Evaluation the Effect of Pressure Head and Soil Type on Erosion and Subsidence of Soil Due to Defective Sewers

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Abstract

Internal degradation induced in the metropolitan areas by leakage of sewers. As the resistance to erosion depends on the distribution of soil particles and the water pressure in sewer pipes, it is worthwhile to research the impact of water pressure on the soil erosion resistance of embedded pipes. This study aims to find physical model tests which simulating erosion and sinkhole development due to cyclic leakage in an experimental ground model through defect sewers. Proposed parameters like cyclic leaks through pipe crashes, eroded soil properties, initiation cavity, and evolution up until sinkhole failure were studied. During this process, the ground settlement monitored with Paricle:Image Velocimetry (PIV). Also, soils with various classification were utilized to identify the total subsidence for the different soil types. Five various water pressures were used:i.e., 0.8,1.1,1.4,1.7, and 2.0 meter,(7.85, 10.79, 13.73, 16.76, and 19.61 Kpa), respectively, and local sandy soil, local loamy soil, and local clayey soil also were used. The results showed that two parameters influence soil failure,noticebliy:- the first is water pressure which has a direct proportion to erosion and subsidence, where the increment of total eroded soil of 2.0 m water head reached 3.95 times 0.8 m head , and the second is soil types which showed that the clayey soil is highly sensitive and suffering more from subsidence rather than erosion on the contrary of other soil types.

Keywords : embedded pipes; leakage; PIV; subsidence; sewer pressure

1. Introduction

Urban sinkholes around faulty sewer pipes because of soil erosion are frequently reported and have become a major urban problem issue [1,5,8,12,16]. Recent reports indicated that in Japan there are…, 3000-4000 accidents in road sinkholes occur annually, because of the deterioration of sewage piping, in Japan alone[3]. Such disasters cause significant economic damage, societal inconvenience, environmental effects, and often human deaths. Detailed reporting on these events is extremely rare, though, because the primary concern of the competent authority is to return the utilities and roads more quickly to minimize public discomfort. Table 1, which based on the official reports, demonstrates the descriptions of a few sinkhole incidents triggered by faulty sewer pipes, it is shows that the most critical parameters (I.e.,the type of the soil, details of the sewage pipe, groundwater level, conditions of weather, pipe defect, the geometry of the sinking hole, etc.) are uncertain and the news only characterized the event in general. Consequently, the mechanism of erosion and the main parameters influencing soil erosion by sewer pipes faulty are not yet clearly understood, where large number of matters have not been clarified[13].

Indiketiya and other researchers presented three approaches to minimize these events and one of the cost-effective geotechnical technological solutions is to enhance soil erosion resistivity surrounding the sewage pipes[10,11,20,28]. A plate of the cross-section, of a standard sewer trench for the main two bedding types, is displayed as shown in Fig (1). The soil in the embedding and filling of trenches surrounding the sewer pipe cracks are eroding and entering to the pipeline by groundwater penetration and exfiltration of the sewer as stated by[20], Which begin to create a void in the soil structure. These voids expanded throughout the rainfall cycles and continuous exfiltration. Eventually, it leads to cavity formation. After a while, the arch roof of the cavity will not be able to withstand the excessive load on it, causing soil failure and land sliding. In several studies, the association between soil properties and the risk of internal erosion that deficient sewers have been studied[8,14,24–26].

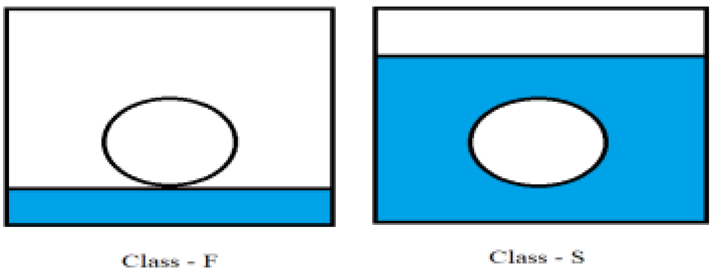

Figure (1) : Bedding main two types

For geotechnical engineering, backfill materials, and pipe embedding play a vital role in soil migration caused by pipe defects, and the precise balance of their properties will increase their internal erosion resistance. Examining the Australian sewer bedding content specifications[29] reveals explicitly a lack of knowledge regarding the value of particle size distribution for the erodibility of these products. Besides, the backfill materials play the same crucial role in identifying the total amount of soil subsidence and surface settlement[17].

