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# Engineering Application of a New Type Geocell Retaining Wall with Variable Cross-Section

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**Abstract:** As a new type of retaining structure, the geocell retaining wall has a broad application prospect in embankment and cutting slope protection. However, the traditional geocell retaining wall with constant cross-section has the disadvantage of high cost due to the use of large amount of geocell. In this paper, the safety factors of geocell retaining walls with different cross-sections are calculated. On the basis of the analysis of calculation results, a new geocell retaining wall with variable cross section is proposed for the purpose of optimum design. Furthermore, the suggested new geocell retaining wall with variable cross section is successfully applied in the relocation project of Yan'an Airport. In addition, the horizontal displacement and the earth pressure acting on the wall back are measured and the construction technology of the new structure is summarized.

***Keywords:*** *Geocell Retaining Wall, Variable Cross-section, Safety Factor, Yan'an Airport, Horizontal Displacement*

## 1. Introduction

GEOCELL is one of the geosynthetic products made from polymeric sheets (e.g. HDPE) interconnected by ultrasonically welded seams. In recent years, geocell has been successfully used in slopes and retaining structures, as a quick and effective technique of soil reinforcement. Chen and Chiu (2008) performed on nine model geocell retaining walls and examined the facing displacement and settlement of backfill [1]. Xie and Yang (2009) studied the deformation and mechanical properties by the FEM numerical simulation [2]. Ling et al. (2009) conducted experiments and studied the seismic response of geocell retaining walls [3]. Liu et al. (2011) analyzed the deformation characteristics and the failure mode of the geocell reinforced retaining wall during construction and discussed the dynamic deformation characteristics in earthquake [4]. However, their researches are confined to case of upright wall back. Song et al. (2011) analyzed the effects of the ratio of wall height to wall width, slope inclination angle and surcharges on the deformation behavior of the geocell retaining wall based on the numerical analysis [5]. Song et al. (2013a) investigated the failure process and failure mode of the geocell retaining wall with surcharge acting on the backfill surface by means of centrifugal model tests [6]. Song et al. (2013b) studied the effects of soil strength, geocell structure strength, and location of high strength geocell structure layer on the failure mode of geocell reinforced retaining wall by the numerical analysis [7]. Chen et al. (2013) performed numerical analysis on the behavior of geocell reinforced retaining structures with various layouts [8]. Mehdipour et al. (2013) carried out numerical study on the stability analysis of geocell reinforced slopes by considering the bending effect using the finite difference program FLAC [9]. They also conducted parametric studies of geocell reinforced slopes. By employing the geotechnical FEM software Plaxis, Song et al. (2014a) investigated the effects of the location and the length of lengthening geocell layers on the mechanical properties of the wall [10]. Song et al. (2014b) studied the effects of the ratio of wall height to wall width and slope inclination angle on the failure mode of geocell retaining wall by means of centrifugal model tests [11]. However, the optimum sectional form of the geocell retaining wall has not been systematically studied, which restrict its popularization and application in engineering practices. Shi et al. (2015) made hazard assessment of debris flows based on the catastrophe progression method [12]. Feng et al. (2015) conducted research on the condition model of drilling fluid non-retention in eccentric annulus [13].

In this paper, the safety factors of geocell retaining walls with different cross-sections are calculated using the geotechnical software Plaxis. On the basis of the analysis of calculation results, a new geocell retaining wall with variable cross section is proposed for the purpose of optimum design. Furthermore, the suggested new geocell retaining wall with variable cross section is successfully applied in the relocation project of Yan'an Airport. In addition, in-situ field monitoring is conducted to measure the horizontal displacement and the earth pressure acting on the wall back. Besides, the construction technology of the new structure is summarized.

