Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Design and performance of a new type of reinforced earth slope

Ohta, H.
Tokyo Institute of Technology

Iwata, E.
Ministry of Land, Infrastructure and Transport/Hokuriku Regional Department Bureau/Toga Dam Construction Office

Arai, K.
University of Fukui

Kawamura, K.
Kanazawa Institute of Technology

Nishimoto, T.
Century Consultants Co., Ltd

Yokota, Y. & Tsuji, S.
Maeda Kosen Co., Ltd.

Keywords: reinforced earth slope, step form, compressive prestress, monitoring

ABSTRACT: Introduced is the field performance of a new type of reinforced earth slope that consists of steps each of which has a horizontal plane of about 0.8 m width retained by an expand metal wall standing nearly vertically. Each step rises about 1 m resulting in the overall slope of 45 degrees, i.e. 1(in height): 1 (in horizontal distance). The flat planes are expected, at the design stage, to be wide enough that short trees and plants can grow there. Each horizontal plane is tie-backed by geogrid. Each of the compacted soil layers sandwiched by two sheets of geogrid is compressed by pre-stressed vertical steel bars connecting geogrids. The pre-stresses introduced into the steel bars at the construction stage may be relaxed after some period of time, but they can be applied again in case that they are needed. During a period from 1999 through 2001, two high embankments of 28 m and 40 m high were constructed with the overall slope of 1:1. These two embankments are fully monitored during and after construction by measuring tension in the steel bars and geogrids, vertical and horizontal earth pressures at several points, horizontal displacement in the fill bodies and displacements of the slope surfaces. Monitoring ensured that these two slopes are in very stable conditions. The monitoring of these two embankments during a period of 5 years made it sure that the slopes are tough enough to keep their stability and resistibility against seepage flow and erosion caused by heavy rains and snowfalls.

1 INTRODUCTION

When performing the embankment construction in the intermountainous area where a rich natural environment spreads through (Photo 1), traditional method of slope grading makes large slope face. Therefore, in case of the road embankments associated with Toga dam construction, a steep grading by high embankment was required because of some problems in construction, such as the protection of natural environment, and transportation of earth and sand (Figure 1). As the geology and topography condition is complicated, and the embankment scale became large, adequate examination for reliability and considerate evaluation were needed. "Technical Committee for steep grading of high embankment construction method on the slope" was established, and the examination for construction methods that took a natural environment and long-term stability of the overall embankment into consideration was performed.

Photo 1. Topography.

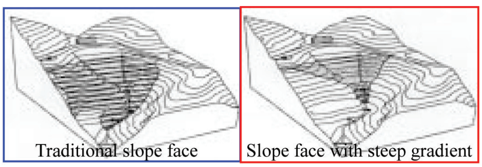

Figure 1. Difference of face of slope.

In the selection of construction method, the point discussed in particular was about the treatment method of a face of embankment slope. In the face of slope, confining pressure by embankment is small, and compaction tends to become insufficient. There was some risk that receives the effects, such as earthquake, seepage flow from rainfall and snowfall. Then the deformation of a slope face and surface avalanche could tend to occur, and the overall slope stability would be worried in the long term. For a reinforcement method of a slope face, soil-quality stabilization methods such as cement or substitution method were thought about. Herein a new construction method (TOGAWALL method) that used the geogrid and prestress on the slope face using light steel plate and steel bar, was adopted because of solving the problems, such as adaptability to deformation, property of long term strength and effective use of developed soil (Figure 2). This paper reports an outline of the TOGAWALL method and field observation for behavior of reinforced embankment.

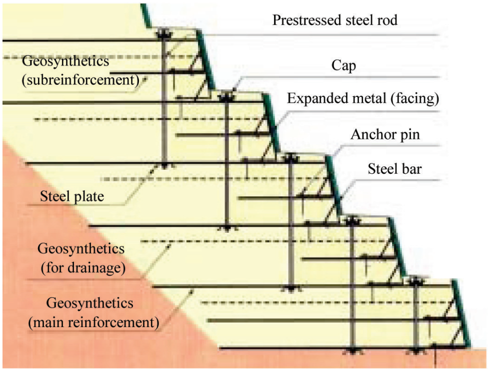

Figure 2. Cross section of a new type of reinforced slope.

