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Evaluation of the Effect of Leak Size of Defective Sewer Pipes on Soil Erosion

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Abstract: Defective sewer pipes allow water and soil in the vicinity to drain into the pipe through defects. This eventually leads to sinkhole accidents. Such accidents have been reported around the world and cause economic losses and present a threat to human life. Many factors affect the state of soil erosion around defective sewer pipes, leak size is one of the most important of these factors. The present study studied the effects of leak width on soil erosion using local sandy soil and subbase type (D) which is a sewer pipe embedment material according to Iraqi specifications. Model tests were conducted with different leak widths of the following measurements: 3-7 mm where the experimental model involved soil exposed to cyclic water flow through leaks located at the bottom of the model. Eroded soil is collected, dried, weighted and sieved for each cycle. From the results, it was found that the leak width as well as the soil particle size both have significant effects on the amount of soil discharging into the sewer pipe where the amount of soil entering the sewer pipe through the leak is inversely proportional to the ratio of soil particle size to leak width.

Key words: Sewer pipes, leakage, model test, soil erosion, sinkhole, subbase

INTRODUCTION

Sewer pipes are one of most important underground infrastructures and there construction is continually increasing and spreading in urban areas. Over the last two decades, the number of sinkhole accidents induced by soil erosion around defective sewer pipes in urban areas has increased (Bonelli, 2012; Guo *et al*., 2013; Weil, 1995). Sewer pipes become damaged and their defects increase over the time. Many cities around the world had sewer pipes which were constructed decades ago. Some of them have exceeded their service life and have begun to deteriorate (NILIM., 2006). The deterioration of sewer pipes results in cracks and openings which allow water and soil in the vicinity to enter the sewer during water infiltration (Karpf *et al*., 2011; Meguid and Dang, 2009). The process of water infiltration/exfiltration cycle would remove the contact between soil particles above the sewer pipe resulting in discharging water with soil into the sewer pipe through cracks and openings (Mukunoki *et al*., 2009). The repetition of this process over time eventually ends up creating cavities around the sewer pipe. These expand over time and this eventually leads to the formation of sinkholes (Guo *et al*., 2013). Cavities formed by soil erosion around the sewer pipe could lead to pipe failure due to the loss of support from surrounding soil (Balkaya *et al*., 2012). Sinkholes induced by soil erosion around defective sewer pipes have been widely reported and have caused great economic losses including damage to buried service lines, interruption to traffic, damage to roads, structures and sometimes even loss of life. Such an incident occurred in Guatemala in 2007 (Galve *et al*., 2012; Than, 2010; Weil, 1995). Previous studies have addressed the process of soil erosion and the factors affecting it. The leak width and soil particle size distribution are the most important factors affecting the amount of soil erosion. Soil loss is related to the ratio between leak width or the width of the opening and the soil particle size (Mukunoki *et al*., 2012; Rogers, 1986). For freely flowing sand under gravity, a reduction in the volume of soil loss was observed as the particle to opening size ratio (D_{60}/B) increased, where D_{60} is the sieve size through which 60% of the weight of soil sample passes and B is the opening size (Kamel and Meguid, 2008). For fine sand and gravel, a critical leak width for continuous erosion of soil was expressed as $2.5D_{85}$-$4.5D_{85}$ (Rogers, 1986). For similar types of soil under cyclic water inflow and drainage the critical leak width was expressed as $5.9D_{max}$ where D_{max} is the maximum particle size (Mukunoki *et al*., 2012). The aim of this study is to assess the effect of leak size on soil erosion due to defective sewer pipes to study the susceptibility of local sandy soil and pipe embedment material to erosion through different sewer pipe leak sizes. An economic apparatus has been used which

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has flexibility to change the leak size and soil conditions to facilitate the measurement and observation process.

