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Construction of a geogrid-reinforced counter-weight fill to increase the seismic stability of an existing earth dam

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ABSTRACT: The seismic stability of an existing old earth dam was increased by means of the geogrid-reinforcement technology. The earth dam was completed 1927 for a man-made lake, the Murayama-Shimo Reservoir, located on a hilly area, called Sayama-Kyuryo, in the northwest of Tokyo. When constructed, the earth dam, having a crest length of 587 m and a height of 32.6 m, was the largest earth dam in Japan. The reservoir is exclusively for water supply in Tokyo, which becomes extremely important in supplying water at the time of disaster like earthquakes because of ability of sending raw water in gravity flow to several water purification plants on the downstream. Moreover, the area in front of the downstream slope of the dam has become a heavily populated residential area. This paper describes the design, structure and construction of a counter-weight fill with a 17 m-high geogrid-reinforced steep slope that was constructed on the downstream slope of the earth fill. A HDPE geogrid was used. The total area of the geogrid layers stalled in the fill is 28,500 m^2.

1 OUTLINE OF MURAYAMA-SHIMO RESERVOIR AND IT'S REINFORCEMENT

1.1 *Reservoirs for drinking water in Tokyo*

The Bureau of Waterworks, the Tokyo Metropolitan Government, has three reservoirs on a hilly area, called Sayama-Kyuryo, in the northwest of Tokyo, which are Yamaguchi Reservoir (with a storage capacity of 19,530,000 m^3), Murayama-Shimo Reservoir (11,840,000 m^3) and Murayama-Kami Reservoir (2,980,000 m^3). They store the raw water transmitted from the Tamagawa River, running east of the site from the mountain area in the west of the metropolitan Tokyo. Their total storage capacity is about 35 million m^3, which is nearly the same as the amount of the water spent for one week in the 23 wards (i.e., the central urban area) of Tokyo. As they are located on a relatively high land, they can send the raw water in gravity flow to several purification plants existing in their downstream without using any artificial power. For this reason, they are extremely important in ensuring the water supply at the time of disaster like earthquakes, power failure and so on.

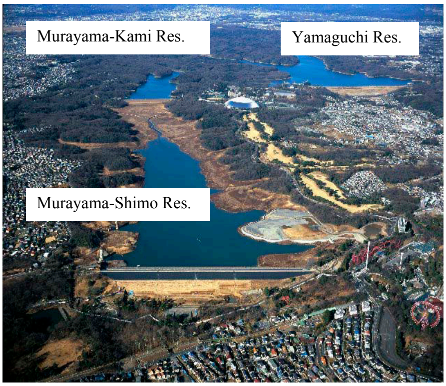

Photo.1. Air view of three reservoirs (the downstream slope of the earth dam for Murayama-Shimo Reservoir under reconstruction)

1.2 *Murayama-Shimo Reservoir*

Murayama-Shimo Reservoir, of which reinforcement works are reported in this paper, was constructed exclusively for water supply use. The earth dam, which was completed on a Pleistocene deposit 1927, is a center-core type earth dam with a crest length of 587 m and a height of 32.6 m.

1.3 *Reinforcement works for Murayama-Shimo Reservoir to increase the seismic stability*

After the Great Hanshin-Awaji Earthquake (1995), the Tokyo Waterworks Bureau performed a seismic resistant analysis of these three earth dams and found that the crest of the dam would settle down about 1 meter if subjected to an intensive seismic motion, as those experienced during the 1995 Hanshin-Awaji Earthquake, caused by an earthquake having a magnitude of the order of eight. Also by taking into account the facts that the dam has become 80 years old and the immediate downstream of the dam has become a heavily populated residential area (as seen from Photo. 1), it was decided to reinforce the earth dams for two relatively large reservoirs (Yamaguchi and Murayama-Shimo) in order to increase their seismic stability. The earth dam for the Yamaguchi Reservoir, which is larger than the Murayama Reservoir, was first reinforced by November 2002. Subsequently, the reinforcement works of the earth dam for the Murayama-Shimo Reservoir started May. 2004.

