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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Experimental assessment of the relationship between rainfall intensity and sinkholes caused by damaged sewer pipes" *by* Tae-Young Kwak et al.

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1. General comments to authors This paper examined the effect of rainfall intensity on the sewer-related soil erosion and its evolution by means of model tests and image analysis. In order to reflect the field conditions in South Korea, the backfill material, rainfall intensity, and compaction criteria were considered in the model tests. The topic is clear and suitable with the subject of this journal. There are, however, several aspects that need to be improved, especially in relation with the test procedure and actual sewer-related soil erosion. Revising the manuscript considering the following comments are also recommended.

Answer: Thank you very much for your thorough and helpful review. Based on your concerns and comments, we believe that our manuscript has been improved. Please check our answers corresponding to your concerns.

2. Specific comments to authors Q1: The terms 'ground cave-in' and 'sinkhole' are used interchangeably which are recommended to be unified.

Answer: Based on your comment, the authors changed the term "ground cave-in" to "sinkhole."

Q2: L101. "The width of the slit was set to 2 cm, based on the study by Mukunoki et al. (2012), such that B/Dmax was 4.2." Justify the width of the slit the authors determined in relation with the listed reference.

Answer: Mukunoki et al. (2012) adjusted the ratio B/Dmax between the slit width B and maximum grain size Dmax of the soil to 1.05, 2.5, and 5.9 in their model tests. A ground cavity was formed after 13 cycles when B/Dmax = 1.05, whereas a sinkhole was observed when both B/Dmax = 2.5 and 5.9. In the model tests that were performed in our study for the adjusted Gwanak soil, which describes the typical backfill materials for the underground pipes used in South Korea, B/Dmax = 4.2. (For the adjusted Gwanak soil, Dmax = 4.75 mm and B = 20 mm.) This B/Dmax value is between 2.5 and 5.9, corresponding to the sinkhole development described by Mukunoki et al. (2012).

Q3: L107-108. Some clarification on the condition of "Relationship between the rainfall intensity and the hydraulic head in the sewage network conditions near Gangnam station" are needed. I wonder if this condition has been sufficiently considered in the model tests of this study.

Answer: The test conducted by National Disaster Management Institute of Korea (2014) shows the relationship between the rainfall intensity and hydraulic head under the sewage network conditions near Gangnam station. The sewage network was simulated by considering the distance between each sewer pipes and burial depth of the sewer pipes. In addition, the sewer pipes were assumed to be 1000 mm in diameter, as reflected in the present study. The authors noted these points in the manuscript.

Q4: L117. typo (#No. 4 sieve passing).

Answer: Based on your comment, the authors removed the term of "#No. 4 sieve passing."

Q5: L141-142. Additional information on the validation of PIV technique, such as accuracy, analysis condition, will be of interest to the readers.

Answer: In this study, to find the optimum size of the pixel subset, various-sized pixel subsets (40 × 40, 60 × 60, 80 × 80, 100 × 100, and 120 × 120) were tested by comparing two digital images: the original image of the model ground and the image artificially shifted by 10 pixels at the 4 edges of the model ground (where crude distortion occurs). The validation test results showed that 100 × 100 was the optimum size of the pixel subset, with a maximum error of 0.0069 pixels in accuracy and precision. The PIV validation results have been included in the manuscript.

Q6: L149. Explanation about the multiple cycles is required. I believe that one cycle consisted of water supply and drainage stage and it was repeated, but the manuscript contains only the result of one cycle.

Answer: Based on your comment, the authors removed the term "multiple cycles."

Q7: Additional information on the rainfall record which can prove the suggested three rainfall intensities in this study are realistic will enhance the credit of this paper.

Answer: Currently, the standard for a heavy rain watch in South Korea is 60 mm/3 h (in the case of intense heavy rain) or 110 mm/12 h (in the case of continuous heavy rain), and the standard for a heavy rain warning is 90 mm/3 h (in the case of intense heavy rain) or 110 mm/6 h (in the case of continuous heavy rain). Because the focus of this study was the formation of anthropogenic sinkholes in the event of intense heavy rainfall, the hourly rainfall intensity distributions corresponding to 60 mm/3 h and 90

mm/3 h (which are the criteria for a heavy rain watch and heavy rain warning) were confirmed using data from the Environmental Prediction Research Institute (2017) (as of 2012–2016). In the cases of 60 mm/3 h (based on a heavy rain watch) and 90 mm/3 h (based on the heavy rain warning level), the hourly rainfall intensity distributions corresponding to 30–50 mm/h and 40–60 mm/h were the highest, respectively. In the heavy rain watch case, the rainfall intensity distribution of 30–50 mm/h was 72.9 %, and in the heavy rain warning case, the rainfall intensity distribution of 40–60 mm/h was 64.9 %. Therefore, 40 mm/h and 50 mm/h were applied in this study by using the average value for the section with the highest rainfall distribution for 1 h in terms of heavy rain watch and heavy rain warning.

Q8: The procedure of calculating the average cavity width in Table 4 is not clear.

Answer: Based on your comment, the authors specified the calculation procedure for the average cavity width in the footnote of Table 4.

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