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Research paper

Volume change study due to moisture variation related to different sources

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Abstract

Volume change in the soil mass due to variation in moisture change may cause several problems and severe damages, especially to the lightweight structures. In this study, numerically volume change caused by variation in moisture content (heave and settlement) around a selected building would be studied using Geo-Studio software. Different types of flowing water resources that cause volume changing to the soil were used. These types are a seasonal wetting-drying effect, surface rainfall, pipe leaking, and infiltrations from the septic tank. In addition four types of soils (having different clay content) which denoted as (S1, S2, S3, S4)* were used in this research work. For speci-fied water resource, the water variation for the selected sources was simulated using SEEP/W and then using SIGMA/W to compute the heave and settlement. Several laboratory tests were conducted to obtain the soil parameters that would be used in the numerical analysis. The laboratory tests include the index, compaction, permeability (saturated/unsaturated), compressibility and soil-water characteristic curve tests. Most of the obtained properties for the soils were used in the finite element simulations. Results showed that the wetting-drying due to sea-sonal rise and existence of septic tank give a significant effect on the soil heave and settlement when compared with other studied sources. For the infiltration case, the influence zone was in the first-meter depth of the soil mass. Thickness variation (ΔH) effect extends outside the edge of the building to about 11-15 m for wetting-drying cases, while its values extend about 12.5 m for other sources. During the initial period, the settlement rate was clearly higher in soil types S4, and S3 than S2, and S1 soils.
* S1: CH soil, S4: SM Soil, S2: 80%CH & 20%SM, S3: 20%CH+80%SM.

Keywords:*Volume Change; Water Flows; Infiltration; Thickness Variation; Settlement.*

1. Introduction

Volume changes in the soil mass under variation of moisture conditions usually cause differential settlement for the building foundations, especially in the case of lightweight structures similar to individual houses of one or two levels superficially founded on strip footings. Consequently, structural damages could happen if there are no special measures taken during the design process.
The moisture in soils near the ground surface fluctuates due to variations in climate, watering of gardens and lawn, the presence of trees and shrubs, change of water table, and leakage from water drainage pipes. All these sources of moisture changes can be controlled to some extent, except climatic variations, [1]. The swelling of expansive soil influenced by environmental factors, including climate, rainfall, drainage systems, and groundwater level fluctuation.Changes in water content in clayey soil, especially expansive clay, would cause volume changes. Water content variation causes the clay to shrink and swell. In the swelling-shrinkage process of expansive clay, the swelling is more complex than shrinkage, [2].
Expansive soils are commonly unsaturated; therefore the concept of unsaturated soil mechanics may be used for predicting the behavior of expansive soils. In recent years, the mechanical behavior of unsaturated soils has become of special interest. Unsaturated soil is considered important for the analysis and design of several geotechnical projects on expansive soils such as light structures, pavements, and embankment, [1].

Various studies introduced by many researchers in this field, Satter and Fredlund (1990) investigated a numerical model of vertical ground movements in expansive soils.A numerical model was developed to relate suction changes and vertical ground movements. The model shows how increases in suction result in shrinkage and decreases in suction results in swelling, [3]. Also, Morsi (2010) studied in detail the different causes of weather variations and their effect on the volume change of expansive soils as a parametric study. The parametric analysis resulting from the program showed that the use of an analytical technique provides a good and simple tool to assess the effect of different water variations on shallow foundation heave, [1]. Yoshid et al. (1983) reported the prediction of the total heave of a slab-on-grade floor of Regina clay. He describes the analytical procedure for the prediction of total heave. It was concluded that the maximum heave took place near the center line of the floor slab, [4]., Abed (2007) estimated numerical simulation of the atrial wall of expansive soil in Sudan, Nine trial walls were built on swelling soil on Barak site in Sudan. This area is known for its highly expansive soil. The test was carried out to investigate the effect of soil replacement on vertical walls movement. The study shows that the assumed and measured soil properties were nearly the same; also the swelling index with respect to suction is the most effective parameter in the study. [5]. However, Kheirbek, et al., (2008) studied the effect of drought and rainfalls on the behavior of lightweight structures. The study presented the results of a numerical model of a structure built on strip footings founded on a sensitive soil to moisture changes. The result shows that the hydraulic boundary condition leads to differential settlement. Also, the imposed drainage condition at the surface

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reduces the permeability of the soil, and finally the water change in the soil mass was slow [6].

This study aims to investigate the variation of volume change (thickness variation (ΔH)and settlement) around a selected light-weight building caused by water flowing from different sources. These sources are seasonal wetting-drying, surface rainfall infiltrations, pipe leakage, and infiltrations from the septic tank. Two-dimensional finite element model was used to simulate the ground movement problem using Geo-Studio software. Water flowing from the selected sources was simulated using SEEP/W and then SIGMA/W to compute the volume change. Four soil samples denoted as (S1, S2, S3, and S4) were selected for this study, soil properties such as: physical and index properties, compaction characteristics, permeability (saturated/unsaturated), compressibility and soil-water characteristic curve were determined experimentally. The majority of these properties of the soils were used in the finite element simulations.

2. Material and testing methods

2.1. Testing methods

1) One-dimensional Consolidation Test: One-dimensional consolidation test was performed in accordance with ASTM D-2435 standard. The soil samples were loaded, from 6.9 up to 800 kPa.
2) Permeability Test: Permeability test was performed using the constant head test, according to the ASTM D-2434 standard. The sample in the mold was first saturated. The water flow was applied from the bottom to the top of the soil samples to avoid air entrapment. After saturation, the water was allowed to seep through the soil sample under a hydraulic gradient of 20. The water flow volume was collected for permeability calculations.
3) Evolution of Unsaturated Permeability: In unsaturated porous media, the pore space generally contains at least two fluids, gas, and liquid. The coefficient of permeability of the unsaturated soil is not constant. The suction gradient strongly influences the coefficient of permeability. The suction may be either matric or osmotic, [7]. Several models were developed and proposed based on a physical and empirical basis, over the years to predict the permeability of the unsaturated soil, (Van G, 1980) [8]. A predictive model through a mathematical relationship between saturated permeability and soil water characteristics curve could be used. The most commonly used model, which was originally developed for soils is the one proposed by, [8], as illustrated in the equations below:

$$K_r = \frac{\{1-(\alpha\psi)^{n-1}[1+(\alpha\psi)^n]^{-m}\}^2}{[1+(\alpha\psi)^n]^{m/2}} \quad (1)$$

$$K_r = \frac{K_{unsat}}{K_{sat}} \quad (2)$$

Where:

K_r is the relative coefficient of permeability

K_{sat} is the saturated permeability

K_{unsat} is the unsaturated permeability

ψ is the matric suction

N, M fitting parameters

4) Suction Measurements: In this study, three techniques for the application of the most obtainable suction range of 0 to about 300000 kPa were used. These techniques are tensiometric plates, osmotic membrane, and vapor equilibrium technique. The SWCC in suction range of 10 to 20 kPawas measured using tensiometric plates. The required suction value of the soil sample was imposed by adjusting the height of a column of water in equilibrium with a high air entry ceramic disk, [9]. The suction in the soil sample is determined directly as a function of the height of water (where 1 meter of a column of water corresponds to a suction value of 10 kPa). A time of 28 days is required for soil samples to reach equilibrium. The SWCC in suction range of 100 kPa and 1500 kPa is determined using an osmotic membrane technique. The soil samples were placed in a semi-permeable membrane, thereafter the soil sample and membrane were submerged in a polyethylene glycol solution with different concentrations to impose various values of suction (i.e., 100 to 1500 kPa), [9]. However, good contact is required between the soil sample and the membrane, and the fragility of the membrane is also a consideration in this technique. A period of 35 days is required for soil samples to reach equilibrium. The SWCC in high suction ranges is determined using the vapor equilibrium technique, [9].This technique is based on the observation that the relative humidity in the airspace above a salt solution is unique to the concentration and chemical composition of that solution. Therefore, by choosing a chemical solution with the correct target relative humidity, a soil sample placed in a closed system (desiccators) with this solution will absorb or yield water vapor to the airspace until it comes into equilibrium with that solution. Given the equilibrium relative humidity of the airspace, it is possible to calculate the total suction using Kelvin's equation:

$$\psi(kPa) = -\frac{RT}{V}\ln\left[\frac{P}{P_0}\right] \quad (3)$$

Where:

R = universal gas constant (8.31432 J/molK).

T = absolute temperature.

V = molar mass of water vapor.

P/P_0 = the relative humidity of air in equilibrium with the pore water.

P = partial pressure of water vapor.

P_0 = saturated water vapor pressure in equilibrium with pure water with a flat surface at the same temperature.

The soil samples inside the desiccator absorb or desorb the moisture until the suction equilibrium is reached which is considered to be 45 days. Finally, it is worth noting that, all previous techniques were generated under null stress and at room temperature (20^0C).

2.2. Soil properties

The soil samples used in this study were collected from two sites within Mosul city, first site from AL-Sedeeq district, which is classified as highly expansive clay soil (CH) and labeled as S1, and the second site is an area near Al-Gabat region and is classified as sandy soil (SM) and labeled as S4. Geotechnical properties of the natural soils are summarized in Table 1. To achieve the objective of the study, two other samples were prepared in the laboratory as the percentage of two main selected soils (20%CH+80%SM: labeled as S3, and 80%CH+20%SM: labeled as S2 in order to examine the volume change phenomenon.

Table 1: Some Physical and Index Properties of the Main Selected Soils

Value				Property
S1	S2	S3	S4	
80	70.7	38.2	26	Liquid limit (%)
36	33.8	26.2	23	Plastic limit (%)
44	36.9	12	3	Plasticity index (%)
26	18.1	10.4	7.8	Natural moisture content in situ (%)
2.74	2.77	2.72	2.68	Specific gravity Gs
14.6	16.3	17.7	18.5	Max. unit weight (kN/m^3)
24.2	22.1	16.6	12	Optimum moisture content (%)
3	16	50	62	Sand (%)
50	46	37	34	Silt (%)
47	38	13	4	Clay (%)
CH	CH	ML	SM	Unified Soil Classification System

Geotechnical properties of the used soils

1) Index Properties and Compaction Characteristics: Figure 1 shows the consistency properties of soil samples S1, S2, S3, and S4. There is an increase in consistency limits for S1, and S2 soils when compared with S4, and S3 soils. Figure 2 illustrates the grain size distribution of soil samples. The compaction curves obtained from the modified compaction tests of soil samples are presented in figure 3.

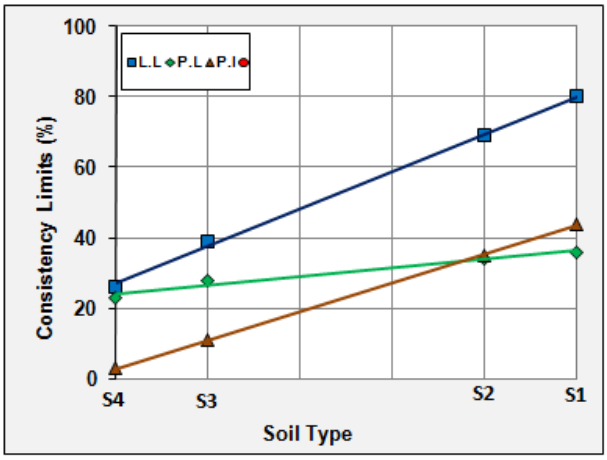


Fig. 1: Variation of Consistency Limits for Soil Samples.

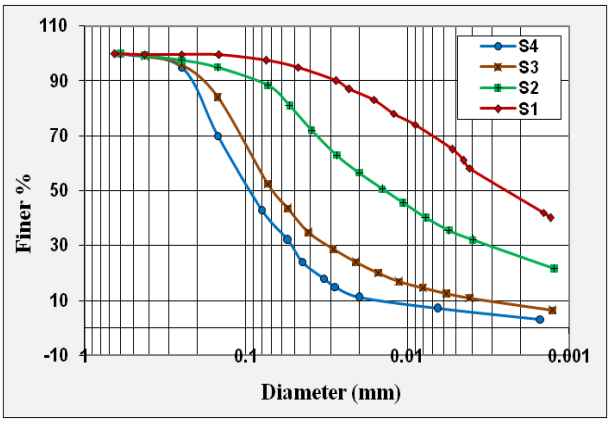


Fig. 2: Grain Size Distribution of Soil Samples.

2) Compressibility: Figure 4 shows the one-dimensional compression behavior of the soil samples, the compression curve of S4 soil sample was located below the compression curves of the other soil samples (i.e.S3, S2, and S1).

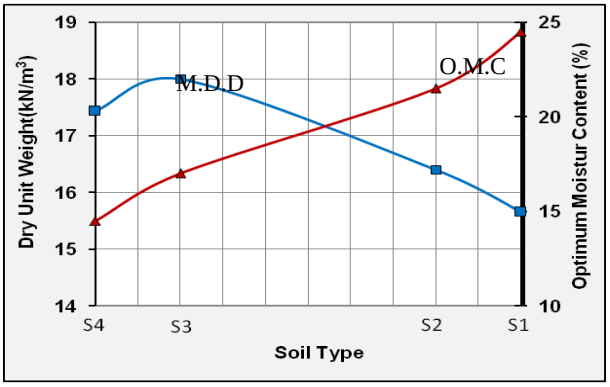


Fig. 3: Compaction Characteristics of Soil Samples.

