Influence of collapse width on the effect of geotextile in controlling subgrade collapse based on symmetrical semi-section model tests

Di Wu¹, Yihuai Liang¹*, Chen Luo¹ and Jianjian Wu²

¹ School of Architecture and Transportation Engineering, Guilin University of Electronic Technology, Guilin, Guangxi, 541004, China
² China Nuclear Industry 23rd Construction Co., Ltd., Beijing, 101300, China

*Corresponding author’s e-mail: 20152301013@mails.guet.edu.cn

Abstract. Subgrade collapse is a frequent geological hazard all over the world, which seriously threatens safety of human life and economic development. Compared with conventional methods of collapse, employing geotextile basal reinforcement with the features of reinforcement and filtration can achieve better treatment. In this paper, four symmetrical semi-section model tests with different width of collapse treated by geotextile and one full-section model test were carried out. Data acquisition instruments and particle image velocimetry (PIV) equipment were applied to research soil pressure, vertical displacement of filling and tensile force of geotextile. The following results were achieved: the results obtained from symmetric semi-section and full-section model test was proximal so that the symmetrical semi-section model test had certain feasibility; the laying of geotextile basal reinforcement had good effect on collapse treatment; the width of collapse area was an crucial factor affecting the collapse treatment using geotextile and the geotextile with high tensile strength and enough buried depth should be employed when dealing with large scale collapse problems.

1. Introduction

In recent years, the accidents of subgrade collapse occur frequently with the characteristics of strong recurrence and complex governance environment [1-2], which has serious harm to life and property security of human, urban construction and economic development [3].

There are a series of ways to control urban subgrade collapse, including backfilling, grouting, deep foundation method and so on. However, most of these methods cannot control collapse from the root, causing collapse often relapse. Previous studies have shown that, compared with conventional methods, geosynthetic materials have the advantages of economical efficiency and preventing collapse again [4-7]. In addition, for the full-section model test commonly used in geotechnical engineering, the data of left and right sections are always inconsistent due to different test conditions (e.g. asymmetrical soil compaction and eccentric force), which are difficult to be selected. Compared to the full-section model test with heavy work and long time, the symmetrical semi-section model test was used in this study.

In this paper, four symmetrical semi-section model tests and one full-section model test were conducted to study subgrade collapse treatment by geotextile basal reinforcement. The feasibility of semi-section model test and the function of geotextile basal reinforcement was verified, and the effects
of different collapse width on soil pressure, vertical displacement of filling and tension distribution of geotextile were discussed.

2. Tests

The prototype of subgrade collapse for this experiment was the collapse treatment item of Xihuan Road in Hechi city, China, which was with 1.5 m length, 1.2 m width and 4 m depth surrounding by sand. The large model test container (150cm×60cm×150cm) was utilized in the symmetrical semi-section model tests and permitted visual surveillance utilizing Particle Image Velocimetry (PIV) equipment. Figure 1 illustrates the dimensions of the symmetrical semi-section model.

The soil utilized in the experiment was Li River sand from Guilin with density, cohesive force, moisture content, and internal friction angle of 1.68g/cm³, 32.8˚, 1.03% and 0.2kPa, respectively. The geotextile can be rationally substituted by medical gauze with tensile modulus of 48kN/m and tensile strength of 3.22kN/m on the basis of tensile tests. Table 1 shows the model test scheme. The similarity ratio of 1:5 was employed for all tests.

| Case | Collapse width $B$ (mm) | Anchorage length $L$ (mm) | Filling height $H$ (mm) | Length-width ratio of anchor $L/B$ |
|------|-------------------------|-------------------------|------------------------|-------------------------------|
| t1   | 150×2                   | 0                       | 1000                   | 0.0                           |
| t2   | 150×2                   | 600                     | 1000                   | 2.0                           |
| t3   | 300×2                   | 600                     | 1000                   | 1.0                           |
| t4   | 600×2                   | 600                     | 1000                   | 0.5                           |
| t5   | 300×2                   | 600                     | 1000                   | 2.0                           |

Table 1. Test scheme.

