Effect of Geogrid on Sinkhole Formation induced Ground Collapse Prevention

Effet de la géogrille sur la formation de siphons

Qaisar Abbas, Yoo Chungsik
Department of Civil and Architectural Engineering, Sungkyunkwan University, Korea, abbasqaisar935@gmail.com

ABSTRACT: The present study describes the results of laboratory model tests to prevent the event of sinkhole formation into the ground by using geosynthetic reinforcement. A series of reduced scale model tests were carried out with emphasis on the effects of geosynthetics reinforcement parameters such as density (number), length and spacing between the geogrid layers to evaluate the behavior of ground over the sinkhole. The purpose of the study is to evaluate the appropriateness of the combination of geogrid reinforcement to reduce the failure on the sinkhole. Based on experimental results, critical values of geogrid parameters for maximum reinforcing effect are suggested. 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.

RÉSUMÉ: La présente étude décrit les résultats de tests en laboratoire afin d'éviter l'apparition de la formation d'un puits dans le sol à l'aide d'un renforcement géosynthétique. Une série de tests de modèles à échelle réduite a été réalisée en mettant l'accent sur les effets des paramètres de renforcement géosynthétiques tels que la densité (nombre), la longueur et l'espacement entre les couches de géogrilles pour évaluer le comportement du sol au-dessus du puits. Le but de l'étude est d'évaluer la pertinence de la combinaison du renforcement de la géogrille pour réduire l'échec sur le puits. Sur la base des résultats expérimentaux, des valeurs critiques des paramètres de la géogrille pour un effet de renforcement maximal sont suggérées. Les résultats de la présente étude indiquent que l'utilisation d'un renforcement géosynthétique de manière efficace peut réduire de façon significative non seulement l'effondrement du sol, mais aussi le remontage de la surface du sol et la pression de la terre sur le puits.

KEYWORDS: Geosynthetic reinforcement, Sinkhole, Reduced-scale model test, Ground deformation, Earth pressure.

1 INTRODUCTION

A sinkhole is basically a hole generated into the ground by erosion and drainage of water. Even though the holes have occurred naturally but they can also be caused by human activities. There are two common types of sinkholes, one those that are generated slowly with the passage of time called “cover-subsidence sinkhole” and the other that occur suddenly called “cover-collapse sinkhole”. These sinkholes caused the collapse of structures constructed in that area drastically. Sometimes possible to choose the location of buildings to avoid the areas that are susceptible to sinkholes but it is not easy to change the alignment of railways and highways.

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. The use of geogrid reinforcement over the buried pipe notably reduced the earth pressure, surface settlement and the deformation of buried utilities as compared to unreinforced bed as demonstrated by Hegde et al. (2014). Shallow strip footing on the geogrid-reinforced bed above a void significantly improved the bearing pressure and surface settlement suggested by Tafreshi et al. (2011).

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). Full-scale test along with numerical investigations to evaluate the stress reduction obtained by geogrid reinforced bridging over the buried utilities explained by Naggar et al. (2015). However, the use of geosynthetic reinforcement to prevent the collapse on the sinkhole and reduction of induced surface settlement is a relatively new concept.

In the present research, parametric study about the geosynthetic reinforcement with 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, model ground deformation and earth pressure distribution along the sinkhole formation.

2 LABORATORY MODEL TEST

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

2.1 Experimental setup

2.1.1 Test configrations

A series of laboratory model test box experiments were performed in a test box made of a steel frame. The inside dimension of test box was 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 sand particles along the failure surface. The possible friction between the inside wall of test box and artificially created model ground were minimized by using WD-40 spray along the inside walls of test box. The model ground was created with a special raining technique for all test cases to achieve the required relative density of 65%. All the tests were conducted to investigate the optimum reinforcement for prevention of total collapse on the sinkhole. The schematic view of test setup shown in Figure 1. and general arrangements of test box shown in Figure 2.

