Laboratory investigation of geosynthetics reinforcement for the prevention of sinkhole formation induced collapse

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ABSTRACT: The concern study presents the results of laboratory investigation on geosynthetic reinforcement to prevent the sinkhole formation induced collapse because of water pipeline leakage. The aim of present study is to investigate the appropriateness of the combination of geogrid reinforcement parameters to reduce the failure mechanism because of sinkhole formation. To achieve the objectives of present study a series of reduced scale model tests were carried out with emphasis on the effects of geosynthetics reinforcement parameters such as density (number) and spacing between the geogrid layers to evaluate the behavior of ground over the sinkhole. The results of present study indicate that the use of geosynthetic reinforcement in an effective way can significantly reduce not only the collapse of ground but also ground surface settlement and earth pressure over the sinkhole.

Keywords: Geosynthetics, Sinkhole, Reduced-scale model test, Ground deformation, Earth pressure

1 INTRODUCTION

These days all over the world everyday there are many collapse occur because of sinkhole formation and which are affected not only that concern area but also surrounding structures. A sinkhole is basically a hole generated into the ground by erosion and drainage of water. Mainly sinkhole formation occurs because of water leakage from water supply line. So, it is necessary to study about formation of sinkhole and how to minimize the collapse because of sinkhole formation

The polymeric reinforcement such as geogrid use in the field of geotechnical engineering has been increased excessively. A geosynthetic covering over the sinkhole is cheaper as compared to other methods. It had been studied by many other researchers to demonstrate the benefits of reinforcement on bearing capacity, surface settlement and the pressure distribution. Yoo. (2001) elaborated that by using geogrid as reinforcement significantly improve the load bearing capacity of foundation. Hegde et al. (2014) demonstrated that the use of geogrid reinforcement over the buried pipe notably reduced the pressure, settlement and the deformation of buried utilities as compared to unreinforced bed. Moghaddas Tafreshi et al. (2011) suggested that shallow strip footing on the geogrid-reinforced bed above a void significantly improved the bearing pressure and surface settlement. Many analytical methods for design of geogrid reinforcement model ground system were investigated remarkably for voids, sinkholes and buried utilities as reported by Tafreshi et al. (2008), Wang et al. (2009), and Giroud et al. (1990).

In the present study, A series of model test box experiments, for effectively use of reinforcement over the sinkhole to prevent the total collapse on the sinkhole and to reduce the surface settlement and model ground deformation along the sinkhole formation. The parametric study was done to minimize the chances of sinkhole formation due to leakage of water from water supply line.

2 LABORATORY MODEL TEST

The reduced model test to investigate the effect of reinforcement consisted of following main parts; the model test box, pressure system, and data acquisition system.

2.1 *Experimental setup*

2.1.1 *Test configurations*

A series of laboratory model test box experiments were performed in a test box made of a steel frame. The inside dimensions of test box are 1.8 x 0.35m in plan x 1.2m height. The four side walls of test box were made of transparent Plexiglas plate to easily observe the collapse occur on sinkhole and movement of soil particles along the failure surface. The schematic view of test setup shown in Figure 1. and general arrangements of test box shown in Figure 2.

