Electronic supplementary materials

for https://doi.org/10.1631/jzus.A2100686

Visualizing the dynamic progression of backward erosion piping in a Hele-Shaw cell

Gang ZHENG[1], Jing-bo TONG[1], Tian-qi ZHANG[1✉], Zi-wu WANG[2], Xun LI[1], Ji-qing ZHANG[3,4], Chun-yu QI[3,4], Hai-zuo ZHOU[1], Yu DIAO[1]

[1]MOE Key Laboratory of Coast Civil Structure Safety, Tianjin University, Tianjin 300072, China

[2]School of Science, Tianjin University, Tianjin 300072, China

[3]China Railway Design Corporation, Tianjin 300308, China

[4]National Engineering Laboratory for Digital Construction and Evaluation Technology of Urban Rail Transit, Tianjin 300308, China

✉ Tian-qi ZHANG, Tianqizhang@tju.edu.cn

Tian-qi ZHANG, https://orcid.org/0000-0003-0145-973X

S1 Test preparation, uniformity verification, and determination of the pipe geometry

S1.1 Test preparation

Preparation of the experiment can be divided into five steps, as shown in Fig. S1.

Step 1: Saturating the sample. The sample was first saturated in a bottle called the supplying bottle. The bottle had one inlet at the top and one outlet at the bottom. Because the density (ρ_s=2650 kg/m^3) of the sand grains was higher than that of the water, the sample existed as sediment in the bottle. Once water was driven from the inlet to the outlet, sediment transport occurred. In this way, the saturated sample was transferred to the Hele-Shaw cell.

Step 2: Assembling the PMMA plates. The upper and lower PMMA plates were fitted together in a water tank (this prevented any air pockets from forming in the gap between the two plates). Then the annular aluminium strip, embedded in the lower plate, was jacked up using 6 bolts uniformly distributed in a circle until the aluminium strip touched the upper plate.

Step 3: Transferring the sample to the Hele-Shaw cell. The samples were transferred to the Hele-Shaw cell from the centre hole of the upper plate by the water-driven method. In the entire filling process, a very small head of water, ΔH (3 kPa), was adopted. To ensure the homogeneous diffusion of the samples, in-plane oscillation was simultaneously imposed on the Hele-Shaw cell via four vibrators. The sand grains were first blocked by the annular aluminium strip (while the water could drain out through the foams surrounding the aluminium strip) and then deposited along the direction from the perimeter to the centre of the Hele-Shaw cell. Once the area inside the aluminium strip was filled by the sample the water supply was cut off. The porosity of the sample was around 0.54, and accordingly the relative density I_d was about 4.4%.

