Experimental Study on Sand Erosion Around Defective Sewer Pipes

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***Abstract*—Groundwater infiltration is a common problem in sewer systems. In underground sewer pipeline systems, when the groundwater table reaches above sewer pipes, water will infiltrate into the sewer pipes through various types of defects or cracks on the pipe wall. Three factors that relate with the erosion process were investigated experimentally: soil particle size, water head, and soil height. To study the erosion process around cracked sewer pipes a set up was used which is usually related with groundwater infiltration in sewer systems. A cylindrical bin with a circular outlet at the bottom centre was used to simulate the erosion process. The quantitative influences of the three factors on the erosion void shape, volume and length were analyzed. It is found that the geometry of the erosion void is determined by water head and soil height. By using analytical method proposed by Guo et al (2013) and ANFIS the correlation values are computed. It is found that ANFIS shows better agreement with the experimental data.**

Keywords— Sewer pipes; erosion; infiltration; erosion void; sink hole; ground water

I. INTRODUCTION

In underground sewer pipe line systems, when the ground water table reaches above sewer pipes, water will infiltrate into the sewer pipes through various types of defects or cracks on the pipe wall. As a common problem existing in sewer systems worldwide, groundwater infiltration has caused great economic losses, since this part of "unwanted water" increases the cost of wastewater treatment and energy consumption and operating costs of pumping stations. Therefore, in the last few decades, significant attention has been drawn on the infiltration control and management, and many methods for infiltration estimation have been developed in different countries.

Ground water infiltration has caused great economic losses, because this part of unwanted water increases the cost of waste water treatment and energy consumption as well as operating costs of pumping stations. Ground water infiltration can also cause soil erosion and structural damages to sewer systems. Surrounding soil particles are apt to be washed into the pipe along with the infiltrating water. As the erosion proceeds with the time, a void may develop around the pipe. The erosion void causes sewer pipes to lose support from the surrounding soil, resulting in structural damages of the sewer pipes. It is important to prevent the erosion void developing into a big sinkhole mainly because the erosion process and erosion void are usually undetectable. Sinkholes due to soil erosion around defective sewer pipes are widely developed.

The present investigation explores the erosion process taking soil layer height, water table and soil particle size into consideration. Laboratory experiments were conducted in a circular outlet at the bottom center of a cylindrical bin to simulate the erosion process under free gravitational flow condition. Three classes of non-cohesive sand grains were used, and altogether 30 runs were conducted by changing the water head above the sand surface, sand height. The quantitative influences of these three factors on the erosion void shape, volume and diameter were analyzed and presented.

II. EXPERIMENTS

Experiments were conducted to investigate the erosion process through an orifice and quantitative influences of different parameters on the geometry of the erosion void. A cylindrical bin was used to investigate quantitative influences of different factors including water head above the sand surface and sand height on the shape, diameter and volume of the erosion void. Diameter of the cylindrical bin was 480 mm. An outlet diameter of 10 mm was drilled on the bottom centre of the cylindrical bin. For simplicity, a flat base with an orifice at the center of the base is used to mimic the defective sewer pipe instead of inserting a true sewer pipe at the bin bottom. The orifice is considered as the crack. This study is restricted to non-cohesive sandy soil types and one class of fine sand sample was used as the soil material. Samples were uniformly screened.

Thirty runs were conducted. Experiments were conducted using three class of sand with particle size 0.17 mm, 0.27 mm, and 0.48mm with a varying water head of 20 mm, 40 mm, 60 mm and varying sand heights of 100mm, 200mm, and 300 mm.

In each experiment sand is added layer by layer and is well compacted [4]. Suitable water height is obtained by adding water from top by using a sprinkler without disturbing the sand bed. During the experiment the volumetric discharge from sand and water mixture from the orifice was measured by using beakers. After the discharge diameter of erosion void and volume of erosion void were measured.