Table (1): Some examples for sinkholes induced by defective sewers.

Date	Locati	Cause of tragedy	Sinkhole size	Damage	Reference
12/2016	San Antoni	Defective sewer	3.6 m deep	1 killed 2 injured	[19]
12/2016	Fraser, Michig	Broken sewer line (12′	100 m long, 33 m wide	Over US$78 million, 23	[4]
5/2016	San Francis	A broken brick sewer which was built in 1875	4 m long, 1.5 m wide, 3 m deep	–	[30]
9/2015	Fremon t.	Broken old vitrified clay	2.5 m deep, 3 m long and 2 m wide	US$30,000	[2]
9/2002	Tuscan, Arizona	Old sewer pipe 42″ in	2 sinkholes	US$7.7 million	[6]

Sato et al., and Indiketiya Performed several experimental tests on a ground model to identify the effect of water head on the time of cavity formation has findings proved that there no large impact for this factor on cavity formation speed[10,11]. Basim et al. stated that through the rainy season the water rises rapidly in the sewer pipe system, which leads to making the pipe under a fully loaded condition, thus will help to accelerate the cavity formation due to the increment of water volume quantities that seepage through the cracks in the sewer pipe and consequently, increasing the infiltration water volume combined with the eroded soil inside the pipe through defects[9,18,21–23].

Furthermore, Gholam et al. 2018 reported that the increase in water flow discharge leads to raising the rate of erosion faster. Also, his study indicated that the eroded soil reaches the eroded soil collection device quickly and continuously through the leak when the ratio of D_{70}/B is less than 0.17, where B equal to the crack width and D_{70} the size of sieve that 70% of the soil sample passing through by weight. On the other hand, his study not gate a sufficient focus on the water head influence on the amount of eroded soil and their gradation[7]. The aim of this study to evaluate the water pressure influence on total amount of eroded soil and subsidence by utilizing Particle Image Velocimetry in Matlab 2019 function. Main aim of the present study to achieves an comprehensive understanding of erosion mechanisms for various soil types, which take a limited focus by the erosion studies.

2. EXPERIMENTAL WORK.

2.1 TEST APPARATUS and MATERIALS.

The present study presents a physical ground model apparatus to identify the study aim, the experimental model contains a soil chamber with dimensions of (70X49X10)mm, as the (length X height X width). And soil collecting unit is attached to the bottom of the chamber can be shown in Plate (1). A local sandy, loamy sand, and clayey soils were brought from Kerbala Governorate. Also,(7.85, 10.79, 13.73, 16.76, and 19.61) kPa. Of water pressure was utilized, which was provided by a variable head water tank . Table (2) and Fig. (3), show the soil specification and particle size distribution according to (ASTM- D 422 Standard soil analysis test method). Furthermore, two digital single lens reflex cameras (DSLR) were placed 1500 mm approximately, away from the soil chamber. Holding the camera near to the target creates a distortion of perspective in captured pictures, as recommended by Thielicke and Stamhuis[27]. A fixed distance of 1500 mm has therefore been selected. This study was based on a Nikon D5300 DSLR camera and selected 23.6 mm x 15.6 mm, CMOS (metal-oxide-semiconductive supplementary), with 6000 x 4000-pixel image resolution (image resolution).The apparatus diagram shown in Fig (2)

