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Application of Geogrid-reinforced Retaining Wall Technology in Factory Construction

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Abstract

In recent years, geosynthetic reinforcement technology has been widely applied in numerous engineering projects. Geogrids are polymer materials formed into planar mesh structures with open grids and high tensile strength through uniaxial or biaxial oriented stretching under heating. This stretching realigns the polymer chains linearly in the direction of tension, significantly enhancing the intermolecular bonding strength and thereby improving the tensile performance of the material. This paper takes the construction of a reinforced retaining wall for an access road in a factory area as a case study. It investigates the failure mechanisms of the modular geogrid-reinforced retaining wall and proposes corresponding treatment suggestions, aiming to provide practical references for similar projects.

Keywords

Geogrid; Reinforced retaining wall; Structural design

As one of the engineering applications of geogrids, geogrid-reinforced retaining walls represent a novel type of retaining structure. Various types of backfill materials are mechanically interlocked within the openings of the geogrid, significantly enhancing the interfacial friction between the materials. The pullout resistance of geogrids embedded in soil is also markedly increased due to the strong frictional interlock between the geogrid and the surrounding soil mass, thus providing a more stable reinforced body [1]. This paper presents a case study of a modular geogrid-reinforced retaining wall constructed in a factory area, analyzing the causes of failure in the road retaining wall system and offering remediation suggestions, with the aim of providing useful references for similar engineering applications.

1. Project Overview

The proposed construction site is located on the eastern side of a municipal solid waste treatment facility, with a relative ground elevation difference of 22,260 mm. The terrain within the site is uneven, characterized by significant elevation changes, and lies within a hilly geomorphic unit. The foundation is a combination of cut and fill. The hydrogeological conditions are relatively simple, with groundwater mainly consisting of fissure water in weathered rock. The height of the typical geogrid-reinforced retaining wall section used in the plant area is 12,000 mm, with an embedded depth of over 1,000 mm. The system configuration and technical requirements are as follows: (1) The facing consists of precast concrete modular panels. (2) The geogrid used is a uniaxial geogrid produced by Tensar, manufactured through an integral punching and stretching process. The minimum carbon black content is no less than 2%, ensuring effective resistance to ultraviolet radiation and aging. Design is based on creep strength, taking into account all applicable reduction factors. (3) The geogrid is connected to the facing modules using mechanical connectors of sufficient strength. (4) The reinforced backfill primarily consists of gravelly soil (with a gravel content of no less than 50% and well-graded). Within the construction zone, well-graded crushed stone is used. The internal friction angle of the fill is not less than 32°, with a maximum particle size of 150 mm, and a compaction degree of not less than 94%. A uniformly distributed load of 30 kPa is considered both for the roadway and the building located at the top of the retaining wall.

2. Site Investigation

2.1 Current Condition of the Geogrid-Reinforced Retaining Wall and Surrounding Environment

According to on-site inspection and testing, the southern boundary of the project site is adjacent to a landfill. To the south of the leachate emergency basin is a cast-in-place concrete counterfort retaining wall. Both the west side of this wall and the western boundary of the site adopt geogrid-reinforced retaining wall systems. On the west side of the counterfort wall, the terrain varies significantly in the east-west direction, with the retaining wall height ranging from 4,900 mm to 8,500 mm. On the west side of the site, the geogrid-reinforced retaining wall reaches a height of 12,000 mm.

At 3,400 mm east of this wall lies a 4,300 mm-wide factory road, which exhibits longitudinal cracks in the north-south direction. The cracks have a total length of approximately 15,000 mm, with a typical width of 3.0 mm. At 13,400 mm east of the wall stands a leachate treatment facility. The road at the southwest corner of this facility displays both longitudinal and diagonal cracking, with crack lengths of 5,900 mm and 5,000 mm, and typical widths of 13.0 mm and 10.0 mm, respectively. Some crack edges are rough, dust-free, and relatively bright in color. Surface unevenness is observed along the aforementioned roadways.

The edge of the flare stack foundation is located 4,550 mm from the west retaining wall and 4,730 mm from the south wall. The top of the geogrid-reinforced retaining wall system and the backfill on the west side of the emergency basin are covered with a geomembrane.

2.2 Damage and Deformation of the Geogrid-Reinforced Retaining Wall

Field inspection reveals that the geogrid-reinforced retaining wall system on the south side is misaligned with the adjacent cast-in-place concrete counterfort wall. The amount of displacement at the joint varies, with measured values at representative locations ranging from 13 mm to 78 mm. The concrete modular facing units of the geogrid wall are uneven and show signs of damage and detachment. In the southern segment of the western retaining wall system, separation and cracking are evident, and outward bulging is observed at the upper portion of the wall. At typical locations, the measured outward bulge at the top ranges from 108 mm to 234 mm (including construction tolerance of the facing panels).

2.3 Geogrid Layout

Three locations were selected for excavation to examine the layout of the geogrid: north of the junction between the counterfort wall and the geogrid wall, north of the flare stack, and west of the leachate treatment facility.

At 4,500 mm north of the counterfort wall junction, a geogrid layer was uncovered at a depth of 400 mm (first layer), with a spacing of 200 mm between the first and second layers. Damage was observed at the outer end of the geogrid.