TABLE 1. DETAILS OF RUNS

Run	**Varying parameters**			
	d_p(mm)	***h_w (mm)***	***h_s(mm)***	***D_o(mm)***
1, 2, 3	0.17	20, 40, 60	100	10
4, 5, 6, 7	0.17	20, 40, 60, 80	200	10
8, 9, 10	0.17	20, 40, 60	300	10
11, 12, 13	0.27	20, 40, 60	100	10
14, 15, 16, 17	0.27	20, 40, 60, 80	200	10
18, 19, 20	027	20, 40, 60	300	10
21, 22, 23	0.48	20, 40, 60	100	10
24, 25, 26, 27	0.48	20, 40, 60, 80	200	10
28, 29, 30	0.48	20, 40, 60	300	10

III. RESULTS AND DISCUSSIONS

The resulting eroded shape of the experiment was like in the Fig. 1.

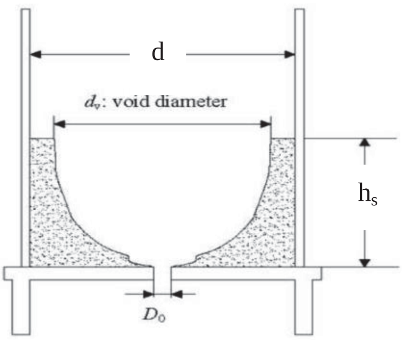
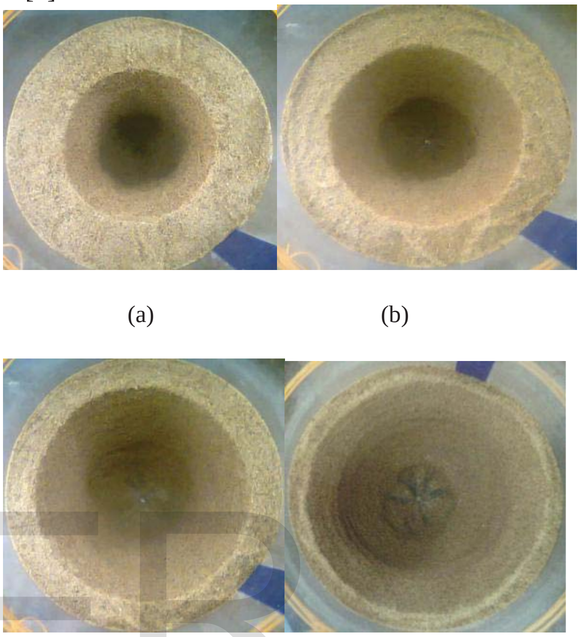


Fig. 1 Resulting erosion void

After the flow begins the surface of the sand was suddenly collapsed during the free gravitational discharge. When discharge progressed, the erosion void rapidly propagates horizontally and vertically. When the water table decreases below the sand surface, the erosion void diameter reaches its maximum and a circular upper boundary of the erosion void is formed [2]. When discharge finishes, an expected conical shape is formed as shown in figure 1. When water head increases erosion void will be smoother. From experimental observations it is noted that the top diameter of the erosion void depends on the water head. Fig 2 shows the final eroded shapes [4].

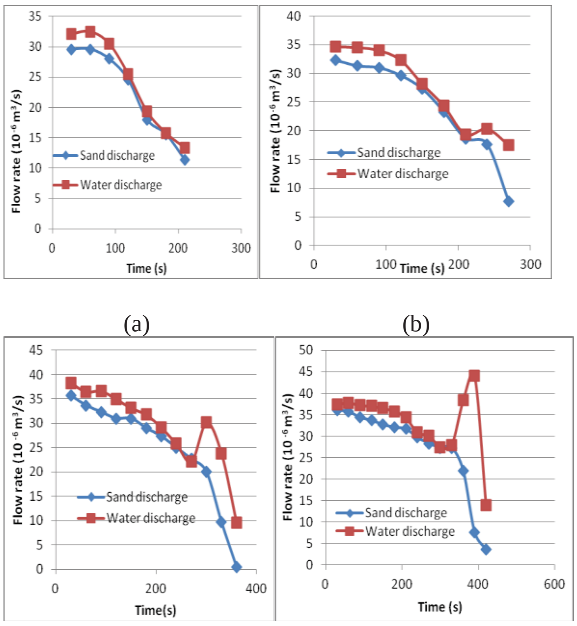


(a) (b)

(b) (d)

Fig. 2 Final eroded shapes for 200 mm sand height

(a) 20 mm water height (b) 40 mm water height
(c) 60 mm water height (d) 80 mm water height