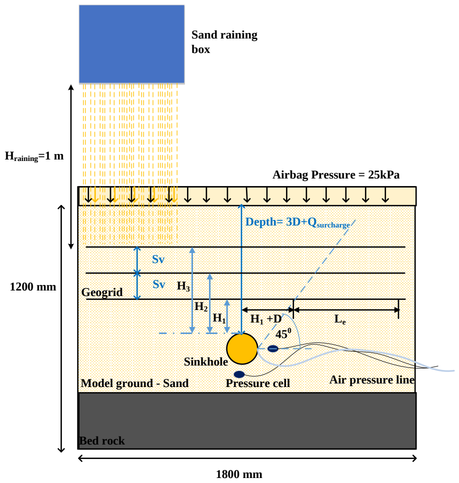


Figure 1. Schematic view of test box

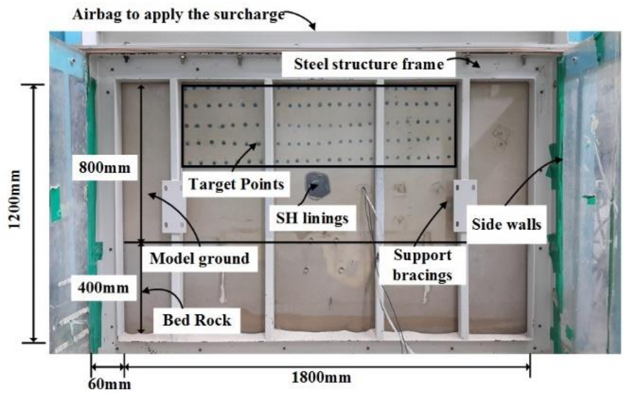


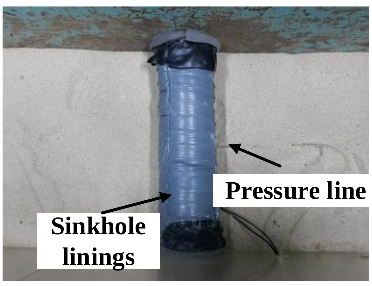
Figure 2. General arrangements of test setup

2.1.2 *Model ground preparation*

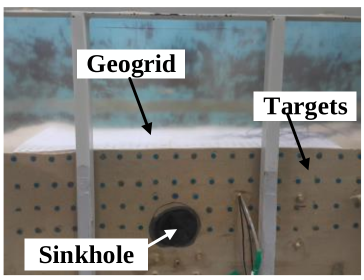
Model ground was prepared using fine sand by raining technique with specified hopper system as shown in Figure 1. Before start of real test, a series of trail test were performed to investigate the specific height of raining to obtain the desired relative density. In each trail test, a small aluminum cup with known volume were placed at different location of test box to calculate the relative density. The raining technique used in this study provided the model ground density of approximately 65% with unit weight of 17kN/m^3. To obtain the consistent sand density of model ground the discharge rate and discharge height were carefully controlled during raining of sand for preparation of model ground.

Before preparation of model ground the sides of test box were washed with WD-40 spray to reduce the side friction. At the bottom of test box, the bricks were placed up to 400mm. After that started to prepare model ground by fine sand up to 200mm and placed the sinkhole at the center of test box with depth of 3D_{SH} with 20kPa pressure inside the sinkhole to bear the weight of soil on the top of sinkhole lining. The sinkhole was made airtight by using hard membrane on the both side of sinkhole opening as shown in Figure 3(a).

To reinforcing the model ground the artificial made geotextile were placed over the sinkhole according to testing program. The geotextile paper was cut in laboratory to make the geogrid with aperture size 10mm x 10mm. The geogrid reinforcement placed into the model ground as shown in Figure 3(b). A number evenly spaced targets with 50mm spacing in horizontal direction and 60mm spacing in vertical direction were placed on the front face of test box to calculate the vertical deformation over the sinkhole as shown in Figure 2.



(a) Sinkhole linings



(b) Geosynthetic reinforcement

Figure 3. Model ground preparation

2.1.3 *Instrumentation program*

All experiment cases were performed in laboratory by adopting following instrumentation program as described in this section. For strain measurement of geogrid, a mold type strain gauges were used at a constant spacing of 0, 50, 100 and 150mm from the center of the sinkhole. Surface settlement of model ground was measured by placing the target point on the surface of the model ground.

Model ground deformation over the sinkhole was analyzed by using GeoPIV by plotting vector plots and further the deformation of model ground was demonstrated by contour plots with a surfer. GeoPIV is a software to measure the soil deformation in geotechnical models using PIV (particle image velocimetry) techniques reported by White et al. (2003).

25kPa surcharge pressure on the model ground was applied by connecting the fully airtight airbag on the top surface of model test box. 150mm diameter sinkhole with inside sinkhole pressure was kept constant up to 20kPa controlled by pressure controller and verified by a pressure sensor connected to the data logger and pressure controller for all test cases. The detail instrumentation program used in this study shown in Figure 4.