1.4 *Reinforcing method for the earth dam for Murayama-Shimo Reservoir*

To determine of the reinforcing method, a technical advisory committee consisting of a number of leading specialists was organized. A geological survey and a geotechnical investigation at the site were performed and the internal structure of the earth dam was investigated. Based on the results from the above, the construction method, including the method to obtain the backfill material and the details of construction process were studied while the cost-effectiveness of several proposed methods was evaluated. The results of the investigation revealed that the stability of the existing earth dam when subjected to the considered high seismic design load may not be sufficient. To reinforce the earth dam, it was finally decided to arrange inclined and level drainage layers on the existing downstream slope of the earth dam to keep the groundwater level inside the dam sufficiently low and then construct a counter-weight fill above the drainage layers (Fig. 1). The counter-weight fill increases the confining pressure in the underlying soil layers in the existing earth dam and the natural ground and the drainage layers and thereby the shear strength of soil. By this way, the resisting moment against rotational failure in the downstream slope of the dam can be effectively increased. Furthermore, it was decided to cover the crest of the dam with a cement-stabilized soil layer to prevent the failure of the crest of the dam by a high seismic response.

The construction of the counter-weight fill was started September 2005 and is scheduled to be completed June 2006. All the reinforcing works is scheduled to be completed March 2009.

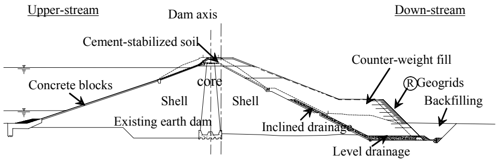

Fig.1. Cross-section of the earth dam for Murayama-Shimo Reservoir after reinforcement works

2 REINFORCEMENT WORKS OF THE EARTH DAM USING A GEOGRID

Despite that it was confirmed that the construction of a counter-weight fill on the downstream slope of the earth dam was the most cost-effective feasible method to reinforce the earth dam, the available space was highly restricted because the present area of the Sayama Park, existing adjacent to the downstream slope of the earth dam (Photo. 1), should be reserved. To alleviate this problem, it was decided to make the slope of the lower part of the counter-weight fill relatively steep with a slope of 1 : 1 in H:V (i.e., the slope angle equal to 45 degrees) reinforced with polymer geogrid layers. The height of the steep slope of the counter-weight fill is about 17 m (see Fig.1).

The reinforcement of the high steep slope of the counter-weight fill with geogrid layers was decided taking into account an extremely high importance of its long-term stability for a long life time of this relatively large scale earth structure. The construction of a counter-weight fill on the downstream slope of the dam was decided because a sufficiently high long-term stability of a geogrid-reinforced steep slope continuously and periodically under submerged conditions when constructed on the upstream slope could not be ensured. It was considered that, when constructed on the down stream slope, even in case the geogrid-reinforced slope is damaged, it does not directly affect the function of the reservoir while its repair works become quite feasible.

3 CONSTRUCTION MATERIAL AND THEIR PROPERTIES

3.1 *Backfill material*

The backfill soil for the counter-weight fill, including a geogrid-reinforced slope, was obtained by mixing in a volume ratio of 1.0 : 1.0 : 1.0 on-site soil and a purchased gravel and a purchased sand. The on-site soil was obtained by excavating a small counter-weight fill that was existing at the toe of the downstream slope. Fig. 2 shows the average grading curve of the backfill soil after mixing. The maximum size is 150 mm and the fines content ranges from 15 % to 30%. On a stockyard adjacent to the construction site, the excavated on-site soil was placed in a 20 cm thick layer, which was overlaid by another 20 cm thick layer each of purchased gravel and purchased sand respectively. This procedure was repeated. The backfill soil to be transported to the construction site was obtained by scraping these soil layers in such way that the three different types of soil are well mixed.

In the geogrid-reinforced slope, the backfill was compacted in a lift of 20 cm by passing a 10-ton class vibrating roller eight times. The minimum degree of compaction and minimum dry density to be satisfied were specified to 95 %, which were determined based on results from compaction tests in the laboratory (Fig. 3) and confirmed by on-site compaction tests performed in advance. The molding water content was ensured to be within +2.0 % - 1.5% from the optimum.