MATERIALS AND METHODS

Test apparatus: The test apparatus used in this study consists of soil chamber, eroded soil collection unit, water flow unit and loaded weights. The soil chamber has dimensions of 800 mm long, 100 mm wide and 500 mm high. The front and back walls of the soil chamber are made from 10 mm tempered glass and the frame is made of steel. The transparent walls are used to allow monitoring of the cavity formation process. The eroded soil collection unit is placed at the base of the soil chamber. It has 100 mm diameter and 100 mm height with conical shaped bottom. The surface of this unit then has the same level with the base of the soil chamber. This represents a defect at the crown of the pipe. More leak sizes can be used by changing the eroded soil collection unit with those which have a different leak size. An O-ring is placed between the soil chamber base and the eroded soil collection unit to avoid the leakage of water or soil through this connection. The eroded soil collection unit has a water inflow valve located on the side of the unit and a drainage plug located at the bottom of the unit where the drainage plug remains closed during the water inflow period and is opened at drainage. Steel weights are placed on timber beams that are to be placed on the soil surface to simulate the weight of backfill soil above the sewer pipe. Different sewer depths can be simulated by changing the amount of load. A constant head tank is used with a 4 mm diameter high stiff pipe from the tank to the water inflow valve. The water flow rate is fixed and measured by water volume with time. Schematic diagrams and image of experimental setup are shown in Fig. 1 and 2.

Testing materials: Local sandy soil and sewer embedment materials were used in the study. The soil is provided from local materials in Karbala Governorate Al-Hur area. The soil was sieved, according to ASTM D 422 standard test method for particle size analysis of soils. The gradation is shown in Fig. 3. Other specifications shown in Table 1

Subbase type (D) are used in the present study according to Iraqi specifications as a pipe embedment material. The gradation and other properties are shown in Fig. 4 and Table 2.

Testing procedure: The eroded soil collection unit with the desired leak width was placed at the bottom of the soil chamber and connected with screws where the surface of the unit is then at same level with the base plate of soil chamber and the leak length is perpendicular to the glass walls. To prevent the soil from leaking out through the defect while filling the soil chamber, icing sugar was placed in the eroded soil collection unit. This substance dissolves when water flows into the soil chamber. Soil

Table 1: Exprimental sandy soil properties

Variables	Values
Specific gravity	2.65
Coefficient of gradation $C_c = D_{30}^2/D_{60}\,D_{10}$	1
Coefficient of uniformity $C_u = D_{60}/D_{10}$	2.28
D_{70}	0.85 (mm)
Optimum water content	9%

