer carried sand out of the stream bank, and the overlying more cohesive upper bank layer was undermined and collapsed. Rinaldi & Casagli (1999) found that a bank failure is likely to occur during the drawdown phase, as the confining pressure of the water in the channel disappears. Tomlinson & Vaid (2000) thought that the grain-size ratio of filters for stream bank is the most important parameter affecting piping erosion, and confining pressure had a minor negative impact on stability. In short, seepage flow may induce the piping erosion in the stream bank.

However, both of groundwater or seepage flow is the flow of water beneath the earth's surface, named subsurface flow, which may induce the collapse of the hillslope / stream bank. This study design a simplified slope in the sandbox to simulate the subsurface flow in the hillslope/stream bank. The slope groundwater level is measured to find the groundwater level of slope collapse.

Experimental design:
Experimental Layout:
The laboratory experiments were conducted in a rectangular sand box with re-circulating water, and the size of 2.5 m long, 0.6m wide and 0.8 m high with glass sides shown in Figure 1. The sand box was divided into three sections, which include water level control area (WLCA), test area (TA) and water storage area (WSA) as follows.
(1) WLCA is located in the left hand side with 0.5cm length to control the groundwater level of test area. An inventor motor transports water from WSA to WLCA by pipes. The RPM of Water pump can be controlled to adjust the water discharge of pipes. WLCA and TA was separated by a steel plate, in which have many circular openings covered by plastic meshes, to pass the water into TA and prevent the sand return to WLCA.

(2) TA is placed in the middle area with 1.05m length. Six pore pressure meters were installed in the bottom every 15cm to measure the pore water pressure. Experimental hillslope was stacked in this section. The water level difference between WLCA and TA will induce the seepage flow in the TA, and form a piping erosion in the hillslope finally. On the other hand, the seepage flow may raise the water level of TA and reduce the speed of seepage flow. Therefore, a pump installed in the rear area was used to drain the water of TA into the WSA. In addition, a camera was installed in the top to shoot the condition of landslide.

(3) WSA (length = 0.95m) is located on the right hand side, separated between TA by a steel plate. Water was reserved in this area, and transported into the WLCA by a pump.

Figure 2 (a) is the picture of camera installation. Figure 2 (b) is the picture of the soil sample layout.

**Fig. 1:** Sketch of experimental sandbox and installation.

**Fig. 2:** Picture of Experimental Layout.

**Experimental Apparatus:**

Pore pressure meter and data receiver (I-7016) were connected by a cable, and stored in the embedded system (I-8000).

(1) **Pore pressure gauge:**

Pore pressure gauge (No. KPA-PA, Tokyo Sokki Kenkyujo), shown in Figure 3 (a), adopted 5V exciting voltage, and the unit of output voltage is 0.8mV/V. The output voltage varies with the water level.

(2) **Data receiver:**

The strain gauge input module named I-7016D (Figure 3 (b)), produced by ICP DAS, is used to receive the output voltage of the pore pressure gauge. The resolution of supply excitation voltage for strain gauge is 16-bit.
DAC (Digital to Analog Converter). The supply power is 24 voltages. Due to the water level range is small in this study, the input voltage is enlarged to improve the resolution of voltage identification.

(3) Data storage:
The data storage module named I-8000 (Figure 3 (c)) produced by ICP DAS, is used to gain and store the data obtained by six pore pressure gauges.

Figure 3 (d) is the practical connection of I-7016D, I-8000 and power Transformer.

![Pore pressure gauge](a) Pore pressure gauge (b) I-7016 (c) I-8000 (d) connection between I-7016 and I-8000

**Fig. 3:** The instruments used in the experiment.

**Calibration of pore pressure gauge:**
Groundwater level (Ew) and Voltage (Vw) can be expressed by a linear relationship $E_w = A + B \times V_w$, where $A$ and $B$ are constants. Table 1 displays the values of $A$ and $B$ for five pore pressure gauges.

<table>
<thead>
<tr>
<th>No of pore pressure gauge</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-71.97</td>
<td>526.10</td>
</tr>
<tr>
<td>2</td>
<td>-105.70</td>
<td>507.71</td>
</tr>
<tr>
<td>3</td>
<td>35.66</td>
<td>663.32</td>
</tr>
<tr>
<td>4</td>
<td>73.99</td>
<td>424.10</td>
</tr>
<tr>
<td>5</td>
<td>-94.24</td>
<td>450.83</td>
</tr>
</tbody>
</table>

**Experimental results and discussion:**
Uniform silica sand of $D_{50}=0.195$mm, which is the medium size of dammed lake located in Chiufenerhshan, Nantou county, Taiwan, is adopted as the test soil sample, and $S = 100\%$ is adopted as the slope angle of hillslope. Figure 4 displays the slope collapse progression: (a) In the beginning period, the water pressure difference between the top and bottom of hillslope leads to see page flow, which initiates soil loss in the bottom of the slope; (b) After the occurrence of seepage flow, more and more soil is brought out into the bottom of the slope, and landslide occurs finally.

![Slope failure process](a) Seepage flow initiates soil loss (b) landslide

**Fig. 4:** Slope failure process.

Figure 5 displays the groundwater variation of pore pressure gauge No.1 during the experiment period. According the phenomena of soil movements, groundwater variation can separated into four time intervals:

1. The fast rising section: At the beginning time, the high water level difference between top/bottom of hillslope forces the fast rising of groundwater, shown in section A.
2. The fast drop section: After the groundwater level reaches the initiation of seepage flow, the flow brings out some soil and water in the bottom of hillslope to drop down the groundwater level, shown in section B.
(3) The slow rising section: Though the seepage flow can transport some water, the water level difference still rises the groundwater level slowly, shown in section C.

(4) The sudden drop section: When the groundwater level of landslide reaches the critical value of landslide, a huge movement of soil and water reduces the groundwater level.

According the observation of laboratory experiment, the soil loss by the initiation of seepage flow can be regarded as the warning signs of hillslope failure. After the seepage flow occurs, if the groundwater level rises sustainable to reach the critical value, the landslide may occur.

**Conclusion:**

This study adopted sand box to develop the laboratory experiment of piping erosion in hillslope. The suitable arrangement of sandbox lets the water level difference between top/bottom of hillslope can be controlled to occur the landslide. A measurement system is also developed to measure the ground water level within the hill slope, and to record the video of the experimental process. The laboratory experiment founds that the failure process of hillslope can be separated into two parts: (1) After the fast rising of groundwater level, seepage flow initiates soil loss, and decreases the ground water level; (2) If the groundwater level rises sustainable, the landslide will occurs to drop down the groundwater level suddenly.

![Graph](image)

**Fig. 5:** Groundwater variation during the experiment period.

**REFERENCES**