3) Permeability: Figure 5 illustrates the variation of the coefficient of permeability (k) of the soils samples. S4 soil samples are much more permeable ($7.1x10^{-5}$ cm/Sec) when compared with S1 soil samples($0.13x10^{-5}$ cm/Sec). The unsaturated permeability obtained from this model versus the suction pressure for soil samples are shown in figure 6 predicted from equations 1& 2.

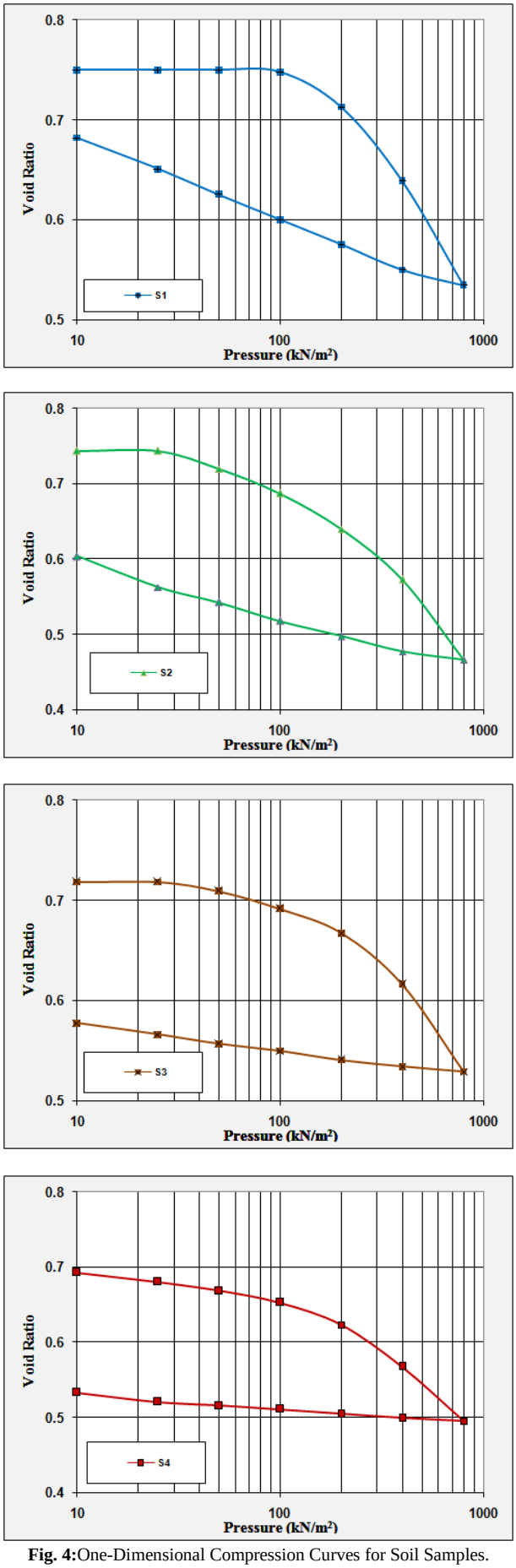


Fig. 4: One-Dimensional Compression Curves for Soil Samples.

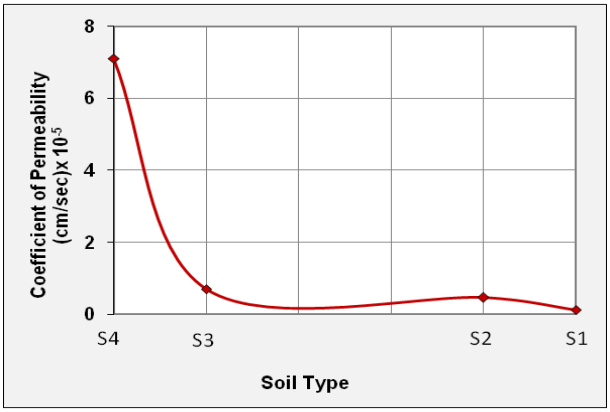


Fig. 5: Variation of Coefficient of Permeability for Soil Samples.

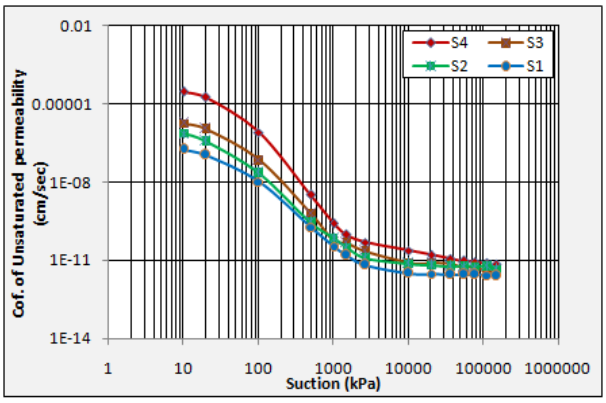


Fig. 6: Unsaturated Permeability of Soil Samples.

4) Evolution of Soil-Water Characteristics Curve: The measured soil-water characteristic curve data were fitted to Fredlund and Xing's model defined by equation 1. Figure 7 shows the fitted curves of the soil samples. Table 2presents the Fredlund and Xing's equation parameters (a, n and m).

Table 2:SWCC Parameters and Statistical Indices of Soil Samples

Equation Parameters			Soil Type
M	n	a	
0.78	4.30	791	S4
0.61	4.40	783	S3
0.51	3.90	716	S2
0.47	3.40	616	S1

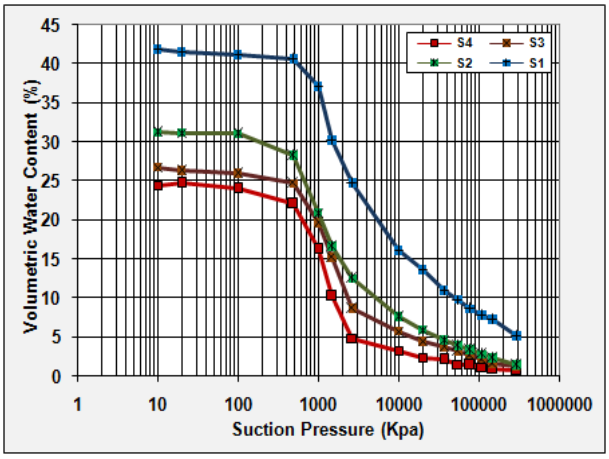


Fig. 7: Soil-Water Characteristics Curve for Soil Samples.