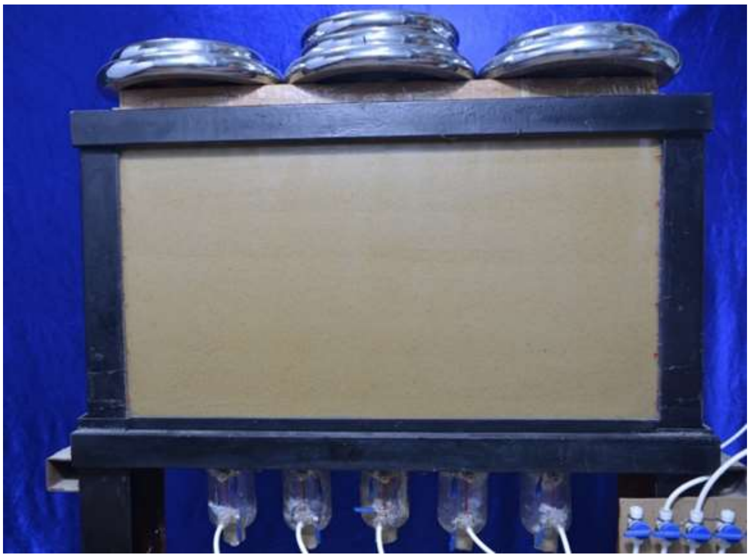

Plate (1): Testing ground model

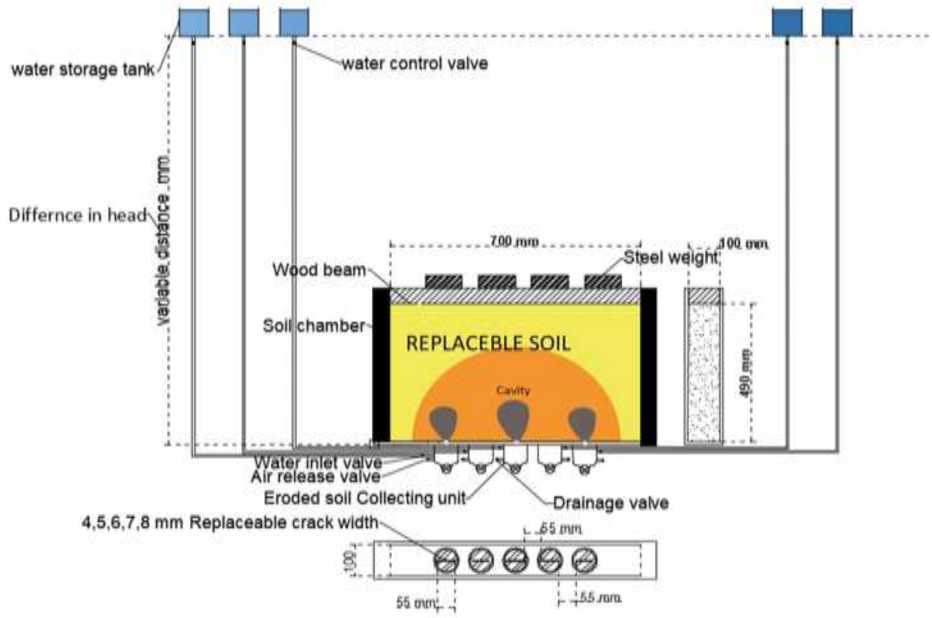

Figure (2) : Schematic diagram of the testing apparatus used in experiments.