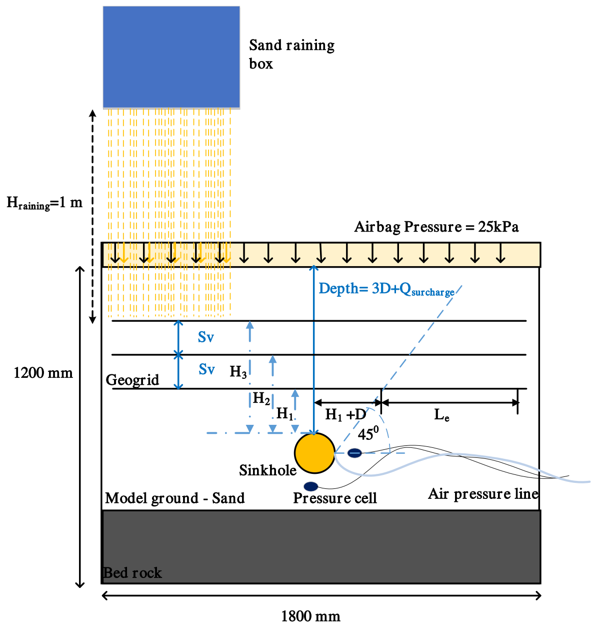


Figure 1. Schematic view of test setup

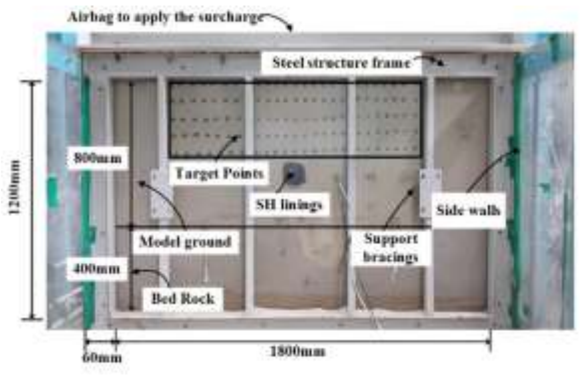


Figure 2. General arrangements of model test box.

2.1.2 Instrumentation Program

All experiment cases were executed 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. Strain gauges were placed along the failure surface to check the geogrid strain profile along the model ground failure at an angle of 45°. Strain gauges used in this study had a normal resistance of 120Ω. Earth pressure distribution over the sinkhole was measured by pressure sensor by placing the pressure sensor 50mm below the sinkhole and 100mm on the side of sinkhole position. 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 3.

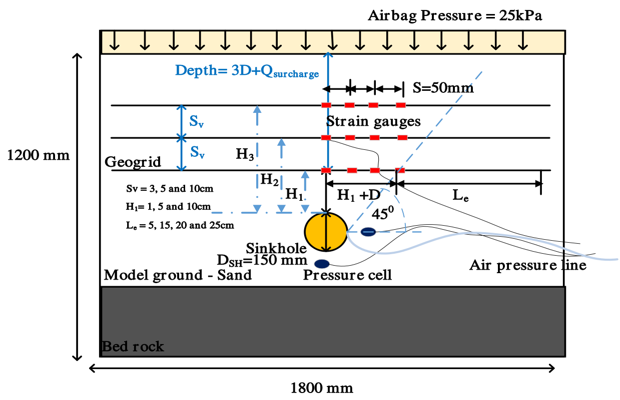


Figure 3. Instrumentation program for model test box experiments

2.1.3 Test Series

To investigate the effect of geogrid reinforcement to prevent the total collapse on sinkhole several cases were tested by varying the length and number of layers. All the test cases were performed at a constant sinkhole depth of 450mm with a surcharge pressure of 25kPa.

2.2 Material Used

2.2.1 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 and the grain size distribution curve shown in Figure 4.

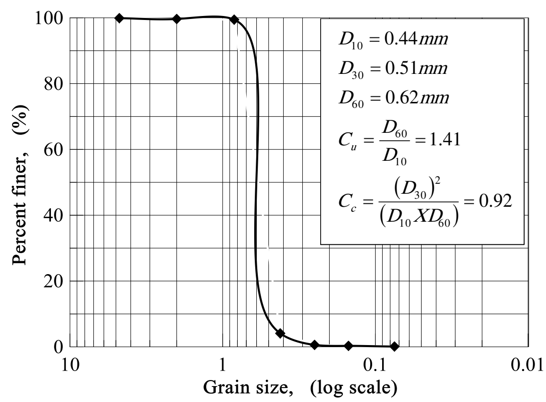


Figure 4. Grain size distribution curve

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° was obtained with a zero-cohesion intercept.

2.2.2 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 fabric cotton paper and polymeric geogrid. In order to eliminate possible scale effect, the reinforcement made of cotton paper 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. Test cases were performed with sinkhole with a diameter of D_{SH} = 150mm (D_{SH} = sinkhole diameter) shown in Figure 5.