2.3. Description of the structure

The studied case was two story individual structures in of 8 ×9 m laid on strip footing of 1.0 m width. Many types of such building exist locally in the studied area. The height of the columns was 3.5 m, with a beam dimension of 0.4 × 0.6 m, and column dimensions of 0.4×0.4 m, while the slab thickness was 0.2 m. The total dead and live loads were7.5 kN/m2, and 5.0 kN/m2 respectively obtained according to (ACI) code. Load transmitted from the building foundation to the soil was calculated using the STAAD PRO program.

Finite elements mesh using quadrilateral element 0.4×0.4 m dimensions. The geometry of the soil mass employed in this study extends as 25 m distance and 13 m depth. This dimension was taken depending on the results obtained from the Slip program; this program was developed using the Visual Basic language. The pipeline was assumed to be located at 1 m below ground surface in 2.5" diameter, the location of the pipe would be changed every 2 m as a horizontal distance. Septic tank is situated at 4 m distance from the side of the building in dimensions of 4m×4m as width and depth.

Figure 8 shows soil mass extension, locations of sections taking for thickness variation (ΔH) and settlement study, as well as the location of the representation rainfall infiltrations, leaking pipe, and septic tank.

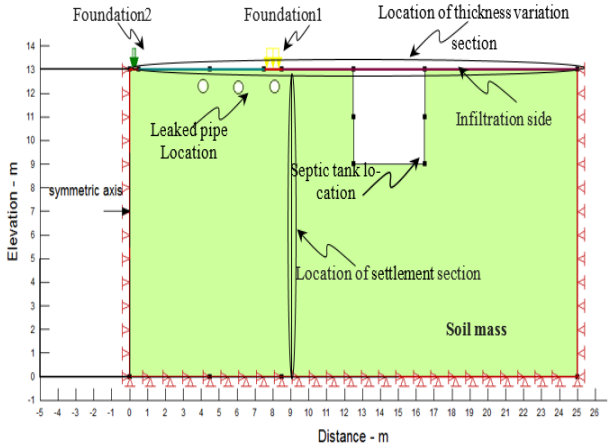


Fig. 8: Soil Mass Extends with Locations of Flowing Sources and Taking Sections.

2.4. Numerical models and boundary conditions

A numerical model was performed using finite element package SEEP/W and SIGMA/W to determine the surface thickness variation and settlement. SEEP/W was used to model the water movement and pore water pressure, while SIGMA/W was used to model volume change. The calculation involves saturated/unsaturated flow as well as deformation (thickness variation and settlement) analysis. The saturated/unsaturated groundwater flow analysis was first done using SEEP/W while SIGMA/W was used for the deformation calculation. Soil parameters that would be used in the numerical analysis belonging to soil samples obtained from laboratory test consisted; Hydraulic conductivity as described in figures 5 and 6, and soil water characteristic curves (SWCC) which are illustrated in figure 7.

The boundary conditions used in SIGMA/W were assumed to be fixed in both vertical and horizontal directions at the base of the soil mass while it was assumed to be fixed in horizontal direction and free in a vertical direction at the left and right sides of the soil mass. On the other hand, the boundary conditions used in SEEP/W were taken as a hydraulic boundary condition to simulate the wetting-drying conditions which were done as head values to represent the change of surface suction at the top of the soil surface. Also, the infiltration alongside the building was specified as a flux boundary equal to (0.001015 m/days), [10]. While the effect of a septic tank and pipe leakage was modeled as zero pressure head.

3. Results and discussion

Figure 9 summarizes the result of the effect of wetting-drying on the soil thickness variation the effect of wetting-drying was along the surface of the soil mass starting from the center of the building to the end of the soil mass. In general, it can be noted that there is an increase in the thickness variation values out of building edge, with a higher value for S1 soils. The maximum predicted the thickness variation at the end time of wetting was 144.3, 65.6, 43.4, and 39.3 mm for S1, S2, S3, and S4 respectively. While for the drying case, the thickness variation values were 128.2, 94.3, 52.9 and 33.9 mm for S1, S2, S3, and S4 respectively.
Also, it is observed that the differential movements caused in S1, S2, S3, S4 soils were 134, 62, 40.2, and 39.1 mm respectively in the wetting case and 126.4, 93.2, 52.3, 33.6 mm for S1, S2, S3, S4 soils respectively in drying case.

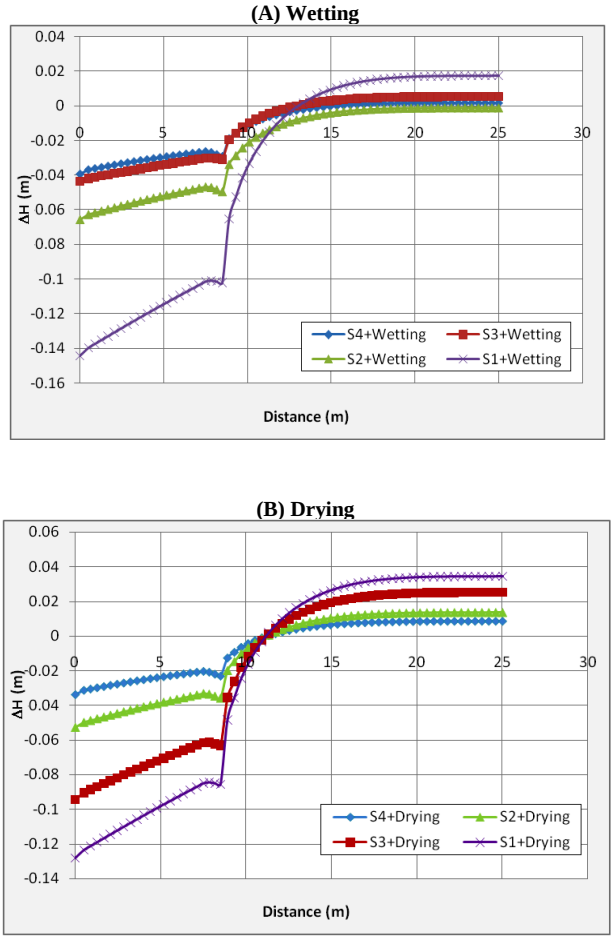


Fig. 9: Ground Thickness Variation for the Wetting-Drying Cases.