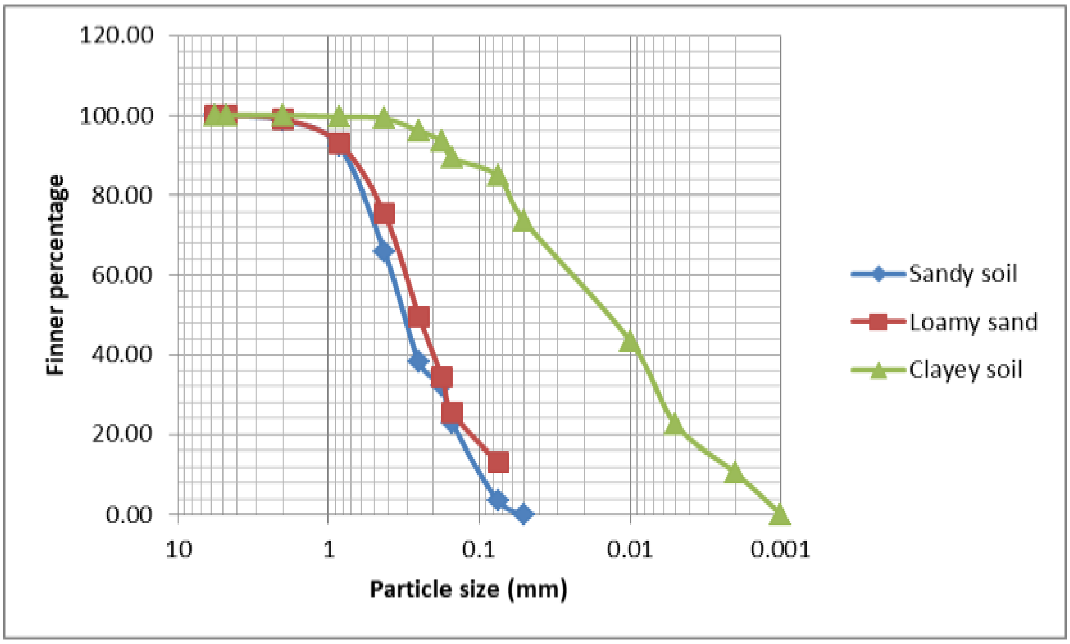

Figure (3): Used soil types according ASTM-D422 Particles Size Distribution.

Table 2: Soil specification according to ASTM D2487-11, ASTM D 2487-17, and ASTM D854-14.

Soil type	Specifications	
Local Sandy soil	Specific gravity	2.60
	Coefficient of Gradation Cc = $D_{30}^2/D_{60}.\ D_{10}$	0.88
	Coefficient of Uniformity Cu = D_{60}/D_{10}	3.18
	D_{75}	0.571 mm
	Optimum water content	8.6%
Local Loamy Sand soil	Specific gravity	2.55
	Coefficient of Gradation Cc = $D_{30}^2/D_{60}.\ D_{10}$	1.22
	Coefficient of Uniformity Cu = D_{60}/D_{10}	4.21
	D_{75}	0.425 mm
	Optimum water content	8.4%
Local Clayey soil	Specific gravity	2.45
	Coefficient of Gradation Cc = $D_{30}^2/D_{60}.\ D_{10}$	0.883
	Coefficient of Uniformity Cu = D_{60}/D_{10}	24.23
	D_{75}	0.052 mm
	Optimum water content	15%

2.2 Experiment Work procedure

The eroded soil collection units of a 6 mm crack width and 55 mm length was placed at the base of the soil chamber and fastened by screws. To keep the soil from spilling out during the soil adding and compacting process into the soil compartment, icing sugar was put in the erosion soil collection units. This substance breaks down when water streams into the soil compartment. Steel loads were set on the timber beam that was fixed on the soil upper surface to reenact 1 m of soil profundity over the sewer pipe. To decreases the implied creep impact, the model was lifted for 12-18 hours. After that, a 0.3 liter of water was applied to the soil model through the crack. Furthermore, after a 3.5 minute, the drainage plug released, and the eroded soil was collected, dried, weighed then sieved individually. An image took before and after the cycle of exfiltration/infiltration for purposes of PIVlab analysis, and every two consecutive frames analyzed separately to evaluate the soil particles' vertical displacement.

3.RESULTS AND DISCUSSION

Throughout the present study, the total eroded soil and subsidence were under continuously observing and monitoring, the results of soil subsidence of the different cycles number against the head pressure are plotted in Fig (4). Moreover, Fig (5) shows the influence on the accumulative amounts of the eroded soil due to the water pressure variation. The results suggest that the increment of water head at the manholes leads to the quickening the process of soil erosion, which could create a cavity more quickly. Fig (4) demonstrated that eroded soil total quantities increased by 1.033,1.74,2.9, and 3.95 times as compared with 0.8 m head for the increase of pressure of the water 1.1,1.4,1.7, and 2.0 m respectively. This results agree with study of [13].