Table 2: Experimental subbase properties

Variables	Values
D70	2.35 (mm)
Optimum water content	8%

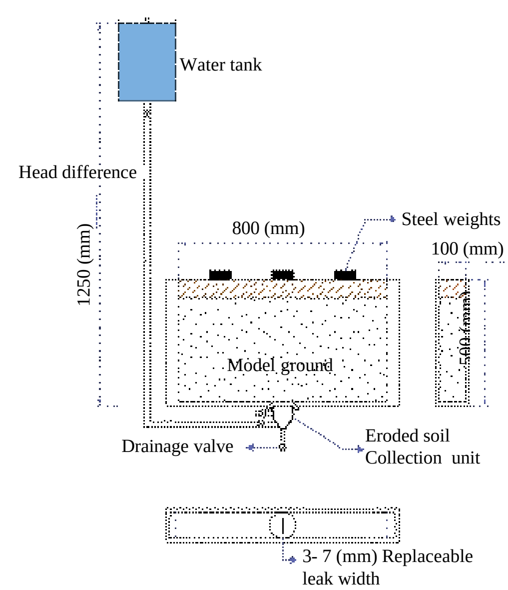

Fig. 1: Schematic diagrams of experimental setup

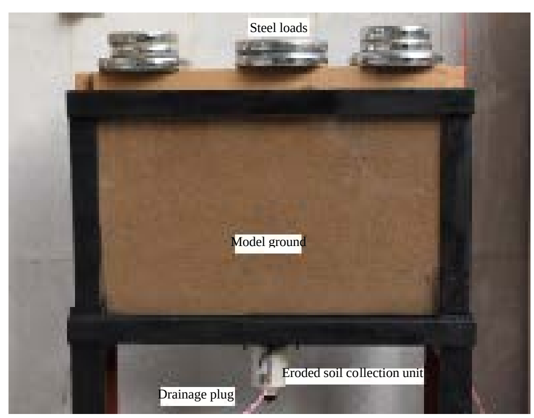

Fig. 2: Image of experimental apparatus

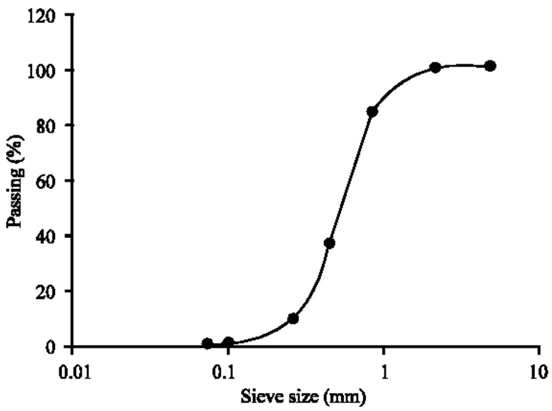

Fig. 3: Particle size distribution of exprimental sandy soil

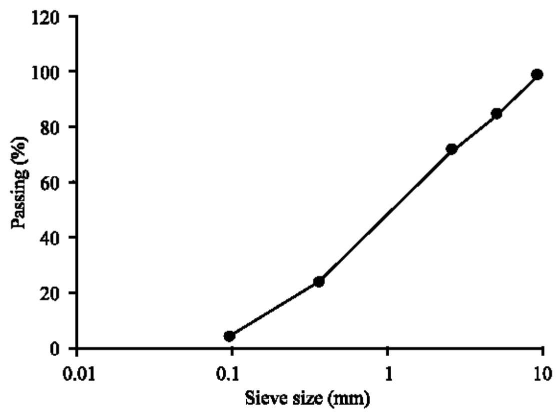

Fig. 4: Particle size distribution of exprimental subbase type (D)

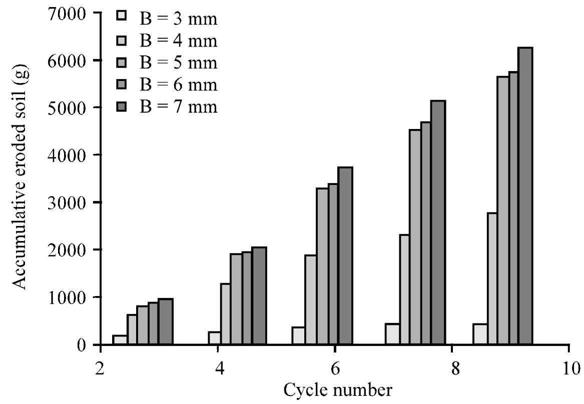

Fig. 5: Accumulative eroded sandy soil in each cycle for different leak sizes (B)

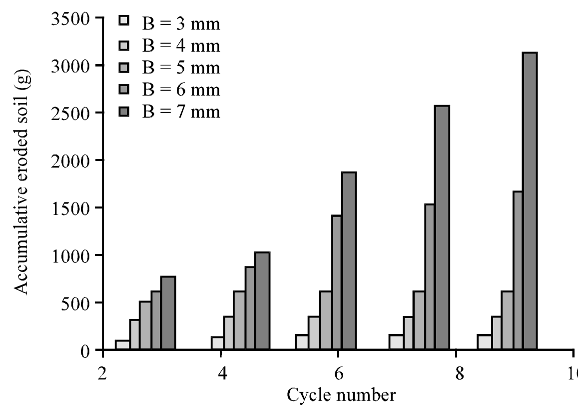

Fig. 6: Accumulated eroded subbase in each cycle for different leak sizes (B)

was then added to the soil chamber in the form of layers. Each layer is 50 mm deep and compacted to 80% of relative density. Steel weights were then placed on the timber beam that was placed on the soil surface to simulate 1 m of soil depth above the sewer pipe. It was then left for 12 h to reduce the potential creep effect. 0.75 liters of water was applied to the model ground through the leak, where from the initial experiments, it was found that the water volume of 0.75 spread appropriately in the soil chamber and caused continuous erosion. After 2 min, the drainage plug was opened to let water and eroded soil flow out. This process of water supply/drainage is called a cycle and is repeated 10 times for each run. For each cycle, the dry weight of the eroded soil was measured and then sieved.

RESULTS AND DISCUSSION

Soil erosion through a defect in a pipe is related to the particle size and opening size. Therefore, the leak width is controlled in order to study soil particle behavior. Five sizes of leak width were used 3-7 mm. For each leak width, the run was conducted with an inflow of water volume of 0.75 L. The soil was in a dry condition with 80% of relative density. The accumulative eroded soil mass is plotted as against the number of cycles for each leak width as shown in Fig. 5 and 6.