It can be seen that the thickness variation effect extends outside the edge of the building about 15 m for the wetting case and 11 m for drying case, but In addition, it does not appear clearly under building foundation. This behavior could be due to the presence of building load which overcomes the soil heave.
The results of the effect of wetting-drying on the settlement at the edge of the building were investigated for the selected soil types presented in figure 10. It can be observed from the figure that the wetting condition gives settlement value of 102.2 mm for S1 soil in the wetting case while the value was of 85.6 mm for drying case. In the case of S4 soil, the values were 29.2 and 23.2 mm for drying case. The settlement variation was clearly shown by soil type change from S1 to S4 especially for the wetting case.

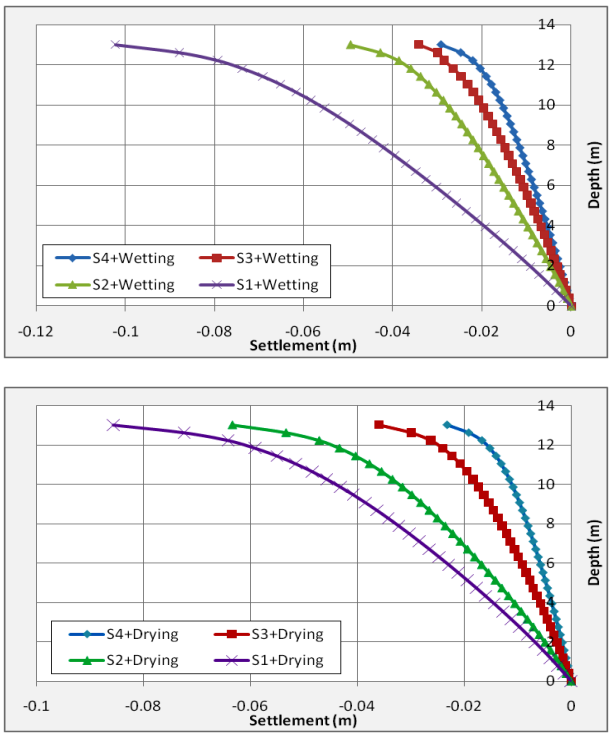


Fig. 10: Settlement of Soils with Depth of Wetting and Drying Cases.

Infiltration of water through the soil mass due to rainfall causes a change in soil thickness. The effect of infiltration onthe selected soil mass in cases of the natural andbuilding loaded is shown in figure 11, This figure shows that the variation of ground thickness appears along the surface starting from the corner of the building with greater values for S1, thus the increase may be attributed to the higher clay content in S1 soil than the other selected soil types. The differential movements corresponding to the building load were 114, 69.8, 26.9 and 15.8 mm for soils S1, S2, S3, and S4 respectively compared with the case of the natural soil was 13.4, 9.7, 8.7 and 6.2 mm for the soil S1, S2, S3 and S4 respectively. These movements extend to about 13 m outside the building edge.

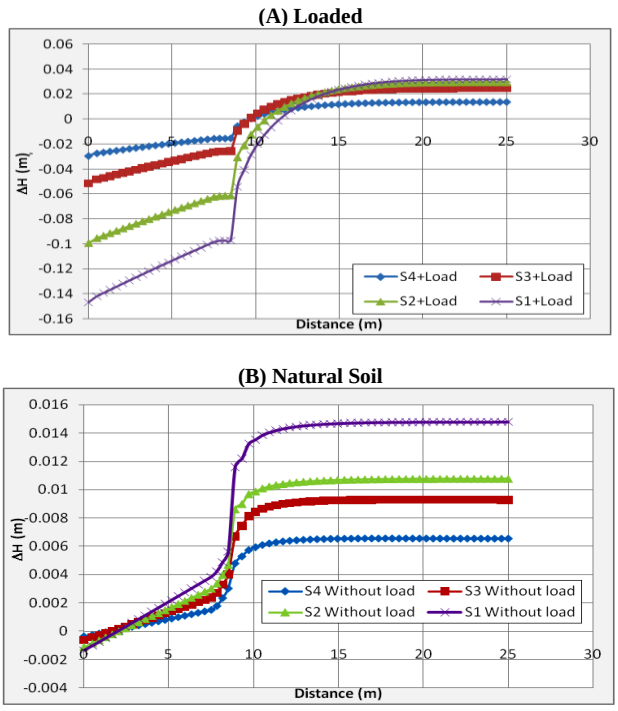


Fig. 11: Ground Thickness Variations for Infiltration Cases

Figure 12 presented the settlement due to water infiltration in cases of the natural and building loaded, for the selected soil types at

the end time of the study. In general, the settlement results at the edge of the building indicated that the presence of the load decreases the value of soil thickness variation. On the other hand, the maximum predicted settlement values under the edge of the building were 97.1, 61.1, 25.6 and 15.2 mm for soils types S1, S2, S3, and S4 respectively. Further, there were no records of settlement values in the soil mass in the case of the natural soil. While the thickness variation values were shown in natural soils case within the first-meter depth for all selected soil types (moisture change zone in soil).

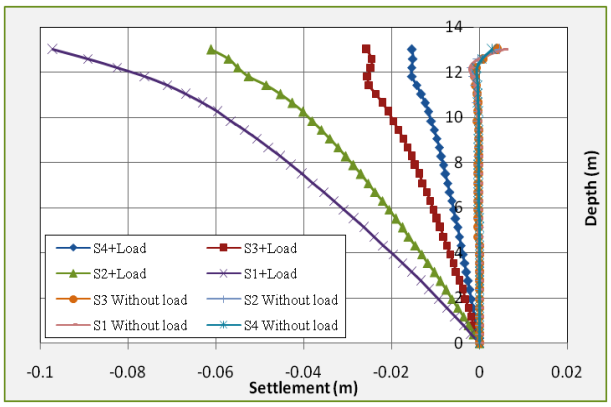
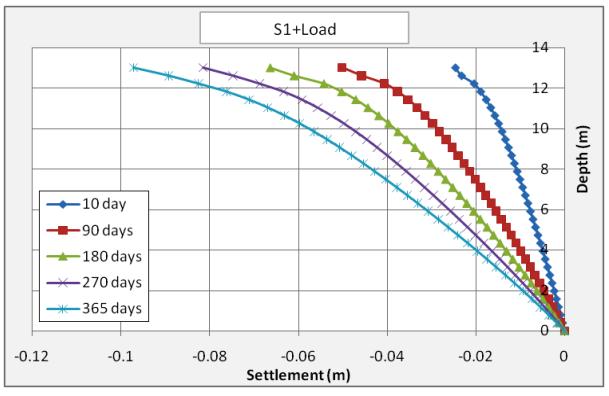
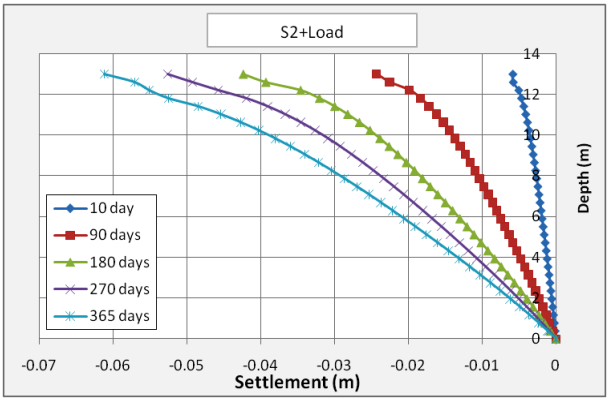
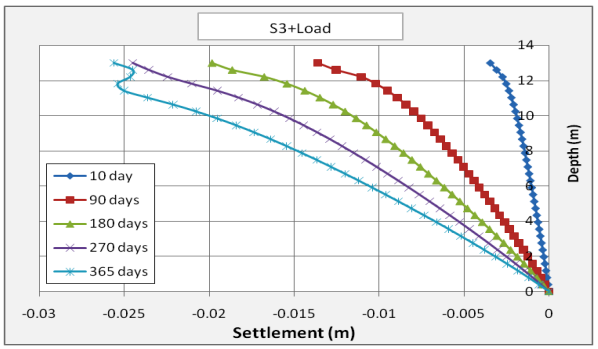