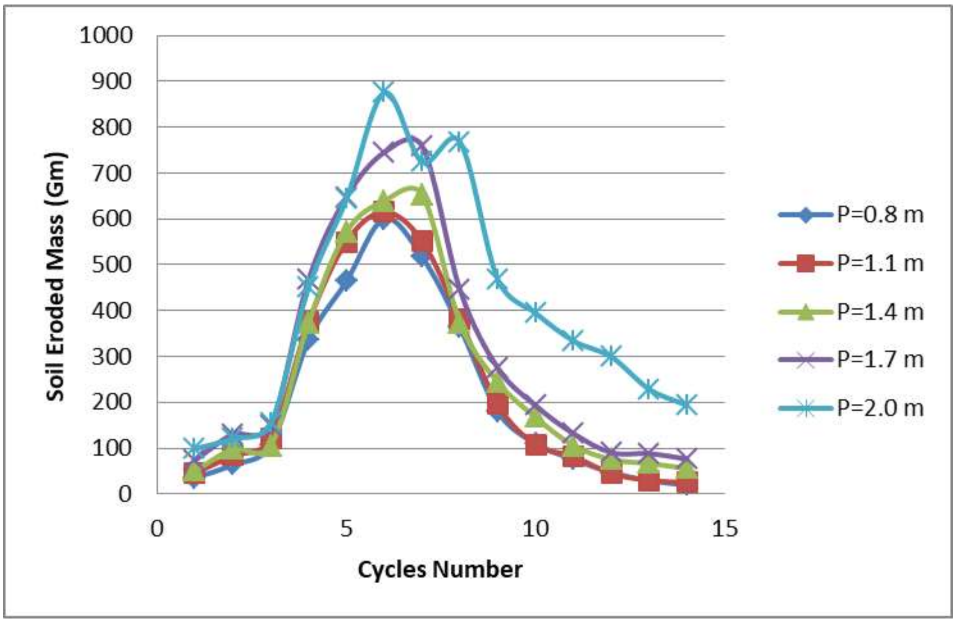

Figure (4): The soil eroded amount against cycles of the test throughout various water head.

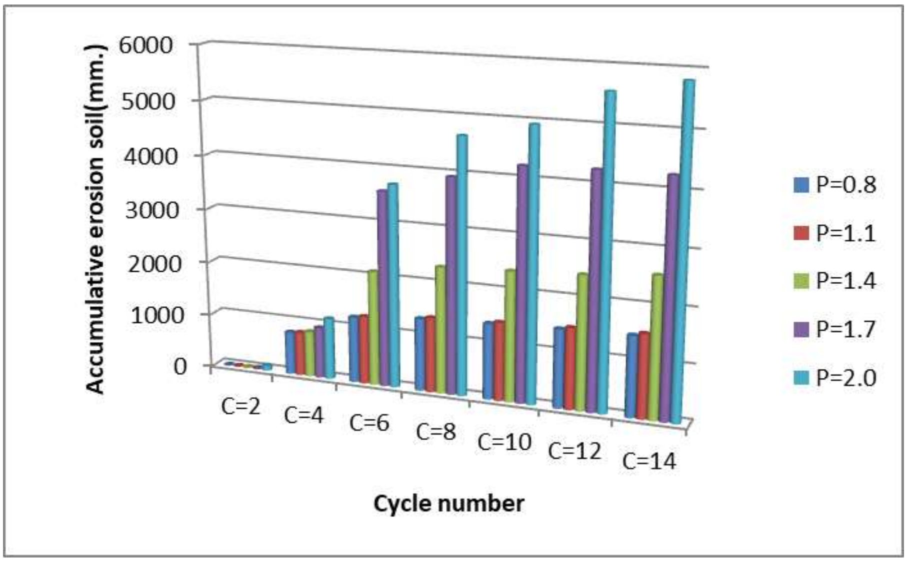

Figure (5): Accumulative erosion soil mass in different cycles of local sandy Kerbala soil.

The impact of the ratio between the soil physical proprieties(permeability and density of soil) to water pressure (ℓ. K2/P) on the overall amount of eroded sandy soil is drawn in Fig (6). It was observed that the variations in water pressure have a meaningful influence on soil erosion mechanisms, where the voids will form more quickly when the soil was in the same permeability and relative density. Also, the cumulative eroded soil content was increasingly rising while this percentage becomes equivalent to or below 0.3.This effect of hydraulic properties of soil agree with the outcomes of [15].