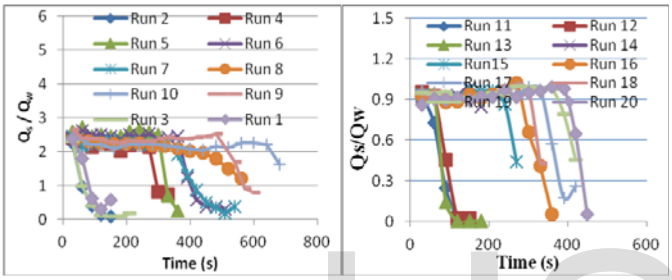


(a) (b)

(c) (d)

Fig 3 Variation of sand and water flow rate with time for 200 mm sand height
(a) 20 mm water height (b) 40 mm water height
(c) 60 mm water height (d) 80 mm water height

Fig 3 shows the variation of sand and water flow rate with time for 200 mm sand height. For the four water heights the sand flow rate was a gradually decreasing curve. Water flow rate was also decreases as increase in time. Water discharges increases abruptly at a certain point due the completely water filled erosion void. Fig 4 shows the effect of particle size on sand water discharge rates of coarse fine and medium sand respectively.



(a) (b)

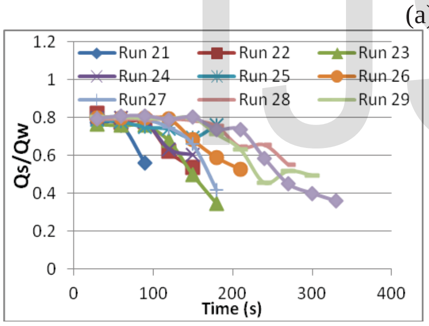


Fig 4. Effect of particle size on sand-water discharge rates of medium sand

(a) Coarse sand (b) Medium sand
(c) Fine sand

Under the same water head, both diameter and volume of the erosion void are larger for fine sand, as finer sand has small submerged angle of repose. Finer sand has smaller average flow rate during discharge, while it lasts for longer time. The time duration is dependent on the particle size. It can be found that the linear relationship exists between the ratio of sand and water flow rate to time. Ratio was maximum for fine sand than coarse and medium sands.

Fig 5 shows the variation of erosion void diameter and erosion void volume for different water heads. Since the final eroded shape is like a shape of a cone the volume can be computed by using the formula of volume of cone.

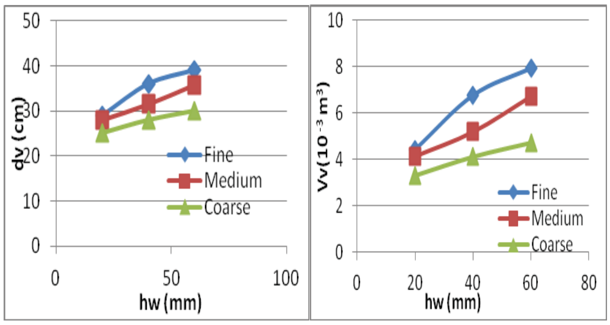


Fig 5. Variation of erosion void diameter and volume with different water heads

It was observed that void diameter formation has a major influence on the water heads, since the higher water heads shows very high erosion voids compared to lower water heads. Increase in sand height shows decrease in void diameter. Since coarse sand shows the lowest erosion diameter and erosion void volume, it is preferable to lay sewer pipes in coarse sand rather than fine sand. Sand height also has an important influence on the geometry of the erosion void. Lesser will be the sand height, more will be the stability of erosion void, also shape of the erosion voids are more good on lesser sand heights. Besides the water head, the loose zone around the orifice enlarges when the sand height increases. Fig 6 shows the variation of erosion void diameter and erosion void volume with different sand heights.