Fig. 12: Settlement of Soils with Depth for Infiltration Cases.

Figure 13 presented the settlement with time for the selected soil types in infiltration case. It is evident that the water infiltration had a significant effect on the settlement for selected soil types and the most settlement has taken place at the end of the selected period. The maximum recorded settlement under the edge point of the building foundation at the end of selected time was: 97.1 mm forS1 soil, 61.1 mm for S2 soil, 25.6 mm for S3 soil, and 15.2 mm for S4 soil. Also, figure show settlement rate for S4 large than S1 soils was noticed this may due to permeability values variations for the selected soil types.







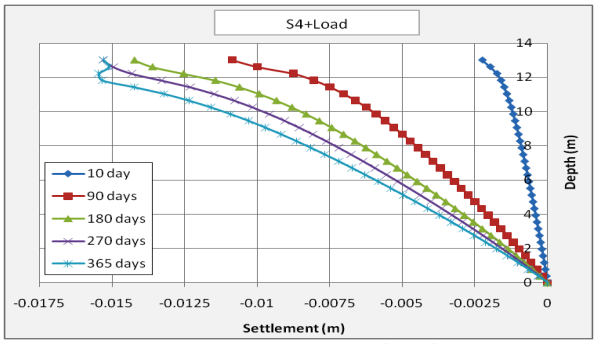


Fig. 13: Settlement Variation with Time for Infiltration Cases.

Figure 14 illustrates ground surface thickness variation in the case of the septic tank. It can be observed in case of existing building load that the thickness variation appears with small values in S1 and S2 soils and does not clearly observed in S3 and S4 soils. The effects of the presence of this tank extend about 12.5 m outside the edge of the building. The differential movement were 137.4, 101.8, 45.2 and 32.3 mm for S1, S2, S3, S4 soil in case of the existence of building load while the differential movement appears in very small values 18.5, 7.8, 2.3 and 1.9 mm for S1, S2, S3 and S4 soils in case of the natural soil.

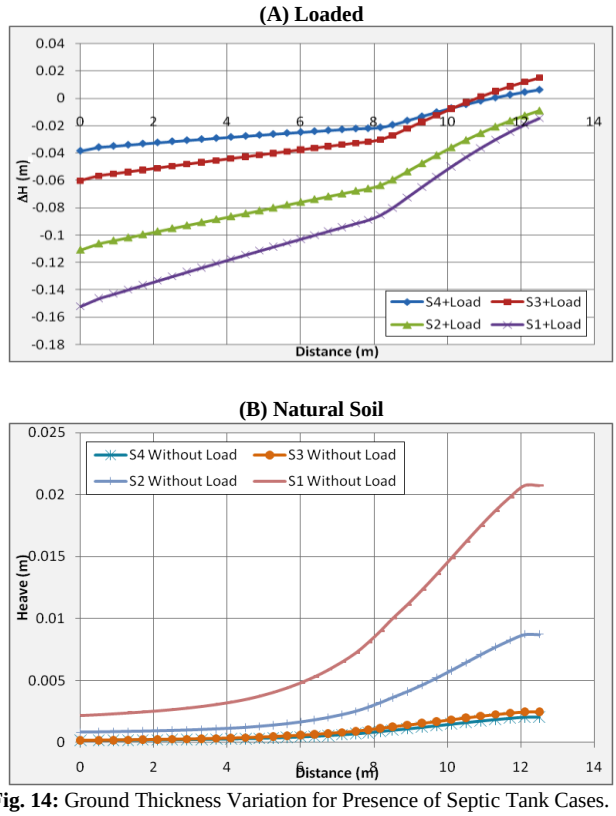


Fig. 14: Ground Thickness Variation for Presence of Septic Tank Cases.

Figure 15 presents the effect of infiltration from the septic tank on the settlement for the selected soil types. The settlement under a

foundation of the building gives a value of 80.2, 59.5, 27 and 19.4 mm for soils types S1, S2, S3, and S4 respectively. Further a very small of the thickness variation values in soil masses in case of the natural soil was observed.

Figure 16 shows the settlement variation with time in the case of the infiltration from the septic tank. The maximum values of settlement at the end of the studied period time were 80.2, 59.4, 27 and 19.4 mm for soils types of S1, S2, S3, and S4 respectively. The settlement occurs in a higher rate during the initial period of time for soils types S4, S3 than for soils S2, S1, this may be due to the difference of permeability values.