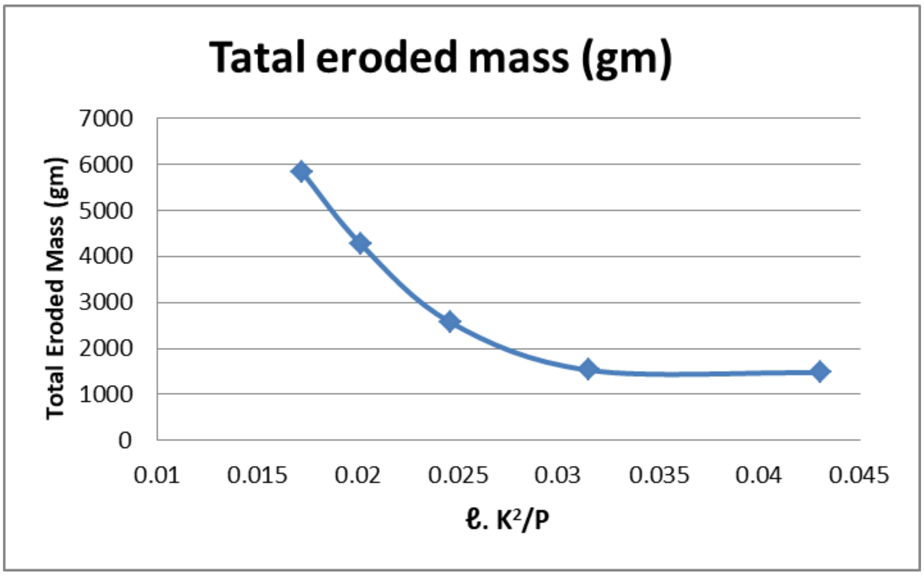

Figure (**Error! No text of specified style in document.**6) : Relationship of the total eroded mass of local sandy soil types with $(\rho . K^2 \ / \ P)$.

The relationship of soil subsidence observed and plotted in Fig (7) during the test cycles against the variations of soil types. The outcomes indicate that clayey soil takes the highest subsidence by 3.5 times higher than sandy soil, which in turn less than the loamy sand soil by 1.28 times, the reason behind that is due to the losses of shear strength and structural failure of the saturated clayey soil on the contrary of sandy soil which the subsidence was due to the expanded of the cavity formation.

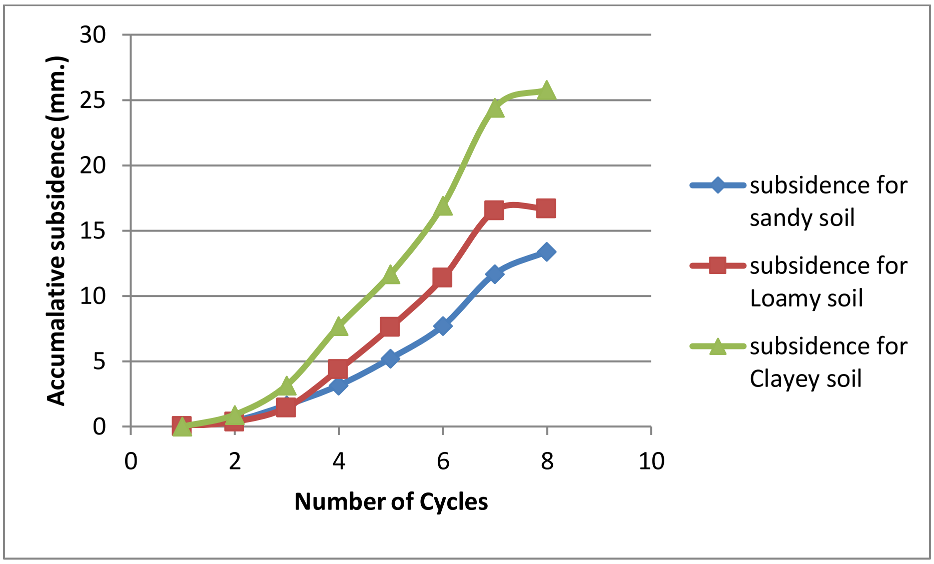

Figure (7): Total subsidence for different type of soils throughout cycles test.