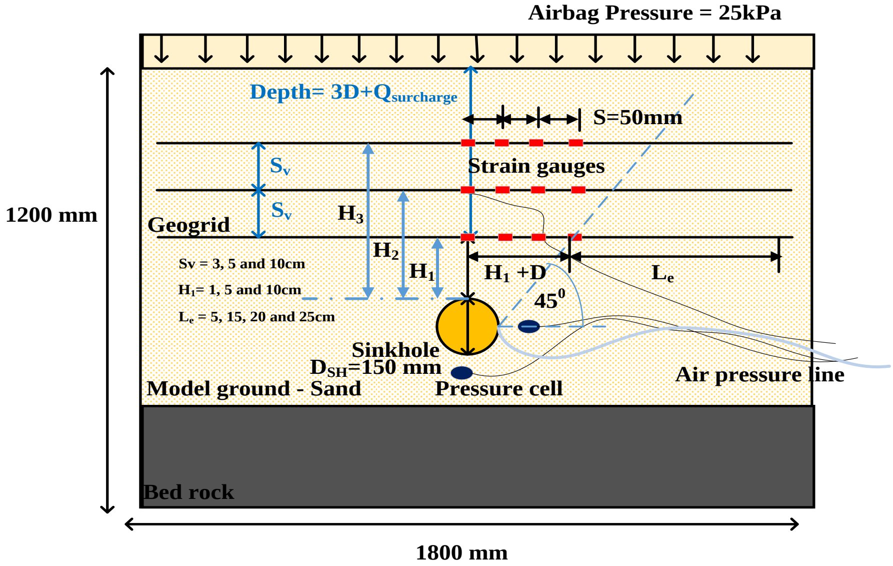
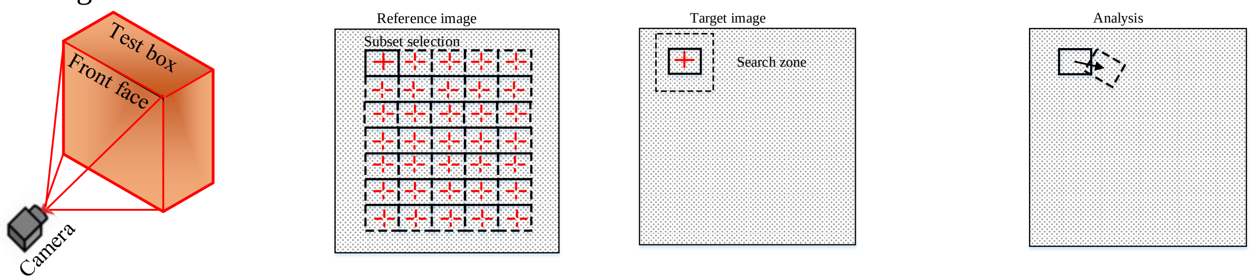


Figure 4. Instrumentation program for model test

2.1.4 *PIV analysis to investigate the deformation field*

GeoPIV is the MATLAB module to measure the soil deformation in geotechnical models using particle image velocimetry (PIV) technique developed by White et al. (2001a) based on images captured during the experiment. There are different techniques to analyze the images in GeoPIV like, meshing and by placing the targets along the failure etc. In present paper, a number evenly spaced targets were placed on the front face of test box over the sinkhole as shown in Figure 2. The conceptual drawings to analyze the images for ground deformation using PIV shown in Figure 5. Once the PIV MATLAB analysis finished, extract the data and by using commercial surfer program drawn the contours and vector plot for better understanding of deformation field over the sinkhole.



(a) Image captured (b) Reference image (c) Target image (d) Deformation

Figure 5. Conceptual drawing for step by step analysis of image with PIV

2.2 *Parametric study*

To investigate the effect of geogrid reinforcement to prevent the total collapse on sinkhole, experiment was performed with without reinforcement, by considering the embedment length L_e = 50, 150, 200 and

250mm and vertical spacing S_v = 30, 50 and 100mm. All the test cases were performed at a constant sinkhole depth of 450mm with a surcharge pressure of 25kPa. The purpose of all laboratory test is to investigate the proper arrangement of reinforcement parameters to reduce the total collapse occur over the water supply line because of sinkhole formation at the place of water leakage

2.3 *Material used*

2.3.1 *Model ground*

Dry sand with an effective particle size (D_{10}) 0.44mm, the coefficient of uniformity (C_u) 1.41 and the coefficient of curvature (C_c) 0.92 was used for model ground setting. All these properties were obtained by performing geotechnical property test. The relative density of sand was 65% with a unit weight of 17kN/m^3. From the results of large scale direct shear tests, the internal friction angle ϕ = 38^o was obtained with a zero-cohesion intercept.