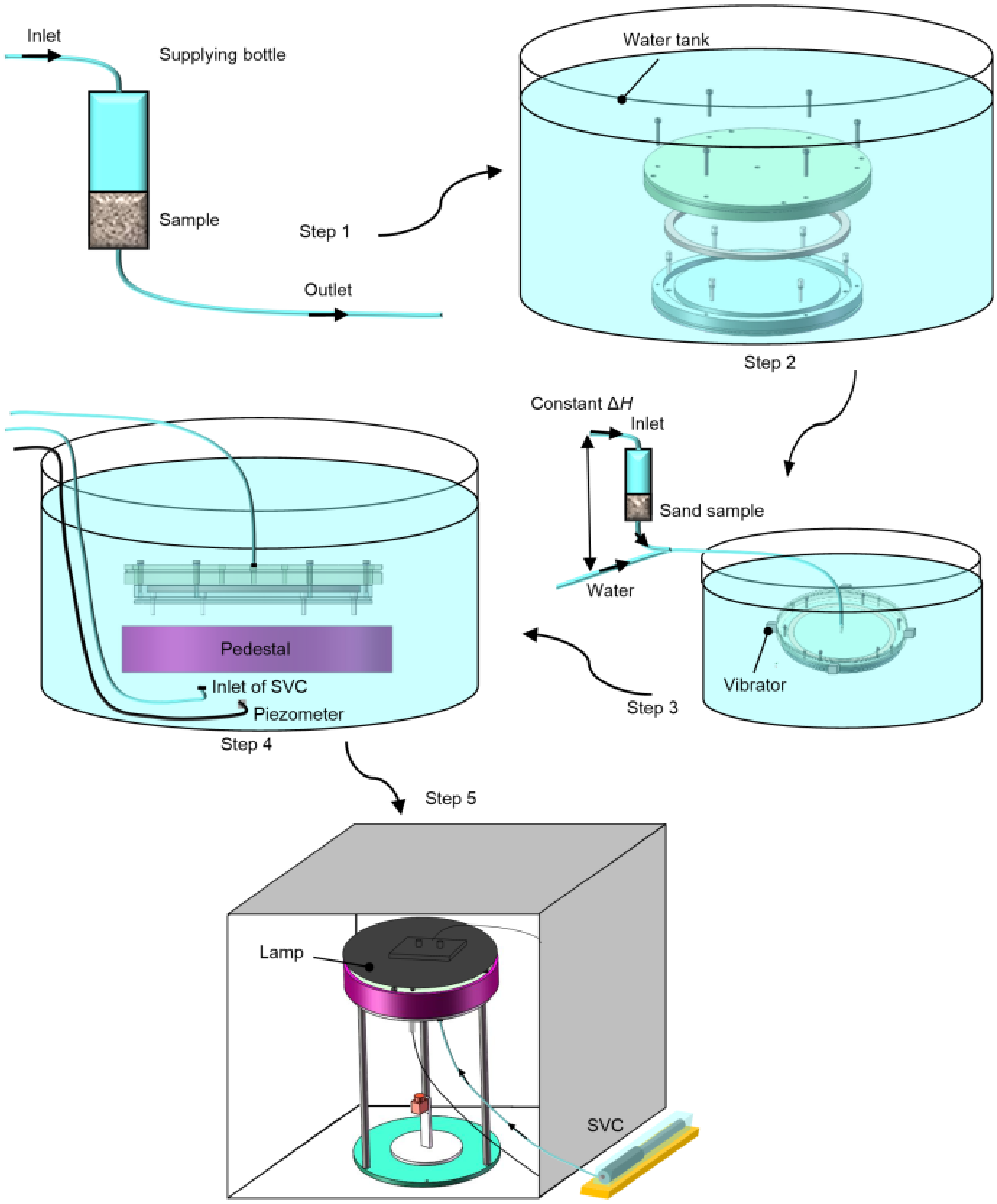

Fig. S1   Flow chart for test preparation

Step 4: Assembling the Hele-Shaw cell. The two PMMA plates were seated on the stainless-steel pedestal in the water tank, and then both the piezometer and the inlet of the SVC were installed on the Hele-Shaw cell.

Step 5: Checking the uniformity of the sample. The Hele-Shaw cell was removed from the water and laid on a shelf in the photographic studio. The high-speed camera was placed underneath the Hele-Shaw cell. An LED lamp with a diameter of 400 mm was laid on the upper plate of the Hele-Shaw cell to provide uniform light. In this way, the uniformity of the sample could be checked based on the distribution of the intensity of the emergent light observed from underneath the Hele-Shaw cell (cf. more details in the Appendix "Uniformity verification"). Once the sample was confirmed to be uniform enough, the test began.

S1.2   Uniformity verification

The uniformity of the sample was verified based on image processing technology. According to the Lambert-Beer law, when a beam of monochromatic light passes through a sample, the intensities of the incident and emergent light beams I_0 and I_1 may follow the relationship

$$\lg\left(\frac{I_0}{I_1}\right) = \varepsilon bc, \tag{S1}$$

where ε is the absorption coefficient, b is the thickness of the sample (0.5 mm in this study), and c represents the compactness of the sample. As a consequence, the uniformity of the sample can be checked via the intensity of the emergent light beam I_1 (given that the sample is uniform, the intensity of emergent light beam I_1 should be the same).