## 2. Safety Factors of Different Cross-Sections

In the numerical computation, Mohr-Coulomb elastic-plastic model is selected for the backfill, the geocell reinforced soil and the foundation. The 15-node triangular element is employed in this analysis to model soil and geocell structure layers. The interface element is set between each geocell structure layer, between the wall back and backfill to model the interaction between the structure and the soil. Phi-c reduction in Plaxis is employed to calculate safety factors of the geocell with different cross-sections. In the phi-c reduction approach, the strength parameters tan$\varphi$ and $c$ of the soil are successively reduced until failure of the structure occurs. The strength of interfaces is reduced in the same way. The details of constitutive model of the material, the interface element, the phi-c reduction method and the definition of safety factor in Plaxis can be referred to Brinkgreve and Broere (2000) [14], Song et al. (2013b) [7].

Based on the analysis of the mechanical property tests of geocell by Fu (2002) [15], Gu (2004) [16] and Yang (2005) [17], with references to calculation parameters adopted by Wang (2004) [18], Xie and Yang (2009) [2], Song et al. (2011) [5] and combined with the experiences in engineering practices, the calculation parameters in this study are determined and listed in Table 1.

***Table 1**: Calculation Parameters of Model*

| Material | Wall Body | Foundation | Backfill |
|---|---|---|---|
| $\gamma$/(kN/m$^3$) | 18 | 20 | 17 |
| $\gamma_{sat}$/(kN/m$^3$) | 20.5 | 22 | 20 |
| $c$/kPa | 60 | 70 | 30 |
| $\varphi$/(°) | 40 | 45 | 25 |
| $E$/MPa | 60 | 65 | 30 |
| $\nu$ | 0.25 | 0.2 | 0.35 |
| Rinter | 0.67 | 0.67 | 0.67 |

The lengthening reinforcement layers of traditional geocell retaining wall are placed beyond the critical failure surface of the backfill computed by general limit equilibrium (GLE) method. The embedment length beyond the failure surface is about 2 meters. The sketch and the mesh generation of the calculation model of the traditional geocell retaining wall with uniform cross-section are illustrated in Fig .1 and Fig.2 respectively.

The geocell retaining wall with variable cross-sections is shown in Fig. 3, in which the width of the lower half of the wall body is twice that of the upper half and the number of the lengthening reinforcement layers is smaller than that of the traditional geocell retaining wall illustrated in Fig. 1. The cases of the wall with variable cross-sections are listed in Table 2, in which the locations of the reinforcement layers are different. The safety factors of the different cases are shown in Table 3, from which it can be observed that the factor of safety of case (1) is the highest and that of the traditional geocell retaining wall with uniform cross-section is the lowest. Therefore, the geocell retaining wall of case (1) has the advantage of saving the amount of geocell, resulting in the reduction of construction cost, besides its good mechanical properties and high safety factor. Consequently, it is the new structure worth recommending to be used in the engineering practices.

