Damage of geogrid reinforced soil wall caused by extreme load - Japanese case histories

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ABSTRACT: Technical committee of IGS Japan chapter collected many case histories on collapsed or deformed geogrid reinforced soil walls. The range of wall height is from 4.0 m to 11.0 m, the maximum embankment height reaches about 20 m, and the range of slope inclination is from 1:0.1 to 1:0.5. Their backfills are mainly sandy soils. The observed failure modes and deformation mechanism were identified and the counter measures were studied. This paper reports the collected case histories and summarizes lesson learned from them. This achievement may contribute for not only developing of design method to decrease the failure and the deformation but also lifecycle management of reinforced soil structures.

Keywords: reinforced soil wall, geogrid, case histories

1 INTRODUCTION

A geosynthetic reinforcement technique for earth and soil structures was established in the 1970s and has been applied to embankments and soft ground that allow large deformation. Interest in the effectiveness of reinforcement techniques has spread widely because of their applications to important structures and ground that has been previously avoided. After various such applications, the deformation of reinforced soil structures has been reported. In one case, a driving force caused by an earthquake or heavy rainfall deformed the structure. Such deformation can be prevented by careful investigation, design, and construction. Analysis of deformation cases and efforts to decrease the deformation amount and the number of deformed reinforced soil structures are urgently needed. A case analysis of the deformation of reinforced soil structures, especially that caused by earthquakes, has been performed. However, efforts to analyze the deformation caused by rainfall are insufficient, even though this is very important for lifecycle management with a high occurrence frequency.

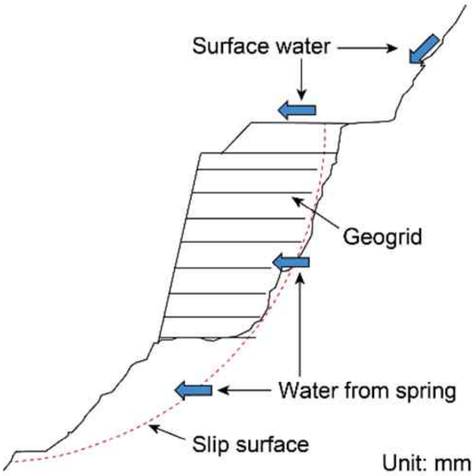
The technical committee of the Japan chapter of the International Geosynthetics Society analyzed eight cases of the deformation of reinforced soil walls, mainly caused by rainfall. Herein, the authors report the four case histories and employ the results of the case study for proposing appropriate actions to ensure that the deformation is below the allowable level.

2 OUTLINE OF COLLECTED CASE HISTORIES

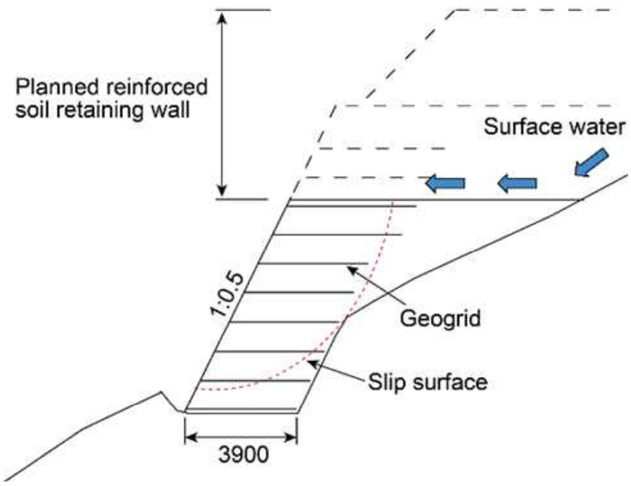
The collected case histories are summarized in Table 1. The wall height ranged from 4.2 to 10.7 m, the wall inclination ranged from 1:0.1 to 1:0.5, and the backfill was partially sandy soil, including slaking materials. The facing wall was flexible, made of a steel frame. All of these reinforced soil-retaining walls were designed according to the design standard published by the Public Works Research Center (2000). Case history No.1-3 has already reported by Miyata and Shinoda (2016). This paper reports No.4-7. In the next chapter, an outline of the structural deformation, the case study, and the actions taken after deformation are presented.

Table 1. Deformed reinforced soil-retaining walls subjected to heavy rainfall.