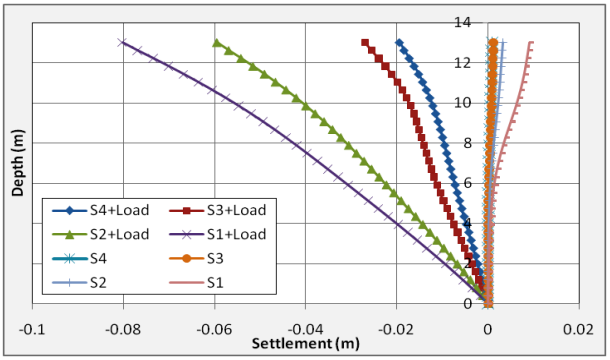
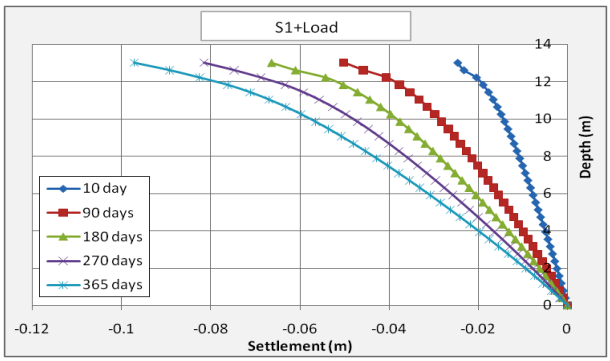
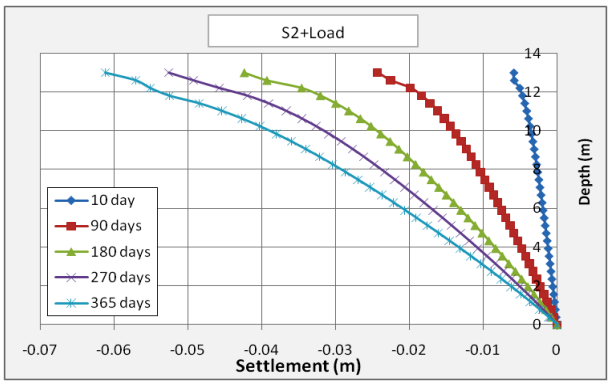
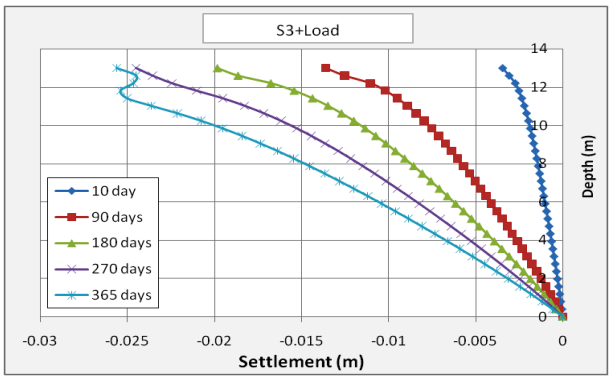


Fig. 15: Settlement of Soils with Depth ofPresence of Septic Tank Cases.







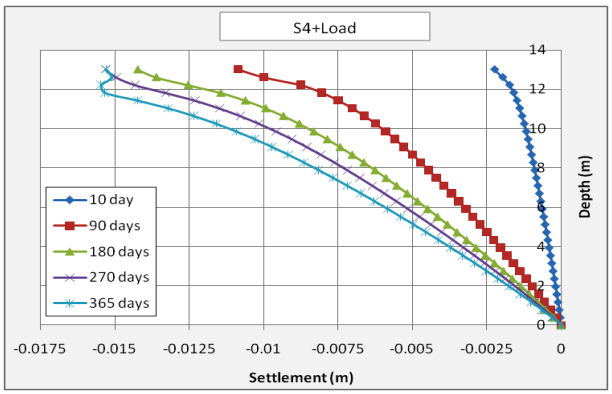
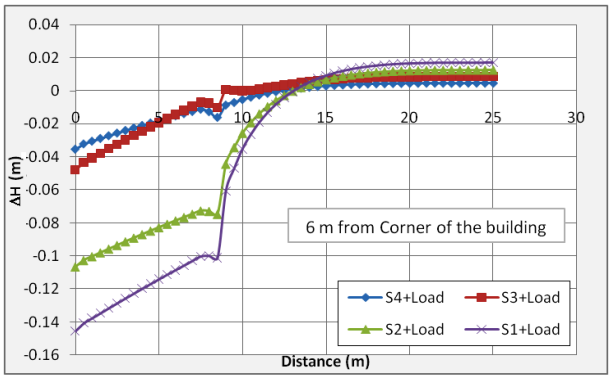
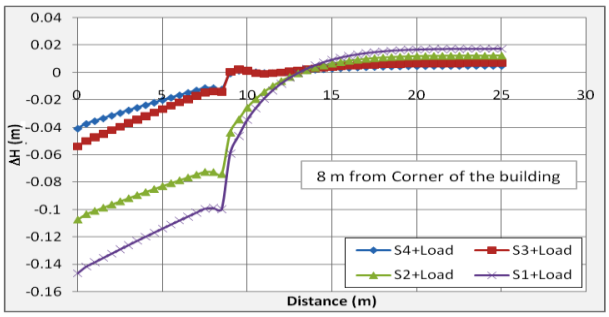
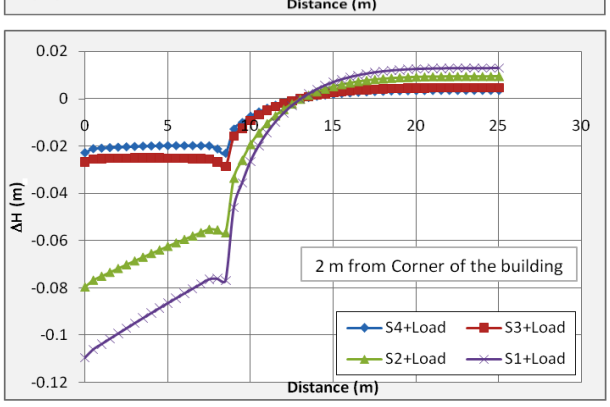


Fig. 16: Settlement Variation with Time for Presence of Septic Tank Cases.

Figure 17 illustrates the effect of pipe leakage on the soil thickness variation with different distances of leaking pipe from the footing edge. According to the results, the leaked pipe distance has an insignificant effect on the thickness variation for S3 and S4 soils but slightly affects in the S1 and S2 soils. The differential movement at 8 m pipe leakage distance was 128.7, 94.5, 47 and 35.8 mm, at 6 m was 127.8, 93.5, 39.2 and 30.3 mm, at 4 m was 127, 93.4, 21.8 and 17.5 mm, at 2 m was 98.7, 77.4, 24.2 and 19.6 mm at 2 m, and at 0 m was 96, 70.6, 22.2, and 19.1 mm at for soils type S1, S2, S3 and S4. It can be seen that the thickness variation effect extends outside of the building edge to about 12.5-13.5 m at all pipe leakage distance for all soils types.