It is clear from the results that the leak size has a crucial effect on the amount of eroded soil where the amount of collected soil increases with the increasing of the leak width. The results also demonstrate that sandy soil is more susceptible to erosion than subbase the comparison of the total eroded soil mass at the end of the 10 cycles in both subbase and sandy soil is shown in Fig. 7.

The results demonstrate that sandy soil eroded in larger quantities through all leak sizes where the ratio between the total eroded subbase mass and the total eroded sandy soil mass ($E_{subbase}/E_s$) is shown in Table 4.

Table 3: Test conditions

Material/Leak width (B) (mm)	Relative density	Volume of water inflow	Cycles
Sandy soil			
3	80%	0.75 L	1-10
4			
5			
6			
7			
Subbase			
3			
4			
5			
6			
7			

Table 4: The ratio between the total eroded subbase mass and total eroded sandy soil mass

Leak width$_{mm}$	$E_{subbase}/E_s$ (%)
3	17.7
4	11.3
5	10.5
6	33.1
7	48.5

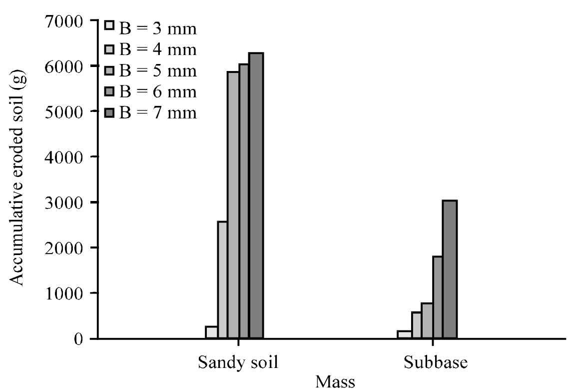

Fig. 7: The total eroded soil mass at the end of 10 cycle for both sandy soil and subbase

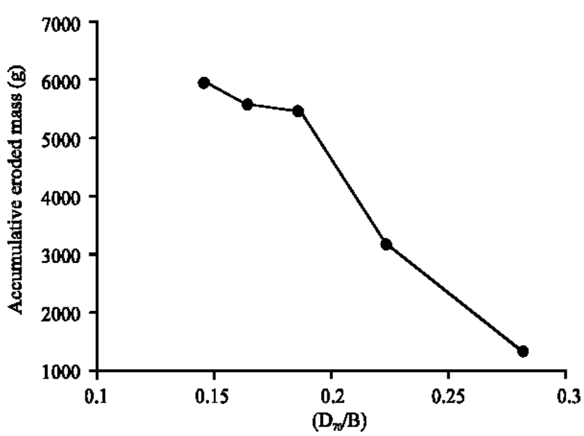

Fig. 8: The total eroded soil mass for different ratios of soil particle size to leak width (experimental sandy soil)

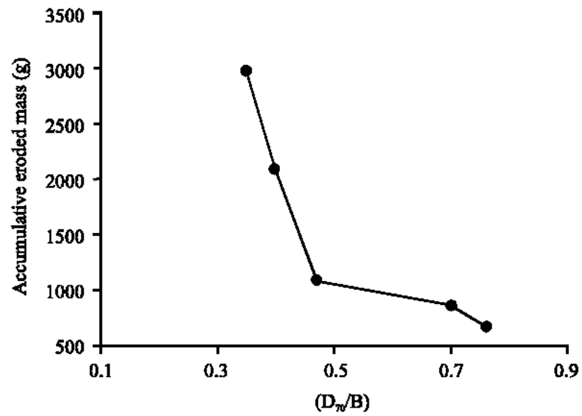

Fig. 9: The total eroded soil mass for different ratios of soil particle size to leak width (subbase)

To illustrate the relation between the amount of eroded soil and soil particle size, D_{70} is used to refer to soil particle size in the present study where D_{70} is the sieve size through which 70% of the weight of the soil sample passes. From the results, it is apparent that the relationship between the total eroded soil mass and the ratio of D_{70} to the leak width is drawn for both sandy soil (Fig. 8) and subbase (Fig. 9).