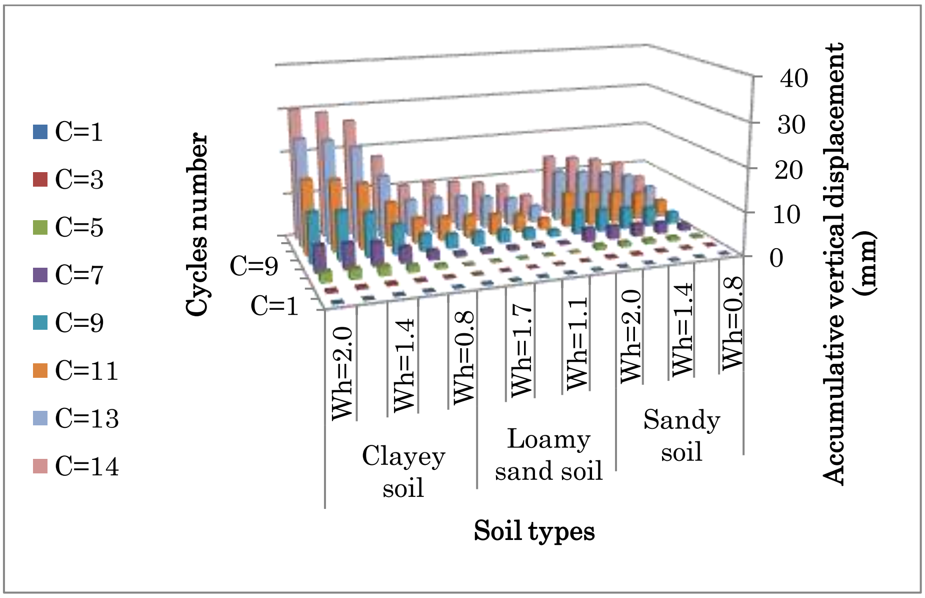

Figure (8): Accumulative soil subsidence for various head pressure of various soil types.

Although the clayey soil has the biggest subsidence among other soil types, it was observed that the clayey soil was the smallest soil affected by the variation of the water pressure. Where the outcomes reveal that the loamy sand soil increment was 4 percent, and the clayey soil increment was 3.5 percent, while the sandy soil raised by 5% when the pressure of water was increased from 1.7 to 2.0 m, as illustrated in Fig (8) which represented the amount of subsidence against various water pressure with different types of soil.

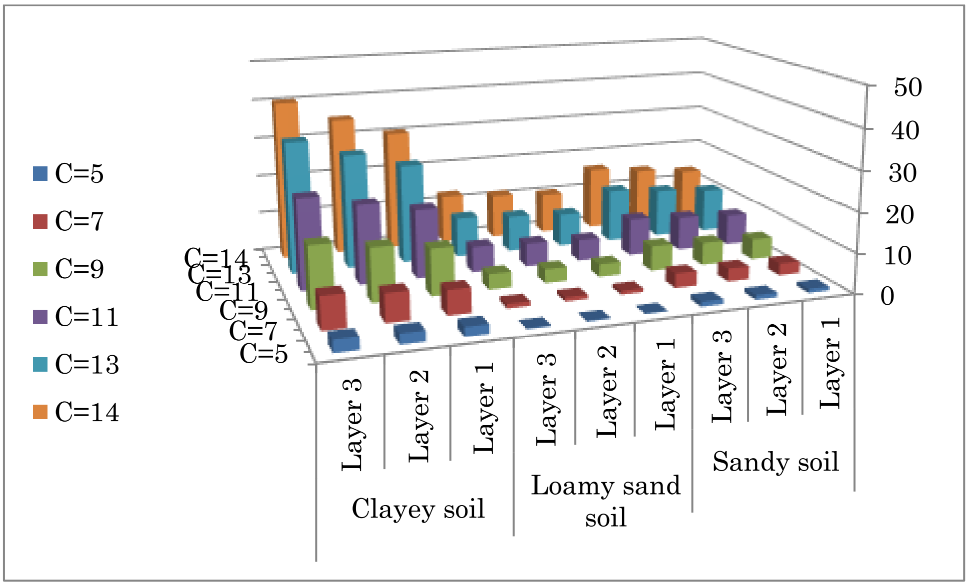

Figure 9: Different layer subsidence of various soil types.