2 OUTLINE OF TOGAWALL METHOD

The TOGAWALL method has two features. One is the step form in which slope face consists of steel panel of 1m high and flat area of 0.8 m wide. Another feature is, by adding compression prestress vertically to the about 2 m area sandwiched by geogrids in the flat area using steel plate and steel bar, to suppress volume expansion (positive dilatancy) generated at the occurrence of shearing deformation of the soil (Figure 3). The slope face having the step form is effective for the greening and planting and useful for the protection of natural environment. It helps maintenance as the space that is tense again when the compressive prestress being relaxed. The embankment of the area sandwiched by geogrids and received compressive prestress remarkably increase the shearing resistivity, and its ductility is drastically improved. A domain of this slope face acts as pseudo-wall of soil and adds shearing resistivity against slipping and retaining effect by the weight of wall surface body. As a result, from the generation of the apparent cohesive strength with the increase of slip protection force and the increase of lateral pressure, the decrease of necessary tensile strength of geogrid and the shortening of laying longitude are expected.

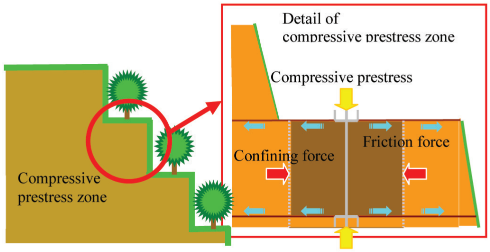

Figure 3. Mechanism of Togawall.

3 OUTLINE OF CONSTRUCTION

3.1 *Situation of foundation ground and shape of embankment*

By a new roadwork associated with Toga dam construction, in an adjacent swamp area (Kitatani and Inotani), TOGAWALL of 28 m and 40 m high was built at the face with the overall slope of 1:1 during from 1999 to 2001. As the mountainous ground is steep and there was the elevation difference of about 50 m, reinforced embankment area was about 2000 m^2 and soil quantity of cutting and filling was about 50,000 m^3. The situation of foundation ground of 28 m high and the shape of embankment are shown in Figure 4. The foundation ground is roughly classified into the talus sediment, old embankment and rock. Old embankment was the surplus soil (N value = about 5 to 10) of previous construction works, extended to the wide foundation area, and its digging was difficult.

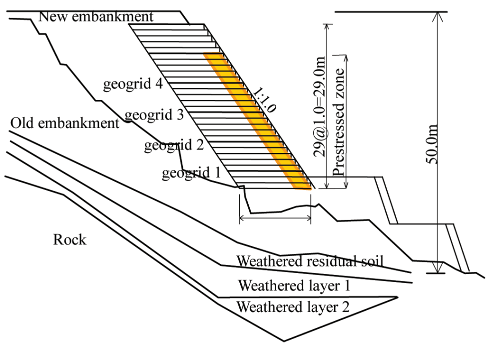

Figure 4. Embankment of 28 m high.

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3.2 *Soil properties of embankment and foundation ground*

Soil parameters used in the stability analysis are shown in Table 1. For the embankment materials, direct shear test (constant volume) was carried out for the actual gravel soil used for banking. Considering long-term stability, the shear strength in drainage condition was used in the stability analysis. However for the strength parameters of the embankment, by evaluating leaning and compaction effects by pseudo-wall of soil, stability analysis was carried out using apparent cohesion c = 30 kN/m^2 and angle of shear resistance ϕ = 30°C. For the foundation ground, soil parameters were determined by laboratory test using undisturbed specimen and on standard penetration test.

Table 1. Soil parameters of embankment and foundation ground.

	Unit weight (kN/m^3)	Cohesion (kN/m^2)	Angle of shear resistance (°)
New embankment	19.0	30.0	30.0
Old embankment	19.0	0.0	28.0
Weathered residual rock	18.5	50.0	23.3
Highly weathered layer	20.0	60.0	23.3
Mid weathered layer	20.0	70.0	23.3
Rock	23.0	0.0	42.5

3.3 *Placement of geogrid*

For geogrid, aramid fiber reinforcement geogrid in which strength is 27 kN/m, was used. It is small creep deformation, high strength and low elongation (4-6%). The placement of geogrid (geogrid interval and laying length) is determined by carrying out stability analysis which contains the internal stability analysis assumed as circular slip surface for pulling and breaking of geogrid, and the overall stability analysis considering envisaged all slip surface in reinforced area and outer edge slip surface.

3.4 *Outline of construction*

Construction procedure is shown in Figure 5 and is as follows : (1) leveling of the foundation ground, (2) assembling and installment of lower plate for reaction and installment of the facing material and geogrid, (3) spreading and rolling of embankment materials, (4) connection of thread steel bar, to installment and assembling of upper plate for reaction were repeatedly performed up to the design height of embankment, and (5) the overall embankment was constructed. Loading of the prestress was first done as preliminary loading during construction. After constructing embankment, the prestress was again applied sequentially from the lower part of embankment (Photo 2).