2.3.2 *Reinforcement and sinkhole*

The geosynthetics reinforcement was used in this study to demonstrate the effect of reinforcement for prevention of sinkhole. To select the proper stiffness of geogrid, wide width tensile tests were performed on different types of artificially created geogrid, such as geotextile paper and polymeric geogrid. In order to eliminate possible scale effect, the reinforcement made of geotextile was used as model geogrid.

The artificially made sinkhole used in this study was created by flexible fabric material having no own strength. The length of the sinkhole was considered as the width of test box 350mm with sinkhole diameter of D_{SH} = 150mm (D_{SH} = sinkhole diameter)

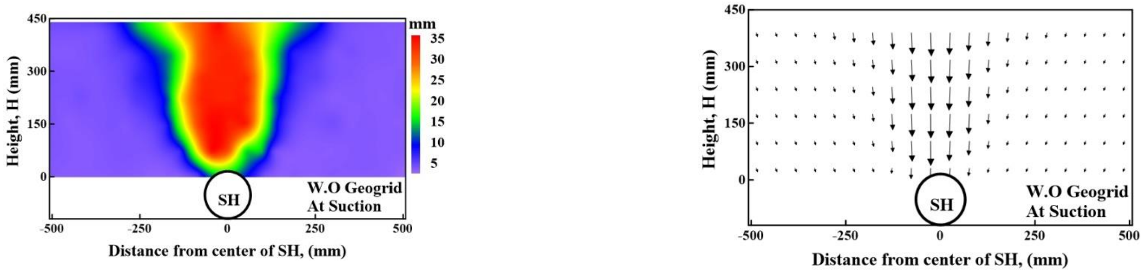
3 RESULTS AND DISCUSSION

3.1 *Effect of reinforcement*

The parametric study was performed on different parameters of geosynthetic reinforcement. The results of a parametric study are demonstrated as given below.

3.1.1 *Baseline cases*

To check the effect of reinforcement, the results are drawn between the without reinforcement and with reinforcement case at vertical spacing of S_v = 50 mm, H_1 = 50mm and N = 2 layer of geogrid. The test results are shown below in Figure 6 using contour and vector plots of ground deformation at the event of sinkhole formation. As shown, it is clearly seen that the deformation of model ground significantly decreased when placing geogrid reinforcement into the model ground. So, from the results, it can be stated that a layer(s) of reinforcement can have a significant effect in reducing the deformation of model ground over the sinkhole and minimizing the chances of collapse over the sinkhole.



(a) Without reinforcement

(b) With reinforcement

Figure 6. Effect of geogrid reinforcement on ground deformation at the event of sinkhole formation

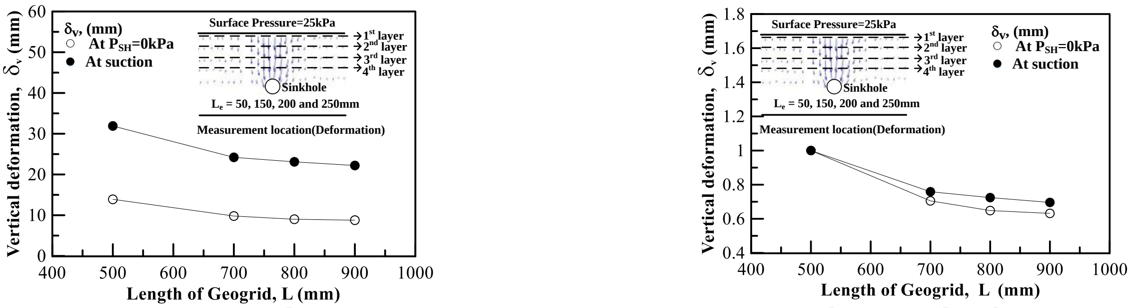
3.1.2 *Effect of reinforcement parameters for sinkhole protection*

To define the optimum parameters of reinforcement for sinkhole prevention, the results are drawn from model ground deformation, surface settlement, earth pressure distribution and strain in geogrid layers in the following section.