It was found that the amount of collected eroded soil increased when the ratio of D_{70}/B decreased. In general, through the experiments when the ratio of D_{70}/B is <0.17, the eroded soil enters the eroded soil collection unit through the leak easily and continuously. It is necessary to identify the soil particle sizes that are more likely to be eroded by water supply/drainage cycle. Eroded soil through different leak sizes is collected with each cycle then sieved separately. The sieve analysis for eroded sandy soil shows that soil particle sizes of <0.42 mm are more prone to erosion while larger sizes were more resistant where the greater the leak width, the greater the proportion of soil with a size >0.42 mm. However, its percentage is always less than that of the original soil. For subbase, soil particle sizes of <0.3 mm were more prone to erosion while larger sizes were more resistant. Furthermore, the early cycles had larger percentages of fine sizes than late cycle for both materials and all leak widths.

CONCLUSION

Based on the analysis of the present study, the following conclusions can be drawn, it was found that the leak width as well as the soil particle size both have significant effects on the amount of soil draining into the sewer pipe where the amount of collected eroded soil is inversely proportional to the ratio of soil particle size to leak size.

The eroded soil drains through the pipe leak easily and continuously when the ratio of D_{70}/B is <0.17. For experimental sandy soil, particle sizes of <0.42 mm were more prone to erosion and larger sizes were more resistant while particle sizes of <0.3 mm was more prone to erosion in the subbase of type (D).

REFERENCES

Balkaya, M., I.D. Moore and A. Saglamer, 2012. Study of non-uniform bedding due to voids under jointed PVC water distribution pipes. Geotext. Geomembr., 34: 39-50.

Bonelli, S., 2012. Erosion of Geomaterials. John Wiley and Sons, Hoboken, New Jersey, USA., ISBN: 9781118587652, Pages: 372.

Galve, J.P., F. Gutierrez, J. Guerrero, J. Alonso and I. Diego, 2012. Optimizing the application of geosynthetics to roads in sinkhole-prone areas on the basis of hazard models and cost-benefit analyses. Geotext. Geomembr., 34: 80-92.

Guo, S., Y. Shao, T. Zhang, D.Z. Zhu and Y. Zhang, 2013. Physical modeling on sand erosion around defective sewer pipes under the influence of groundwater. J. Hydraulic Eng., 139: 1247-1257.

Kamel, M.S. and M.A. Meguid, 2008. An experimental study of soil erosion around leaking pipes. Proceedings of the International Conference and Exhibition on North American Society for Trenchless Technology No-Dig, April 27-May 2, 2008, Japan-America Society of Dallas/Fort Worth, Dallas, Texas, pp: 1-11.

Karpf, C., S. Hoeft, C. Scheffer, L. Fuchs and P. Krebs, 2011. Groundwater infiltration, surface water inflow and sewerage exfiltration considering hydrodynamic conditions in sewer systems. Water Sci. Technol., 63: 1841-1848.

Meguid, M.A. and H.K. Dang, 2009. The effect of erosion voids on existing tunnel linings. Tunn. Undergr. Sp. Technol., 24: 278-286.

Mukunoki, T., N. Kumano and J. Otani, 2012. Image analysis of soil failure on defective underground pipe due to cyclic water supply and drainage using X-ray CT. Front. Struct. Civ. Eng., 6: 85-100.

Mukunoki, T., N. Kumano, J. Otani and R. Kuwano, 2009. Visualization of three dimensional failure in sand due to water inflow and soil drainage from defective underground pipe using X-ray CT. Soils Found., 49: 959-968.

NILIM., 2006. Annual report of waste water management and water quality control. National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure and Transport, Japan.

Rogers, C.J., 1986. Sewer deterioration studies: The background to the structural assessment procedure in the sewerage rehabilitation manual. Water Research Centre, London, UK.

Than, K., 2010. Guatemala sinkhole created by humans, not nature. National Gergraphic Washington, DC., USA.https://news.nationalgeographic.com/news/2010/06/100603-science-guatemala-sinkhole-2010-humans-caused/

Weil, G.J., 1995. Remote infrared thermal sensing of sewer voids. Proc. SPIE., 2454: 1-9.