(a) (b)

Figure 5. Sinkhole used in experiments: (a) plan view; (b) top view

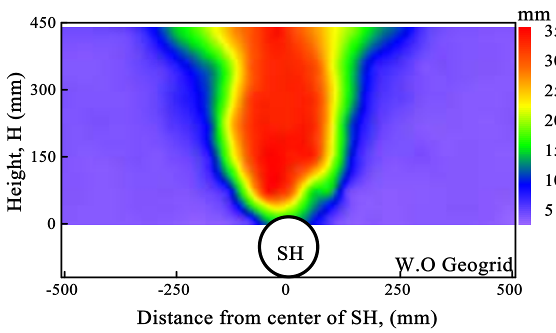
3 RESULTS AND DISCUSSION

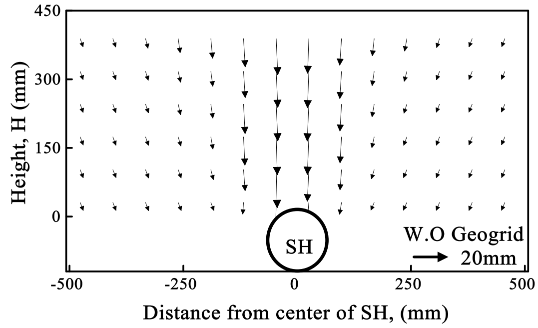
3.1 Effect of reinforcement

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

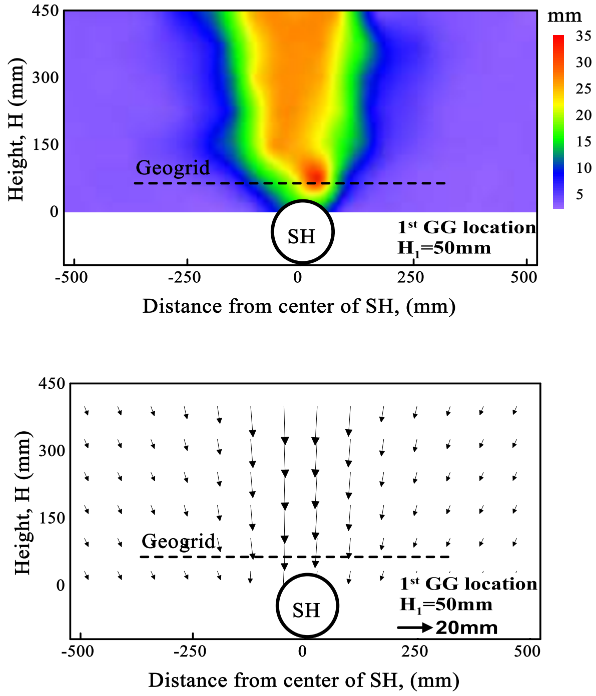
3.1.1 Baseline cases

To check the effect of reinforcement, the results are drawn between the without reinforcement and with reinforcement case at H_1 = 50 mm and N = 1 layer of geogrid, where H_1 =location of the 1st geogrid layer from the sinkhole crown. 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)



(b)

Figure 6. Effect of geogrid reinforcement on ground deformation at the event of sinkhole formation: (a) without reinforcement; (b) with reinforcement.

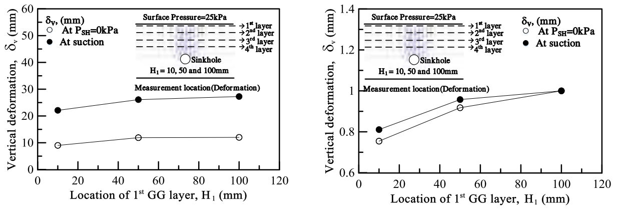
3.1.2 Effect of reinforcement parameters for sinkhole protection

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) Location of 1st geogrid layer

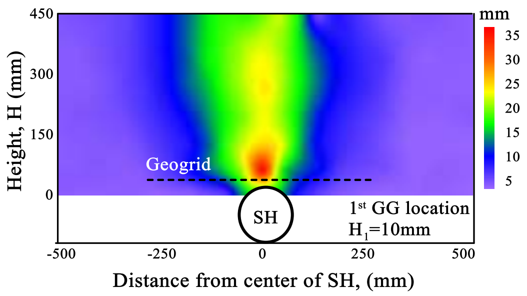
The effect of the location of 1st geogrid from the crown of the sinkhole (H_1) on the ground deformation at the event of sinkhole formation is given in terms of contour and vector plots and the sinkhole crown as well as ground surface settlements in Figures 7 and 8.

Figure 7 shows the variations of the sinkhole crown as well as ground surface settlements with H_1. Note that Figure 7(a) shows the measured settlements while Figure 7(b) shows normalize vertical settlements. As can be seen, the effect of geogrid reinforcement on the settlement reduction is maximized as the reinforcement is installed closer to the sinkhole as expected. The results in Figure 7 are fully supported in Figure 8 where the reduction in ground deformation due to the geogrid reinforcement is more evident when the geogrid reinforcement is installed closer to the sinkhole, i.e., H_1=10 mm.