At 3,900 mm north of the flare stack, geogrids were uncovered at a depth of 1,030 mm, with the first layer buried at 200 mm and a spacing of 200 mm between the first and third layers. Between 3,900 mm and 7,000 mm from the top of the wall, a fourth layer was uncovered at a depth of 1,030 mm, with a length of 10,000 mm.

West of the leachate treatment facility road, a geogrid layer was found 3,400 mm from the top of the wall at a depth of 600 mm. No geogrid was found on the east side of the road.

2.4 Backfill Conditions of the Geogrid-Reinforced Retaining Wall System

Excavation of the backfill revealed that the upper backfill consists of sandy gravel soil, with gravel content below 50% and poor gradation, containing clay. The gravel content and gradation do not meet the design requirements [2].

In areas where the retaining wall exhibited damage, field density and compaction tests (sand cone method) and laboratory geotechnical tests were conducted. Results indicate a field density of 1.98 g/cm^3, natural moisture content of 7.4%, and a maximum dry density of 2.2 g/cm^3 based on the standard Proctor compaction test. The optimum moisture content was 6.6%.

Direct shear tests (quick shear) yielded an internal friction angle of 37° and cohesion of 20 kPa. The compaction degree measured using the sand cone method was 90%.

3. Verification and Analysis of the Geogrid-Reinforced Retaining Wall

3.1 Selection of Analysis Method

At present, traditional analytical methods for reinforced retaining walls in China do not account for both structural strength and deformation simultaneously, nor can they evaluate panel displacement and backfill settlement [3]. The Chinese design code adopts the 0.3H method (single-wedge method), which considers a single potential sliding wedge. The design is generally based on the factor of safety approach (limit equilibrium method), which imposes certain constraints and often yields conservative results.

In contrast, the German DIBt design method for reinforced soil structures (also known as the double-wedge method) is based on the limit equilibrium principle and considers two sliding wedges in stability analysis. By altering the inclination and height of the bottom wedge, various wedge shapes are formed, and stability is evaluated for each configuration individually [4]. The DIBt method also accounts for panel connection strength and serviceability under static loading. Compared to the 0.3H method, which evaluates only one failure surface, the DIBt approach is more comprehensive in its internal stability assessment.

Table 1. Technical Specifications of Uniaxial Geogrids

Type	Polymer Material	Quality Control Tensile Strength (kN/m)	Long-Term Creep Rupture Strength at 20°C (kN/m)
UXB	HDPE	70	26.96
UXD	HDPE	144	55.47

Note: All geogrids have aperture strengths greater than 350 mm, with a minimum carbon black content of 2%.

According to the geotechnical investigation report, the foundation of the reinforced retaining wall lies on completely to strongly weathered granitic gneiss, with a bearing capacity of 300 kPa. The analysis considers a uniformly distributed load of 30 kPa from the road and the structure at the top of the wall. The technical specifications of the uniaxial geogrids are shown in Table 1.

The minimum safety factors adopted in the calculations are as follows: bearing capacity—2.0, base sliding—1.5, geogrid rupture—1.75, geogrid pullout—2.0, connection to panel—1.75, and internal sliding within the geogrid—1.5.

3.2 Load Cases

Design Condition: Under drained conditions, the reinforced backfill and the soil behind the wall are assumed to have zero effective cohesion, an effective internal friction angle of 28°, and a unit weight of 19 kN/m³. The foundation soil is also assumed to have zero effective cohesion, an effective internal friction angle of 30°, and a unit weight of 19.5 kN/m³.

Actual Condition (Geogrid Considered as Designed): Under drained conditions, the reinforced backfill and backfill behind the wall have a cohesion of 20 kPa, an internal friction angle of 37°, and a unit weight of 19.4 kN/m³. The foundation soil has an effective cohesion of 20 kPa, an effective internal friction angle of 15°, and a unit weight of 19.5 kN/m³.

3.3 Calculation Results

According to the verification results, under both the design and actual conditions (with geogrid performance considered as per the original design and without accounting for moisture-induced degradation of fill material properties), the geogrid-reinforced retaining wall meets all code requirements for external stability—including sliding stability, overturning stability, bearing capacity, eccentricity, and overall stability—as well as internal stability, particularly the pullout resistance of the reinforcement layers.

4. Analysis of Factors Affecting the Stability of Geogrid-Reinforced Retaining Walls

4.1 Topographic and Hydrological Conditions of the Site

The site presents relatively simple hydrogeological conditions. Groundwater exists mainly in weathered rock fissures and is primarily recharged by precipitation and surface runoff, with evaporation being the main discharge pathway. The site is classified as having an uneven foundation. The inspected area lies within a fill zone, where the original terrain slopes from the northeast to the southwest, which is consistent with the findings in the geotechnical investigation report. The topography significantly influences the interaction between the soil and the geogrid–soil composite system. Under saturated conditions, both horizontal and vertical displacements of the retaining wall increase considerably compared to dry conditions, indicating a tendency for outward deformation [5].