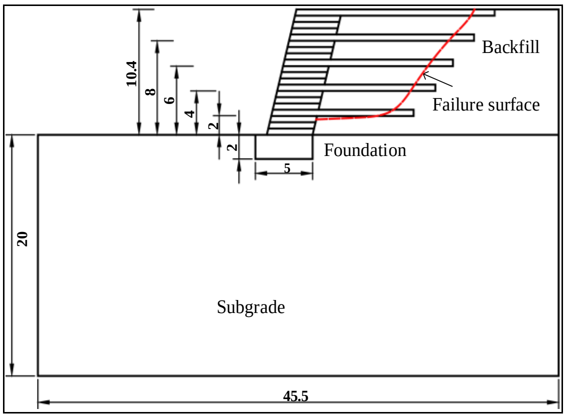


***Figure 1:** Sketch of the geocell retaining wall with uniform cross-section (unit: m)*

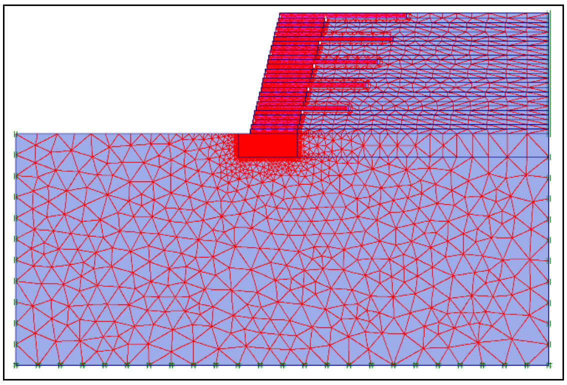

***Figure2**: Mesh generation of the geocell retaining wall with uniform cross-section*

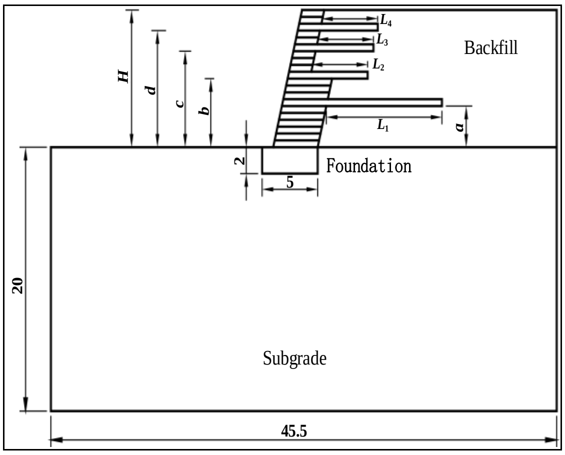


***Figure3:** Sketch of the retaining wall with variable cross-section (unit: m)*

***Table 2**: Cases of Geocell Retaining Wall with Variable Cross-section*

| Case | Location of reinforcement layer | Length of reinforcement layer |
|---|---|---|
| (1) | a=$H$/3, b=$H$/2, c=3$H$/4, d=7$H$/8 | $L_1=H$, $L_2=L_3=L_4=H/2$ |
| (2) | a=$H$/3, b=$H$/2, c=7$H$/10, d=7$H$/8 | |
| (3) | a=$H$/3, b=$H$/2, c=7$H$/10, d=3$H$/4 | |

***Table 3**: Safety Factors of the Geocell Retaining Wall with Different Cross-sections*

| Cases | | Factors of safety |
|---|---|---|
| Uniform cross-section | | 1.780 |
| Variable corss-section | Case (1) | 1.794 |
| | Case (2) | 1.783 |
| | Case (3) | 1.787 |

## 3. Application in Yan'An Airport Relocation Project

### 3.1. Construction Process

The proposed new geocell retaining wall with variable cross-section is applied in the relocation project of Yan'an Airport locating in the Liulin town, Baota District, Yan'an City for the embankment protection. The soil of the site is collapsible loess. The height and the length of the geocell retaining wall are 10m and 50m, respectively. The design sketch of the project is illustrated in Fig. 4. The construction steps of the new structure include the following 6 ones: The first one is the preparation work including the quality inspection of the purchased geocell. The second one is the construction of the foundation of the wall. The foundation is made of cement-sandy gravel. The ranges of the diameter of the sand and the gravel are 0.5～2mm and 2~50mm respectively. The third one is the expansion of the pockets of the geocell shown in Fig.5. The fourth one is the filling the backfill in the pockets of the geocell, leveling and compaction of the geocell cushion, illustrated in Fig. 6, 7 and 8, respectively. As can be seen in Fig.7 and 8, the central part of the geocell cushion is compacted by the 22 ton vibratory roller and the marginal part is compacted by the miniature vibrating rammer. The fifth one is the connection of the geocell. The adjacent geocell is connected by rivets in the horizontal direction and steel bars in the vertical direction, illustrated in Fig.9. The diameter and the length of the steel bars are 1cm and 60cm respectively and they are placed every 2 meters parallel to the wall face and every 1 meter perpendicular to the wall face. The sixth one is the greening of the wall face, shown in Fig. 10. The construction of the wall started on March the 15th of 2014 and finished on May the 15th of 2014. The whole wall after the completion is illustrated in Fig. 11.