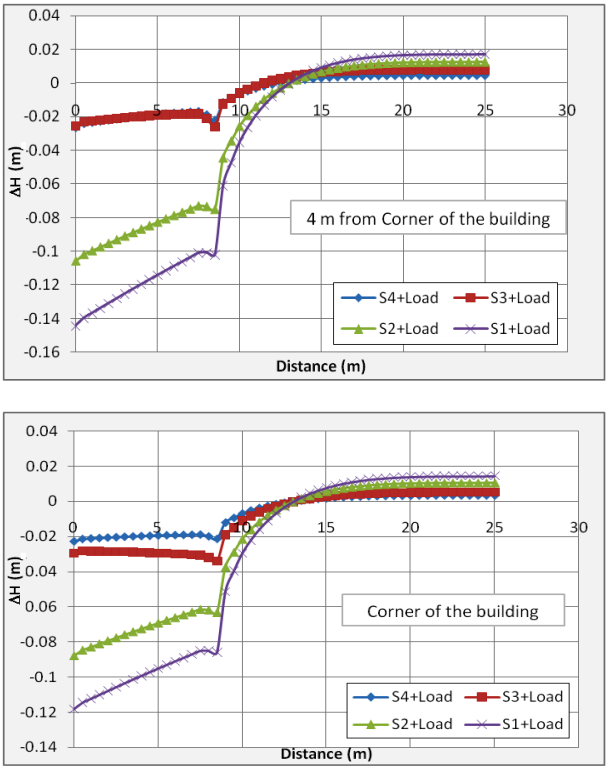
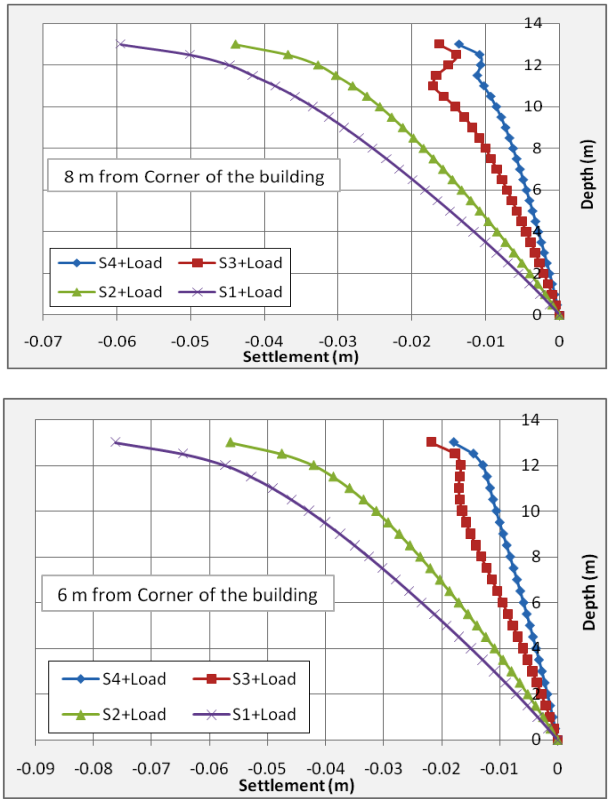


Fig. 17: Ground Thickness Variation with Different Distance of Leaking Pipe Cases.

Figure 18 illustrates the variations of footing settlement due to pipe leakage below the building foundation with different distance from building corner for S1, S2, S3, and S4 soils; respectively. From the figure, the maximum settlement observed when the pipe site is located at 4 m from building the center, the minimum settlement observed when the pipe site is located at 8 m, while the settlement values were in close values for 0, 2, 6 m pipe distance from building corners. Further, the effect appears clearly at distance 0 and 2 m from the foundation center for all soils types. While at 4 to 8m, the effect was clearly visible for soils types S1 and S2.



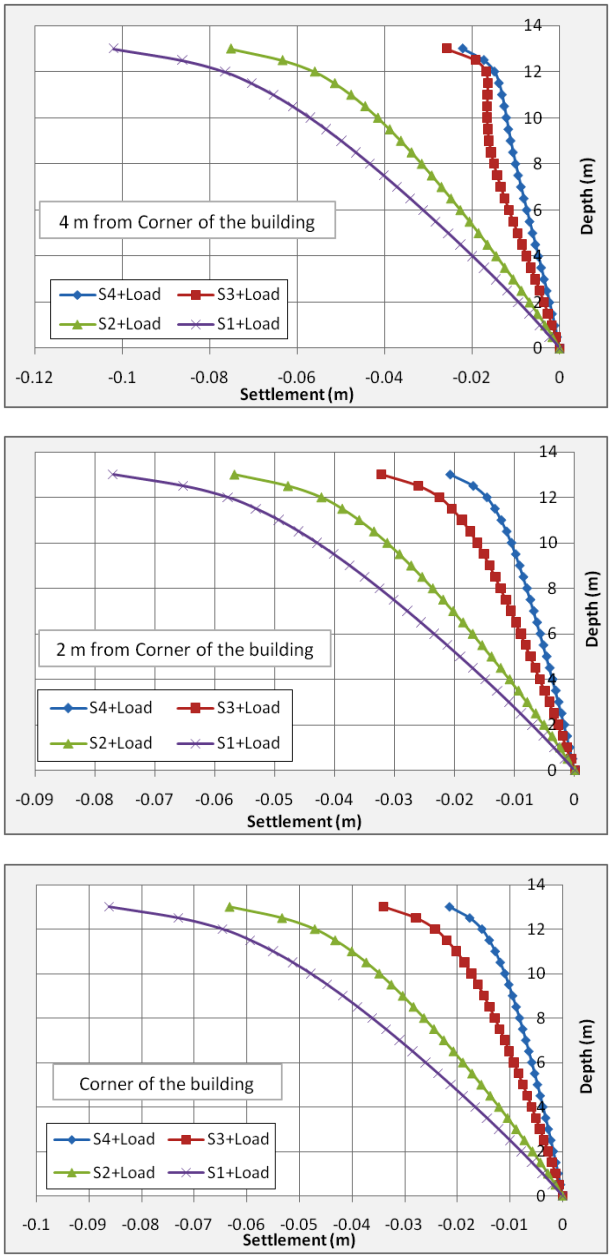


Fig. 18: Settlement of Soils with Depth with Different Distance of Leaking Pipe Cases.

4. Conclusion

On the basis of the numerical analysis of the modeling of the volume change behavior for the selected soil types as a result of variable water flowing source it can be concluded:

1) Wetting- drying and presence of septic tank cases have a significant effect on the thickness variation and settlement compared with the other selected sources.
2) For the infiltration case, the zone of affected soil was located at the first-meter depth in the soil mass.
3) Thickness variation effect extends outside the building edge for wetting-drying cases compared to the other sources.
4) Thickness variation and soil settlement were strongly influenced by soil water content changes due to water flowing from different sources. Also, soil properties variation has a significant effect on the volume change behaviors.
5) The numerically model showed an acceptable impression on how the thickness variation and settlement varied through soil mass.

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