![Figure 1. Model dimension and instruments layout (unit: mm).](image)

![Figure 2. Comparison of soil pressure: (a) $d=1\%$; (b) $d=5\%$.](image)
Following processes were carried out in the scale modeling:

1. In order to decrease the friction between container and soil, two-double Teflon sheets were laid to the inside surface of container;
2. The soil pressure cells were laid in predetermined location and shallowly covered with a layer of 50mm thick sand, and then laying the model geotextile pasting with strain gauges in predetermined place on it;
3. The sand with 100mm thickness and filled in layers was compacted fully using electric plate compactor. The compaction coefficient was controlled to 96%;
4. The PIV equipment was installed and corrected. And the movable bottom plate was stopped settling at 30mm by controlling the settlement device with 2mm/min rate. The data of soil pressure, geotextile tension and filling vertical displacement were required by data collection system and PIV equipment;
5. The artificial observation of the joint state between movable bottom plate and model geotextile was needed during the study, and plate settlement during the separation process was needed to be recorded.

3. Results and discussion

3.1. Verification of symmetrical semi-section model

The symmetrical semi-section model test t2 and the full-section model test t5 were selected for comparison to verify the rationality of symmetrical semi-section model test. The relative settlement \( d \) was the ratio of settlement \( S \) to width \( B \) of the movable bottom plate. Figure 2 shows the comparison of horizontal distribution of soil pressure when the relative settlement \( d \) was 1% and 5%, respectively. It can be seen that the soil pressure distribution curves of t2 and t5 are similar on the whole, so that the characteristics of soil pressure for full-section model test can be represented by the results of symmetrical semi-section model test.

![Figure 3. Comparison of tensile force.](image)

![Figure 4. Comparison of vertical displacement.](image)

Figure 3 compares the tensile force of four gauging points between t2 and t5. The tensile force of symmetrical semi-section model at Y1 was smaller than that of full-section, while the Y4 tensile force of symmetrical semi-section model was larger. The Y3 tensile force between them was not very different and both of them had lower tensile force at Y6. The tendency of tensile force curves between the two models was proximal at overall. Figure 4 shows the vertical displacement of filling at the end of tests (i.e. \( d=10\% \)). The vertical displacement of symmetrical semi-section model test was higher than that of full-section model, but they were similar on the trend. Overall, the results between symmetric semi-section and full-section model were not significantly different and had proximal trend even if there was a little difference in some places. The symmetrical semi-section model test had certain feasibility.
3.2. Soil pressure
Figure 5 illustrates the soil pressure of t1~t4 at different positions T1~T4 in symmetrical semi-section model tests. According to figure 8a and 8b, all the soil pressure of t2~t4 at T1 and T2 in the subsided area decreased at beginning of settlement, and t2 with lower collapse width was more obvious compared with t4. For the non-reinforced test group t1, the stabilized soil pressure at T2 was 3.88kPa, less than that at T1, which was 6.64kPa. The reason was that the partial vertical load of filling at subsided area boundary would convert into friction with the boundary of subsided area during the settlement. It can be seen from figure 8c and 8d that the soil pressure at T3 and T4 in the stable area increased during the settlement, and the soil pressure with larger collapse or approaching collapse interface had large increase. But the soil pressure of non-reinforced test had no significant change. It indicates that geotextile could transfer the load near the collapse interface (T3) to the stable area (T4) through the tensioned membrane effect. In addition, the soil pressure curves of t3 was close to that of t4 in the stable area, which was possibly related to the earlier fracture of geotextile. In summary, the soil pressure under geotextile had finite reduction and it in stable area had higher growth. Therefore, the reinforcement strength should be considered to ensure safety for the treatment of wider collapse.