In this study, the photos taken by a high-speed camera were first turned into intensity images. Then, greyscale distribution analysis was performed to check the uniformity of the sample.

S1.3 Determination of the pipe geometry

The determination of the pipe geometry was also based on imaging processing technology. The key to accessing the information of the pipe geometry was to obtain the coordinates of the points on the boundary of the erosion pipe. Specifically, this process could be divided into five steps (herein, we show an example using the "imaging processing toolbox" in MATLAB R2016b), as shown in Fig. S2:

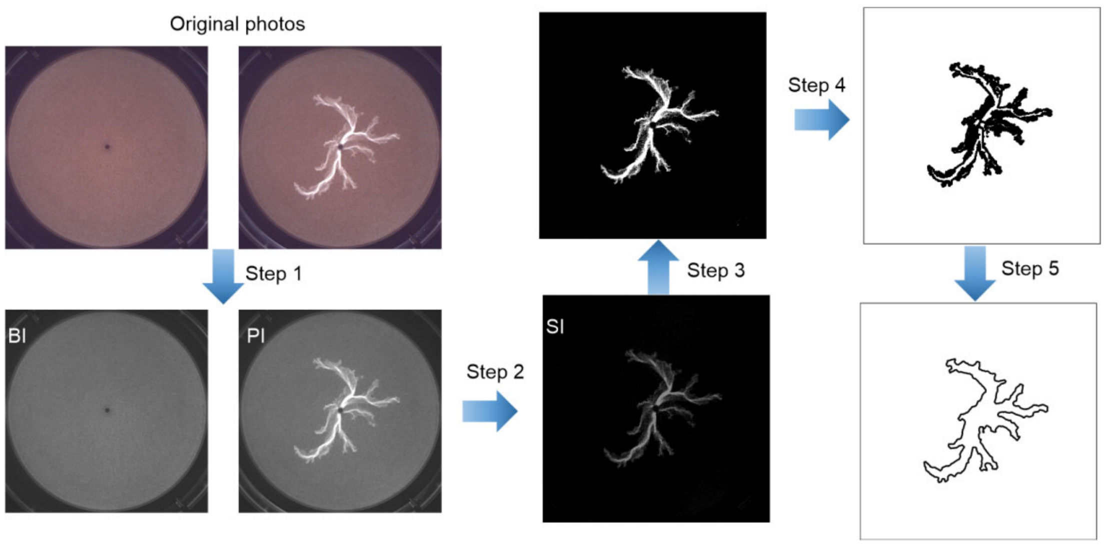

Fig. S2 Flow chart for determination of the pipe geometry

Step 1: Convert the photos into intensity images. For instance, we can use the "rgb2gray" function to convert true colour images to grayscale by eliminating the hue and saturation information while retaining the luminance.

Step 2: Subtract the background from the image that needs to be processed (PI). In general, an image obtained before the experiment can be used as the background image (BI). Then, we can use the "imsubtract" function to perform the "subtraction" work. In this way, we obtain a new image (SI).

Step 3: Adjust the intensity values of SI to make the eroded area more distinct. We may use the "imadjust" function to perform the "adjustment" work. In this way, the intensity values of the points within the eroded area can be limited to a very narrow range Y.

Step 4: Seek out the points that have an intensity value of y (the point collection is termed Z), $y \in Y$ and output their coordinates. We can use the “contour” function for this task.

Step 5: Characterize the boundary of the point collection Z. We can use the “boundary” function to find the points on the external edge of point collection Z.

Once the coordinates of the points on the boundary of the eroded pipe are derived, other information on the pipe geometry, e.g., the erosion area A and maximum erosion radius R_{max}, can be easily obtained.