No.	Wall height (m)	Height of upper embankment (m)	Wall inclination	Wall material	Backfill soil property	
					Cohesion (kPa)	Friction angle (°)
1	10.7	0.0	1:0.3	Steel frame	10	30
2	9.5	9.6	1:0.3	Steel frame	10	35
3	9.5	5.2	1:0.3	Steel frame	0	30
4	8.0	2.0	1:0.3	Steel frame	NA	NA
5	9.1	3.0	1:0.5	Steel frame	8	36
6	4.2	4.2	1:0.3	Steel frame	0	35
7	4.2	2.0	1:0.1	Steel frame	5	36
8	8.7	1.5	1:0.3	Steel frame	10	35



(a) Case-4



(b) Case-5

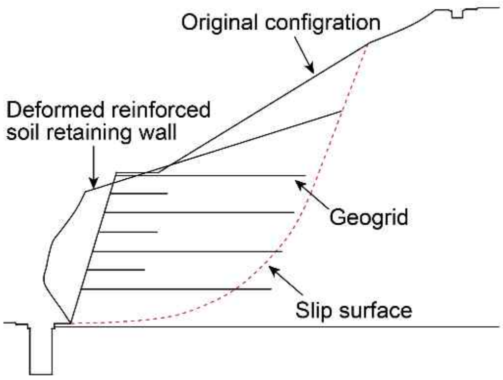
Figure 1. Cross section of the damaged reinforced soil-retaining wall.

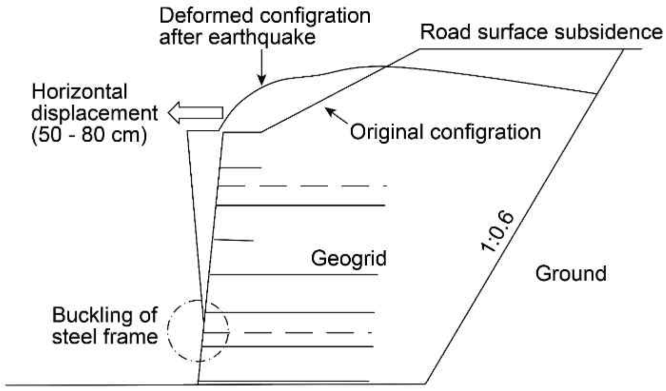
3 CASE HISTORIES

3.1 *Case 4 – Rainfall-induced deformation of reinforced soil wall constructed on inclined ground –*

A reinforced soil-retaining wall with a height of 8.0 m, an upper-embankment height of 2.0 m, and a wall inclination of 1:0.3, which was constructed on inclined ground, was collapsed by rainfall. Figure 4 shows an outline of the deformation. The collapse occurred because of a deep slip surface, including the base of the ground and the backfill soil and reinforcement that was nearly over the nearby erosion-control dam. There was no information on the properties of the backfill soil used in the reinforced soil-retaining wall. The designed tensile strength of the geogrid was 100 kN/m.

Reconnaissance after the collapse revealed that a large volume of spring water came from three points in the surface of the ground. Spring water had not been detected via an investigation before the design of the wall. Thus, drainage equipment such as an underdrain was not constructed in the structure. Additionally, in the area of the collapse, there remained tree stumps that were cut before construction. This indicates that the backfill soil was installed without removing the surface soil. In the above situation, it is considered that the reasons for the collapse of the reinforced soil-retaining wall were record heavy rainfall and the absence of drainage equipment. After deformation, the reinforced soil-retaining wall was reconstructed with the same height and configuration, but the drainage capacity was increased after the collapsed soil was removed.





(a) Case-6 (b) Case-7

Figure 2. Cross section of the damaged reinforced soil-retaining wall.

3.2 *Case 5 – Rainfall-induced deformation of reinforced soil wall constructed on inclined ground –*

A reinforced soil-retaining wall with a height of 9.1 m, an upper-embankment height of 3.0 m, and a wall inclination of 1:0.5 on inclined ground was deformed during construction. Figure 5 shows an outline of the deformation. The reinforced soil-retaining wall collapsed after reaching a height of 6.0. The backfill soil used in this reinforced soil-retaining wall had a unit weight of 18.1 kN/m^3, a friction angle of 36.2°, and cohesion of 8.0 kN/m^2. The designed tensile strength of the high-density polyethylene (HDPE) geogrid was 60 kN/m.