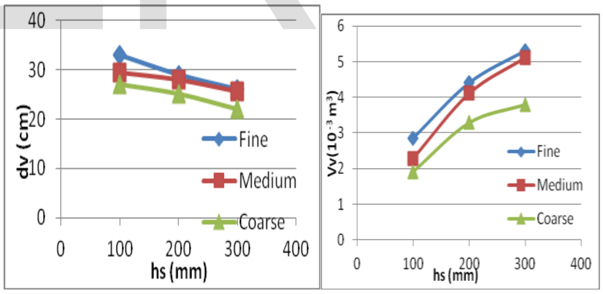


Fig 6. Variation of erosion void diameter and volume with different sand heights

MODELING BY ANALYTICAL METHOD

The void diameter given by the equation of Guo et al (2013) is noted as computed void diameter [1].

$$d_v = \left(\frac{6(1+n)d^2 h_w}{(1+(1+n)(1-\varepsilon))\tan\varphi_i} \right)^{1/3}$$

Where n = constant, d = bin diameter, h_w = water head, d_v = void diameter, φ_i = angle of internal friction

Regression plot was drawn for the computed and measured erosion void diameters. Correlation coefficient obtained by this method was 0.83. For fine sand and coarse sand, the computed void diameters are high compared to the measured void diameters. But in the case of medium sand, it is quite different. Fig 7. shows the computed erosion void diameter with measured data proposed by Guo et al (2013). Fig 8 shows the scatter plot for observed and computed void diameter for cylindrical tank.

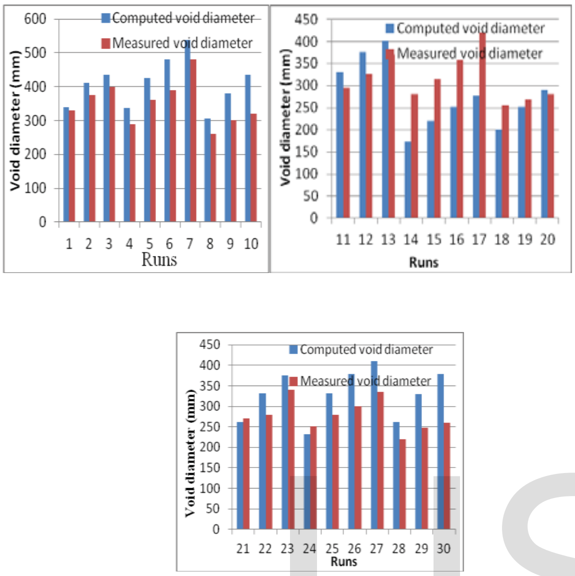


Fig 7. Computed erosion void diameter with measured data proposed by Guo et al (2013)

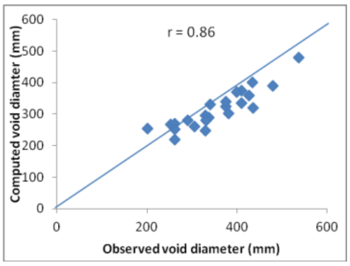


Fig 8. Scatter plot for observed and computed void diameter for cylindrical tank

MODELING BY ANFIS

ANFIS is a graphical network representation of the Sugeno first order fuzzy system, combined with neural learning capabilities. Although neural networks are good at recognizing patterns, they are not good at explaining how they reach decisions.

Out of 30 data available, 22 data are used for training and 8 data are used for testing. Since the number of data during testing period was very small, the scatter plot for observed and predicted void diameters was as shown in Fig 9. The input parameters used are water height, sand height and particle size. 16 models were prepared. Fig. 9 shows the scatter plot for observed and predicted void diameter during testing period. Correlation coefficient obtained as 0.975.

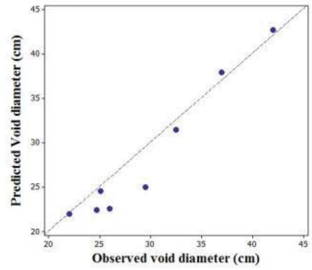


Fig 9. Scatter plot for observed and predicted void diameter during testing period

IV. CONCLUSION

When water head increases, sand flow rate and water flow rate increases accordingly. A conical shaped erosion void was formed. When water head increases erosion void diameter and void volume also increases. Erosion void diameter was more for fine sand. Sand and water flow rate functions are linearly related before the test ends. When sand height increases, erosion void diameter decreases. Using ANFIS model, r value is obtained as 0.975; it shows better agreement with the experimental data. The erosion process can be generally divided into initial stage, steady stage, and seepage stage. The initial stage is relatively short and ends when the surface collapses.

By using analytical method, the correlation coefficient was obtained as 0.86 and by using ANFIS model, correlation coefficient was 0.975, shows better agreement with the experimental data.

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