Fig (9), shows that the highest effect of the water pressure variation acted on the deeper layer, or the nearest layer to the pipe defect, that in turn means that the smallest vertical displacement appears in the farthest soil layer, or by another word the ground surface. Furthermore, the findings revealed that the surface layer was lower than the nearest layer to the crack by 21% for sandy soil, while the clayey settlement was decreased by 32% from the first layer. The Plate (2) shows the

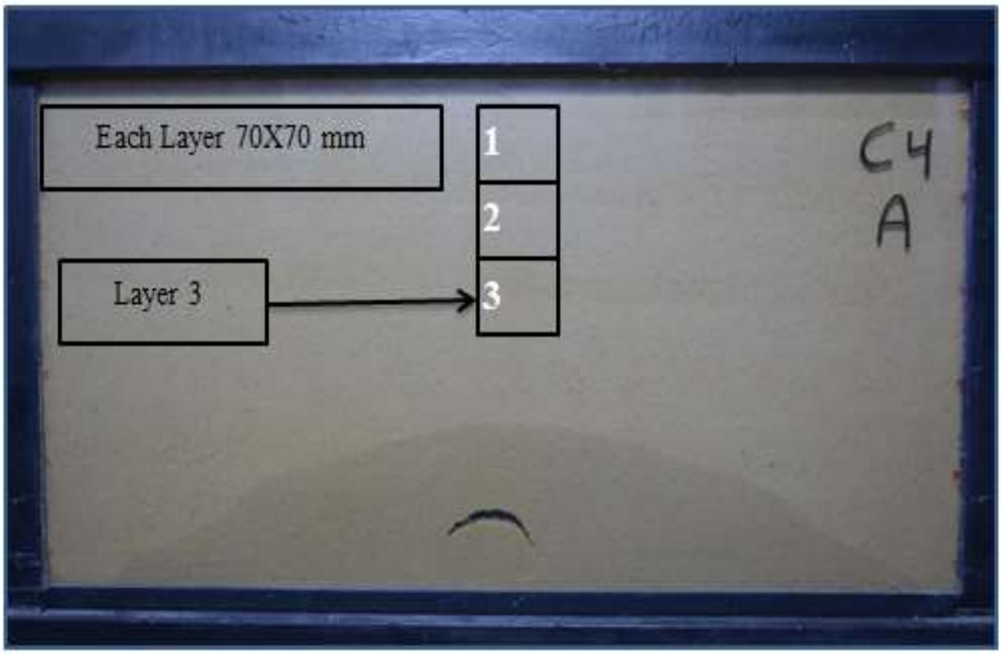

Figure (10): Total cumulated soil for different cycles recorded.

Moreover, the outcomes show that the higher accumulative eroded soil was the sandy soil with 24 times more than the clayey soil, which in turn lower the loamy soil by 14.3 times, the results were in good agreement with Karpf study [14], as demonstrated in Fig (10).

CONCLUSIONS

The following conclusions are taken from the results analysis of the present study:

- The pressure of water in the sewer pipes has significant effects on the amount of soil entered into the sewer pipe, where the total volume of collected erosion soil is directly proportional to the water head. The results revealed that the increment of the total eroded soil reached 3.95 times with a water head of 2.0 m than of 0.8 m.
- Different soil types are suffering from different types of failure, where the sandy soil fails by cavity formation and expansion and the clayey soil failure represented by high settlement(settlement for clayey soil 2.93 times more than loamy sand soil, while this soil has the smallest amount of eroded soil with 24 times lower than sandy soil).
- It was found that when the water pressure is more than one 1.1 the sandy soil will be more prone to erosion. Also, soil particles of bigger sizes have a higher portion in that cycle that was at the beginning of voids creation than that of fine particle size.

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