Reconnaissance after the collapse indicated that the ground-water level increased because of the penetration of rainwater into the backfill soil from the unpaved surface at the top of the wall, which resulted in the slippage of the backfill. Moreover, the lower part of the wall moved forward, and the upper part of the wall moved backward. Thus, the slip surface was estimated to be circular. On the basis of the aforementioned reconnaissance results, the reinforced soil-retaining wall was reconstructed to increase the drainage capacity after the collapsed soil was removed. A gravel drain layer with a depth of 30 cm was constructed along the ground under and behind the wall. Additionally, two drainage pipes were installed: one to collect rainwater parallel to and under the wall and another to drain the collected rainwater to the outside.

3.3 *Case 6 – Rainfall-induced deformation of reinforced soil wall constructed with slaking geomaterial –*

A reinforced soil-retaining wall with a height of 4.2 m, an upper-embankment height of 4.2 m, a wall inclination of 1:0.3, and a construction length of 50 m, which was constructed on plain terrain, was collapsed by rainfall. Figure 6 shows an outline of the deformation. The accumulated rain precipitation reached 250 mm for 8 days before the collapse, and the total amount of rainfall was 182 mm for 4 days before the collapse, the total amount of continuous rainfall was 110 mm, and the maximum hourly precipitation was 30 mm/h. Horizontal displacement with a maximum of 1 m occurred at the middle of the wall because of the heavy rainfall, and subsidence ranging from 2.0 to 2.5 m on the road surface of the upper embankment was observed. The backfill soil used in this reinforced soil-retaining wall had a unit weight of 18.0 kN/m3, a friction angle of 36.0°, and cohesion of 8.0 kN/m^2. The designed tensile strength of the HDPE geogrid was 30 kN/m.

Reconnaissance after the collapse revealed that the backfill soil was susceptible to slaking. It is considered that the slaking of the backfill soil made progress in the embankment and that the natural water of the backfill soil approached the liquid limit in one part of the embankment. A series of triaxial compression tests were performed with several extracted samples. In the total-stress condition, the friction angle was 3.5°, and the cohesion was 13.1 kN/m^2. The aforementioned analysis after collapse indicated that the backfill soil should not be reused and that the reinforced soil-retaining wall should not be reconstructed, because of the insufficient drainage capacity. Consequently, a retaining wall was constructed with gabions.

3.4 *Case 7 – Deformation of reinforced soil wall induced by rainfall and earthquake –*

A reinforced soil-retaining wall with a height of 4.2 m, an upper-embankment height of 2.0 m, a wall inclination of 1:0.1, and a construction length of 23 m, which was constructed on improved weak ground, was collapsed by an earthquake. Figure 7 shows an outline of the deformation. It rained before the earthquake. The top of the wall was displaced by 50–80 cm, a large depression was observed on the surface road of the upper embankment, and the steel frame buckled in the lower part of the wall. The backfill soil used in this reinforced soil-retaining wall had a unit weight of 20.0 kN/m^3, a friction angle of 36.0°, and cohesion of 5.0 kN/m^2. The designed tensile strength of the HDPE geogrid was 21.6 kN/m.

Reconnaissance after the collapse revealed that the bearing capacity of the foundation was insufficient and that the failure mode was the tilting of the reinforced soil mass. In accordance with analysis after the collapse, the foundation was improved with cement, and the reinforced soil-retaining wall was reconstructed with the length of the reinforcement increased from 2.7 to 4.7 m.

4 LESSONS LEARNED FROM CASE STUDIES

When a reinforced soil-retaining wall is constructed on marshy or inclined ground, site reconnaissance should be performed before construction to investigate the surface water flow and location and the amount of water coming from springs, and drainage should be planned accordingly. From the viewpoint of the backfill soil material, a slaking material induces the deformation of the structure. Surplus soil should be efficiently used to construct the embankment without industrial waste disposal. To this end, the backfill soil should be sufficiently compacted with crushing and adequate drainage. When large deformation is expected, a stabilization technique can be applied to increase the stability of the wall. Seismic forces other than water pressure caused by rainfall have considerable influence on the deformation of reinforced soil-retaining walls. Regarding countermeasures after deformation, in many cases, reinforced soil-retaining walls were reconstructed with the same height and inclination and an increased drainage capacity or reinforcement length.

The aforementioned case studies reveals that the design conditions do not always correspond to the construction site. Additional investigation or redesign may be necessary. For example, record-braking rainfall may cause an unexpected amount of water to flow into the drainage. In such a case, there are signs indicating unusual water flow from the end of the drainage. When an external force beyond the design considerations acts on the structure, requisite measures should be taken as soon as possible after deformation of the structure is confirmed. For enabling mutual management at all stages, a new information or communication technology is necessary to centralize the management.

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