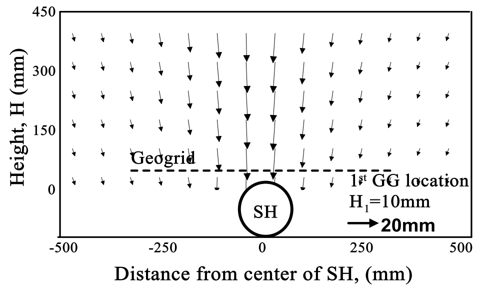


(a) (b)

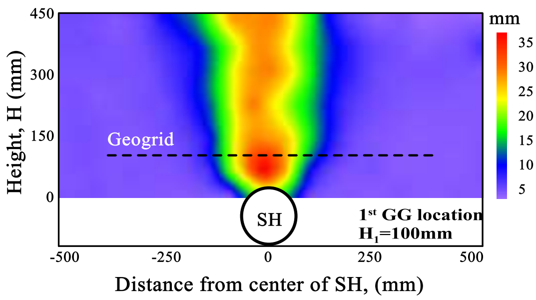
Figure 7 Effect of location of 1st geogrid layer on ground settlements: (a) measured; (b) normalized

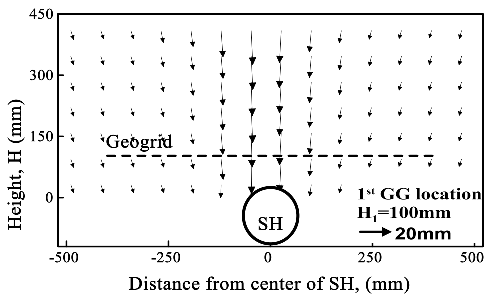


(a)



(a)



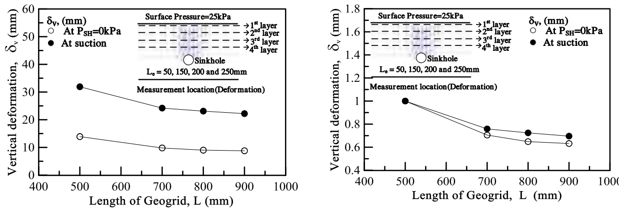


(b)

Figure 8. Contour and vector plots of model ground deformation at different location of 1st geogrid layer from crown of sinkhole; (a) H_1 = 10mm: (b) H_1 = 100mm

2) Length of geogrid layer

Figure 9 demonstrates the effect of the length of geogrid. As shown in Figure 9, 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.



(a) (b)

Figure 9. Maximum vertical deformation of ground: (a) Measured vertical deformation; (b) Normalized vertical deformation

4 CONCLUSION

A series of reduced-scale model test box experiment were performed to investigate the effect of geogrid reinforcement on sinkhole induced ground deformation. A number of cases were tested considering the location of a 1st geogrid layer from the sinkhole 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. Also shown is that there exits critical geogrid reinforcement length beyond which no benefit in terms of ground deformation can be achieved. Further study is required to generalize the effect of geogrid reinforcement on reducing the potential for sinkhole induced ground deformation and collapse.

ACKNOLDGEMENT

This research was supported by the Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport of the Korean government. (Project Number: 16SCIP-B108153-02)

5 REFERENCES

Hegde A., Kadabinakatti S. and Sitharam T.G. 2014. Protection of Buried Pipelines Using a combination of Geocell and Geogrid Reinforcement: Experimental Studies. Ground Improvement and Geosynthetics GSP 238 © ASCE 2014.

Wang F., Han J., Miao L.C. and Bhandari A. 2009. Numerical analysis of geosynthetic-bridged and drilled shafts-supported embankments over large sinkholes. Geosynthetics International 16, No. 6.

Giroud J.P., Bonaparte R., Beech J.F. and Gross B.A. 1990. Design of soil layer–geosynthetic systems overlying voids. Geotextiles and Geomembranes 09 (1), 11–50.

Naggar H. EI., Alper Turan and Arun Valsangkar. 2015. Earth Pressure Reduction System Using Geogrid Reinforced Platform Bridging for Buried Utilities. J. Geotech. Geoenviron. Eng., 141(6): 04015024.

Moghaddas Tafreshi S.N. and Khalaj O. 2008. Laboratory tests of small-diameter HPDE pipes buried in reinforced sand under repeated load. Geotextiles and Geomembranes, 26, No. 2, 145–163.

Moghaddas Tafreshi S.N., Khalaj O. and Halvaee M. 2011. Experimental study of a shallow strip footing on geogrid-reinforced sand bed above a void. Geosynthetics International, 18, No. 4.

White D.J., Take W.A. and Bolton M. 2003. Soil deformation measurement using Particle Image Velocimetry (PIV) and photogrammetry. Geotechnique, 53(7), 619-613.