1) Length of geogrid layers

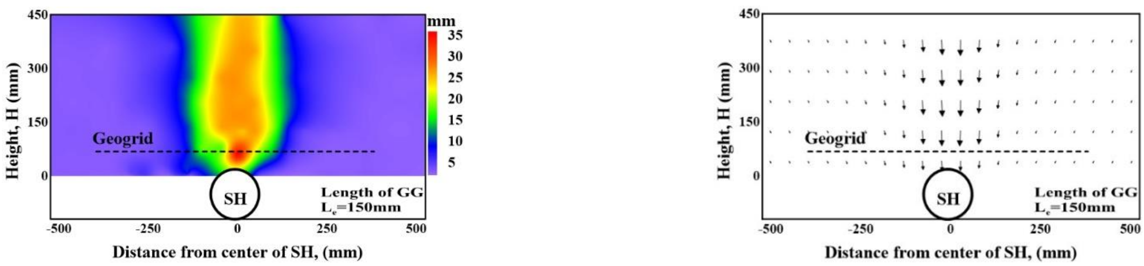
To check the effect of length of geogrid, the length of geogrid changed by changing the embedment length L_e of geogrid and two test cases were drawn at the embedment length of L_e = 50, 150, 200 and 250mm. The effect of the length of geogrid on the ground deformation at the event of sinkhole formation is given in terms of the sinkhole crown as well as ground surface settlements and contour and vector plots in Figures 7 and 8 respectively.

Figure 7 shows the variations of the sinkhole crown as well as ground surface settlements with embedment length L_e. Note that Figure 7(a) shows the measured settlements while Figure 7(b) shows normalize vertical settlements. As shown in Figure 7, the ground settlement over the sinkhole decreases with increasing the length. The increase, however, tends to level off at 700 mm beyond which it becomes constant. Such a trend suggest that no extra benefit can be achieved when extending the geogrid beyond the length of 700 mm. The results in Figure 7 are fully supported in Figure 8 where the reduction in ground deformation due to the reinforcement is more evident when the geogrid reinforcement is installed at large embedment length L_e = 200mm as compared to L_e = 150mm.

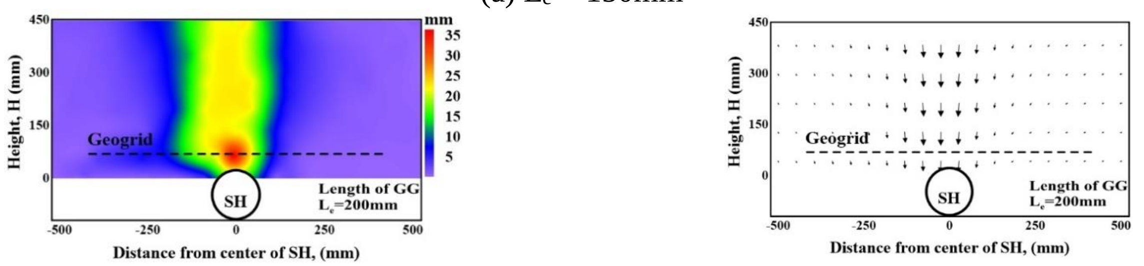


(a) Measured (b) Normalized

Figure 7. Effect of length of geogrid layer on the ground settlement



(a) L_e = 150mm



(b) L_e = 200mm

Figure 8. Contour and vector plots for deformation at different length of geogrid from crown of sinkhole

2) Spacing between the geogrid layers

Figure 9 demonstrates the effect of the vertical spacing (S_v) between the geogrid layers. As shown in Figure 9, the ground settlement over the sinkhole decreases with increasing the spacing between the geogrid layers. The increase, however, tends to level off at S_v = 50mm beyond which it becomes constant. Such a trend suggest that no extra benefit can be achieved at the spacing less then 50mm and also greater then 50mm.

(a) Measured (b) Normalized

Figure 9. Maximum vertical settlement with different spacing of geogrid

4 CONCLUSIONS

A series of reduced-scale model test box experiment were performed to investigate the effect of geogrid reinforcement on sinkhole induced ground deformation due to leakage of water supply pipeline. A number of cases were tested considering the spacing between the geogrid layers and the geogrid reinforcement length. The results indicated that the use of geogrid reinforcement can reduce the potential for ground deformation due to sinkhole formation on the area suspected to sinkhole formation due to leakage of water from water supply pipeline. Also shown is that there exits critical geogrid reinforcement length beyond which no benefit in terms of ground deformation can be achieved and similarly spacing between the geogrid. Further study is required to generalize the effect of geogrid reinforcement on reducing the potential for sinkhole induced ground deformation and collapse.

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