3.3. Tension distribution of geotextile
The comparison of tension force among the gauging points of Y1, Y3, Y4 and Y6 reveals in figure 6. The largest tensile force of different collapse width occurred in Y3, and the bigger difference of tensile force between Y3 and other points (i.e. Y1, Y4 and Y6) had emerged with the increased collapse width. For the different tests of collapse width, the tensile force at Y1 increased parabolically in the previous stage and then increased linearly with the settlement. And there was a positive correlation between tensile force and collapse width at Y3. In the early stage of settlement at Y4, the tensile force of t3 and t4 were both smaller than t2, then the t2 tensile force became steady and was gradually exceeded by the tensile force of t3. The tension of each group at Y6 were small with little difference.
For the different gauging points, the tension of t2 entered into stabilization stage at the later stage of settlement, while the tension of t3 and t4 had augment until the geotextile break.

3.4. Vertical displacement of filling

Figure 7 shows the vertical filling displacement at different heights in the center of collapse at the end of the test. The non-reinforced test t1 with the curve angle of 45° had the vertical filling displacement of 28.6mm at $h=0m$ by this time. It indicates that the filling displacement control of t2 geotextiles was obviously better than that of t3 and t4. The vertical deformation of filling was transmitted gradually from bottom to top. The vertical displacement of test t2 was about 25mm at $h=0m$, and the displacement gradually decreased as the filling height increased and decreased to zero at the height of 0.8m. The vertical displacement of test t3 was about 20mm at the lowest marker. And it decreased with height but was still high, so that the governance goal that was to prevent the upward development of the lower subsidence was not achieved. The vertical deformation of test t4 was about 11mm at each height, and the filling in subsided area presented an “overall” vertical slide. Compared with the unreinforced test t1 and reinforced test t2, the vertical displacement of top filling of geotextile can be effectively controlled using the geotextile.

4. Conclusions

The subgrade collapse can be availably controlled by employing geotextile. Four symmetrical semi-section model tests with different width of collapse treated by geotextile and one full-section model test were conducted in this study. The following conclusions can be drawn:

1) The results obtained from symmetric semi-section and full-section model test was proximal so that the symmetrical semi-section model test had certain feasibility;
2) The laying of geotextile basal reinforcement had good effect on the collapse treatment of appropriate collapse width;
3) The width of collapse area was a crucial factor affecting the collapse treatment using geotextile. The geotextile with high tensile strength and enough buried depth should be employed when dealing with large scale collapse problems.

Acknowledgments

Financial support for this work is gratefully acknowledged from the Natural Science Foundation of China Grant 42067044 and Natural Science Foundation of Guangxi Grant 2018GXNSFAA294130.

References

[1] Chen, C.Y., Xiao, M., Jia, H., Su, Z.F., Zhang, H. (2013) The genesis of urban underground roads diseases and classification of engineer[J]. Bulletin of Surveying and Mapping, (S2): 5-9.
[2] Lei, M.T., Gao, Y.L., Jiang, X.Z. (2015) Current status and strategic planning of sinkhole collapses in China. Engineering Geology for Society and Territory, 2015(05): 529-533.

[3] Chen, F.Q., Lai F.W., Li, D.Y. (2018) State of the art in research of geosynthetic-reinforced embankment overlying voids. Rock and Soil Mechanics, 39(9): 3362-3376.

[4] He, W., Li, K., Wang, F.H., Yin, P.B. (2016) Experimental study of load distributing behavior of multi-layer geotextile reinforced embankment subjected to the underneath sinkhole in a karst terrain[J]. Hydrogeology and Engineering Geology, 43(01): 79-84.

[5] Sireesh, S., Sitharam, T.G., Dash, S.K. (2009) Bearing capacity of circular footing on geocell-sand mattress overlying clay bed with void. Geotextiles and Geomembranes, 27: 89-98.

[6] Wan, L.L., Chen, F.Q., Zou, W.L. (2017) Mechanisms of load transfer in geosynthetic-reinforced embankments subjected to localised karst collapse[J]. Journal of Yangtze River Scientific Research Institute, 34(02): 56-62.

[7] Wu, D., Wu, J.J., Xu, C., Chen, X.J., Huang, X. (2020) Model test of geotextiles in controlling the collapse of karst roadbed. Rock and Soil Mechanics, (S2): 1-11.