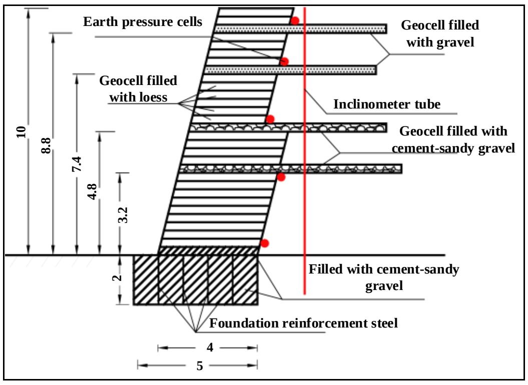


***Figure 4:** Design sketch of the geocell retaining wall in Yan'an Airport Project (unit: m)*

***Figure 5:** Expansion of the geocell*


***Figure 6:** Filling the backfill in the geocell*

***Figure 7:** Roller compaction on the central geocell cushion*

***Figure 8:** Compaction of the margin of the geocell cushion*

***(a)** Horizontal* ***(b)** Vertical*

***Figure 9:** Connection of the geocell*

***Figure 10:** Planting grass in the wall face*

***Figure 11:** The geocell retaining wall after completion*

### 3.2. Field Monitoring of the Geocell Retaining Wall

Earth pressure cells are used to measure the earth pressures against the wall back and tilt sensors are fixed on them to measure the deflection of the cells, which is illustrated in Fig. 12. In addition, the horizontal displacement of the wall is measured by inclinometers. The measured earth pressures and horizontal displacement are shown in Fig. 13 and 14, respectively.

***Figure 12:** Installation of the earth pressure cells and tilt sensors*

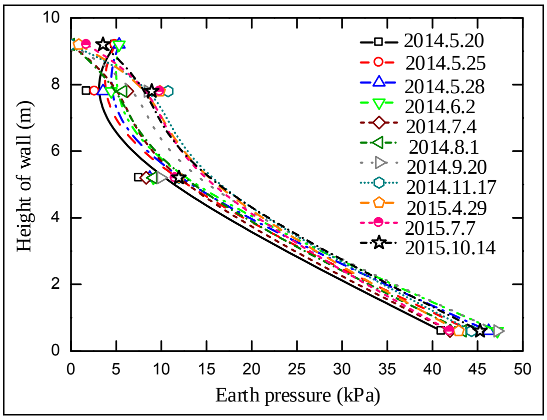


***Figure 13:** Measured earth pressures against the wall*

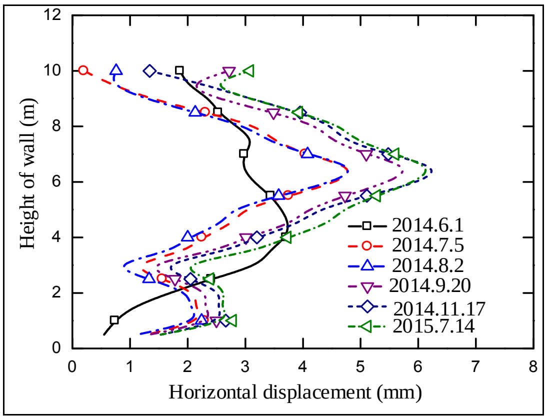


***Figure 14:** Measured horizontal displacement behind the wall*

It can be observed from Fig. 13 that the earth pressures against the wall back are very small. The unit weight of the soil is 17.6kN/m$^3$ and the lateral earth pressure coefficient is about 0.26 by the calculation. The maximum horizontal displacement is only about 6.4mm, which is also very small, indicating that the wall and the backfill are at the stable state. The increment of the horizontal displacement is very small after November the 17th of 2014.

## 4. Conclusions

A new geocell retaining wall with variable cross section is proposed based on the analysis of the safety factors obtained by the geotechnical FEM software Plaxis. For the new geocell retaining wall, the width of the upper half of the wall body is half that of the lower half and the number of the lengthening reinforcement layers is smaller than that of the traditional geocell retaining wall. The distances between the four lengthening reinforcement layers and the wall bottom are *H*/3, *H*/2, 3*H*/4 and 7*H*/8, respectively. The lengths of the lower two lengthening reinforcement layers are about the height of the wall and those of the upper two ones are about half of the height of the wall. The new geocell retaining wall with variable cross-sections is applied in the relocation project of Yan'an Airport. In-situ field monitoring is conducted to measure the horizontal displacement and the earth pressure acting on the wall back. Besides, the construction technology of the new structure is summarized.

## 5. Acknowledgement

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