4.2 Design-Related Factors

The retaining wall system in this project was designed without considering water pressure acting on the facing or the fill material. Vertical and horizontal gravel drainage layers and gravel blind trenches were installed instead. Based on verification results, both external and internal stabilities of the reinforced retaining wall meet the code requirements under both design and actual load conditions. However, no water outlet pipes were observed on-site. During the service period, water within the wall was found to drain through gaps between concrete facing panels.

4.3 Construction-Related Factors (Secondary Works)

Field inspection revealed damage to the geogrid in the pipe installation area near the leachate treatment facility. The west end of the building foundation is located at an elevation of -2000 mm, where DN50 to DN200 water supply and drainage pipelines (pipe elevation: 1300 mm) connect to an outdoor self-cleaning drainage system. The burial depth of these pipelines ensures a minimum soil cover of 1000 mm above the pipe crown. However, no geogrid was found beneath the exterior ground surface at the excavation site. Geogrid damage was also observed near the southwest corner flare stack foundation and the east support foundation of the flare. In some areas, geogrids were disturbed or damaged during pipeline installation and building or structure construction.

4.4 Backfill-Related Factors

Most codes and standards, both domestic and international, prohibit the use of cohesive soils in reinforced soil retaining walls and impose strict requirements on particle size distribution. Well-graded, coarse-grained soils with good permeability are preferred as reinforced backfill. These materials provide high interfacial friction, stable mechanical behavior, low pore water pressure (often near zero), and minimal creep, ensuring long-term performance of the reinforcement system. Although granular soil was specified in the design, site investigation and laboratory testing indicate that the actual backfill properties do not meet the design requirements.

5. Analysis of Deformation Causes in the Geogrid-Reinforced Retaining Wall and Roadway

According to feedback, visible water seepage marks were observed in the middle and lower sections of the facing panels on the south side of the retaining wall during service. Settlement and deformation occurred in the backfill behind the reinforced wall at the southwest corner. The original terrain slopes from northeast to southwest. Surface water infiltration and groundwater runoff from the adjacent hill may have accumulated in this area. Clogging of the drainage layer or insufficient drainage capacity of the gravel layers may have led to increased hydrostatic pressure within the wall. This, in turn, caused damage to concrete panels, detachment and cracking in the southern section of the western wall, and outward bulging in the upper part of the retaining wall.

Water accumulation at the top of the wall and subsequent infiltration into the backfill can lead to saturation, softening, settlement, and deformation of the reinforced soil mass [6]. Inadequate compaction in localized zones and improper geogrid installation (particularly at corners) during construction cannot be ruled out as contributing factors to localized wall deformation.

The original design did not account for hydrostatic pressure in front of the wall or within the backfill. In the typical cross-section, a 500 mm-thick vertically graded gravel drainage layer was provided, along with horizontal gravel drainage and blind drains [7]. Verification results indicate that both external and internal stabilities meet code requirements under both design and actual conditions (assuming geogrid performance as originally designed). However, drainage should have been discharged through weep holes in the wall. Cracking and surface unevenness were observed on the roadway atop the wall. Notably, the roadway was already in use during fill placement and construction of adjacent structures, and deformation had already occurred during service. Some cracks have rough edges, are free of dust, and appear relatively fresh in color, indicating that they are recent and were likely caused by deformation of the retaining wall and backfill.

6. Remedial Measures

The internal failure mechanisms of the reinforced retaining wall include: (1) tension-induced splitting at the top of the wall, and (2) shear banding in the middle and lower sections, where conjugate shear zones slide and drive lateral extrusion of surrounding soil.

Integrated slope stabilization should focus on reducing driving forces or eliminating triggering factors, while simultaneously enhancing resisting forces or stabilizing conditions. It is recommended that the southwest corner backfill area be temporarily covered with a geomembrane. Temporary surface drainage ditches should be installed around the area to quickly divert rainfall runoff, prevent ponding atop the wall, and minimize infiltration into the backfill [8]. Additional weep holes should be installed on the wall face to allow water to discharge outside. From a structural mechanics perspective, any reinforcement system for the failed retaining wall should provide resistance to both overall failure and localized deformation. A practical solution could involve a prestressed inclined anchor system, combined with high-pressure grouting to improve the mechanical properties of the surrounding soil. Surface shotcrete with steel mesh reinforcement should also be applied to enhance the wall's integrity and control localized deformation.

7. Conclusion

Geogrid-reinforced retaining walls are a type of flexible retaining structure. Through interlocking and friction between the reinforcement and the backfill soil, deformation behind the wall can be effectively constrained, thereby improving the engineering properties of the backfill and enhancing the overall stability of the wall. During construction, it is essential to control key parameters such as backfill gradation and compaction. Secondary disturbances and construction-related damage should be avoided. The potential impacts of topography, surface water, and groundwater on the backfill and wall stability must be fully considered. Drainage layers or blind drains, in compliance with design codes and performance requirements, should be included in both the wall facing and interior. For geogrid-reinforced retaining walls that exhibit significant deformation or failure, a comprehensive reinforcement scheme can be considered. This may include pressure grouting, bidirectional inclined prestressed anchorage, and steel mesh—shotcrete application to restore structural integrity.

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