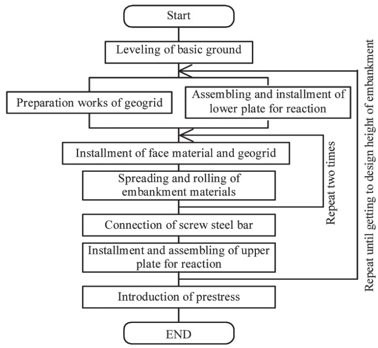

Figure 5. Flow of construction.

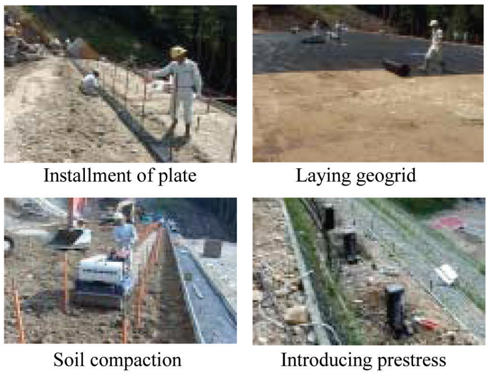

Photo 2. Procedure of construction.

4 FIELD OBSERVATION OF EMBANKMENT

4.1 *Result of field observation*

Field observation for the TOGAWALL of 28 m high and 40 m high was carried out to obtain basic data for future design and to ensure safety of embankment during construction. In the measurement in Kitatani of 28 m high, 5 data items were observed stress of geogrid, stress of steel bar for introduction of compressive force, vertical and horizontal earth pressures for each zone, displacement of the foundation ground and the toe of slope, and displacement of the slope face of embankment. The measurement section and the result of measurement at the time of embankment completion were shown in Table 2. In the result of observation, deformation of embankment including the foundation ground is small with about 2.0% of embankment height in vertical displacement, about 1.0% of embankment height in horizontal displacement. The force of reinforcement materials converged to about 30% of the design strength and embankment is keeping stable state.

Table 2. Result of measurement.

Item	Method	Result
Force of reinforcement material	Strain gauge (1.0 m interval)	Force increases until 9 kN/m during construction and reaches 32 kN/m after introducing prestress.
Force of steel bar	Strain gauge (0.5 m interval)	Force acting on steel bar is reduced to 1/3 after introducing prestress.
Earth pressure	Earth pressure meter	Horizontal earth pressure in the prestress zone is smaller than active earth pressure calculated by earth pressure theory.
Displacement of foundation ground	Clinometer	Foundation ground deforms 50 mm horizontally.
Displacement of slope face	Optical distance measuring	Vertical displacement is 63 cm and horizontal displacement is 37 cm in middle part of slope.

4.2 *Effect by introduction of compressive prestress*

Stress measurements were carried out for four geogrids in Figure 4. The geogrid 3 and 4 in Figure 4 in which stresses change significantly at the time of compressive prestress introduction are shown in Figure 6. Some effect by introducing compressive force was verified. The change of earth pressure in case of introduction of compressive force is as follows. At the time of introduction of compressive force, about 10 kN/m^2 increase in vertical earth pressure and about 2 kN/m^2 increase in horizontal earth pressure were observed. The stress change of reinforcement materials and earth pressure change at the back face of area introduced compressive force, show the increase in the retaining wall effect and slope stability due to introducing compressive force.

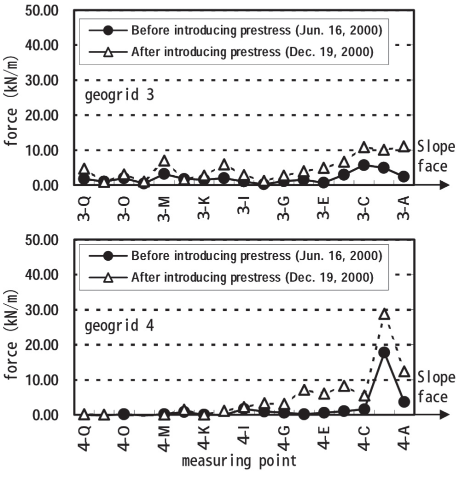

Figure 6. Force change of reinforcement materials by introduction of compressive force.

Photo 3. Overall view of embankment.

5 CONCLUSION

The construction site neighbors the specified area of ground slip, and steep embankment must be constructed over the old embankment layer which was soft and inhomogeneous. This was the construction works under very severe condition. However, from an observation result during about 5 years in a heavy snowfall area more than 3 m and a stability calculation result, we think that this method is superior in the long-term stability of embankment and has high resistivity to seepage flow and erosion from rainfall or snowfall. TOGAWALL can build a high embankment having high reliability as a permanent structure even under a severe topographical condition. An application as repair and reinforcement maintenance of existing reinforcement construction method can be thought about. The application of TOGAWALL in more wide area is expected hereafter.

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