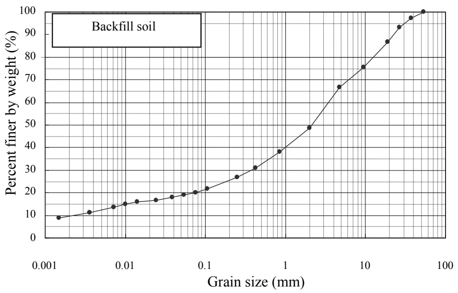

Fig.2. Example of grading curve of the backfill soil for the counter-weight fill

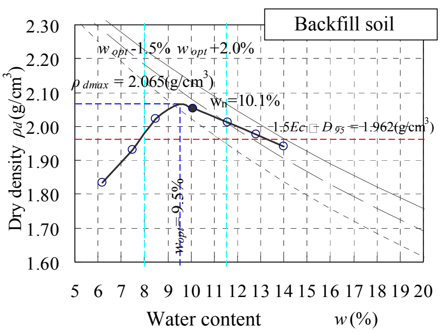

Fig.3. Example of compaction curve of the backfill soil

3.2 *Geogrid*

A geogrid of HDPE was selected to ensure a high interlocking with the backfill having some amount of fines. Four different types of geogrid having different rupture strengths were used depending on the required strengths at the respective zone in the steep slope. The nominal tensile rupture strengths obtained by tensile tests at a strain rate of 1% or 20%/min using 20 cm wide specimens were, respectively, 2.0 kN/m, 21.6 kN/m, 30.0 kN/m and 36 kN/m. It was investigated whether it is additionally necessary to arrange layers of a non-woven geotextile in the backfill to dissipate excess pore water that might build up during the construction of the counter-weight fill. It was found based on results from consolidation tests on the backfill material and associated analysis that this measures is not necessary.

3.3 *Pull-out tests*

Considering the fact that the backfill soil includes some amount of fines, a series of pull-out tests, as shown in Fig. 4 and Photo.2, were performed. The pull-out displacement rate was 1 mm/min and the confining pressure applied ranged from 5 kPa to 70 kPa. It was confirmed that the bond shear strength at the interface between the backfill and a geogrid layer is sufficiently high; i.e., a minimum bond shear strength expressed as: $\tau_f = c + \sigma\tan\varphi$ (c= 9.5 kPa; and φ= 26.4 degrees) could be confirmed.

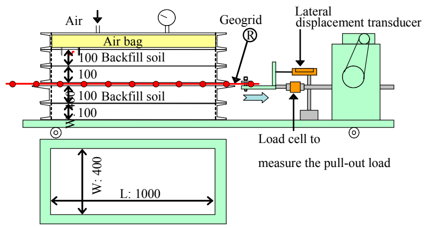

Fig.4. & Photo.2. Pullout tests of the geogrid used in the project (all the units in mm)

4 PLACEMENT OF GEOGRID LAYERS

4.1 *Structure of the geogrid-reinforced fill*

Based on results of limit equilibrium-based stability analysis assuming circular failure planes, a cost-effective arrangement of geogrid layers that ensures the necessary seismic stability was determined. That is, eight 7 m-long layers of a geogrid having relatively high tensile rupture strengths 21.6 ~ 36.0 kN/m were placed with a vertical spacing of 1.6 m, as shown in Fig. 5.

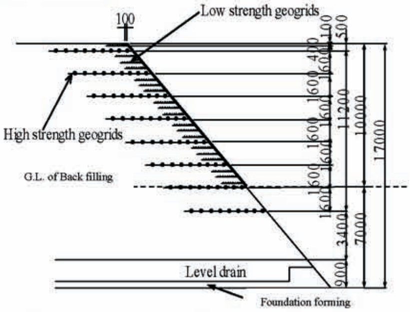

Fig.5. Cross-section of the geogrid-reinforced steep slope.

According to the necessary tensile rupture strength at the respective geogrid layer at a different level, four types of geogrids having different rupture strengths, described in the preceding section, were used as shown in Fig. 6.

Moreover, to prevent the surface failure in the steep slope, a number of 2 m-long low strength geogrid layers were arranged with a vertical spacing of 0.4 m, as show in Fig. 5. The total area of the installed geogrid layers is 28,500 m^2.

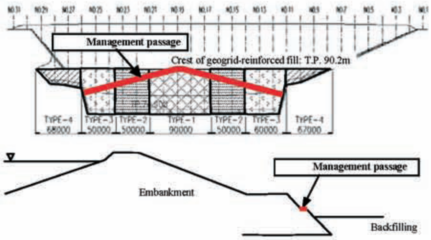

Fig.6. Four types of geogrids used

4.2 *Other details*

The lower part for a height of about 6 m of the 17 m-high geogrid-reinforced steep slope (Fig. 5) will become below the final ground level after backfilling the area in front of the slope to make the ground level the same as the one of the existing park, Sayama Park. The buried part of the slope was reinforced only with one layer of geogrid as shown in Fig. 5 based on stability analysis.

The face of the geogrid-reinforced steep slope will be vegetated so that the complete slope looks a natural one. The greening works aim at also a protection of the slope face against erosion in case of heavy rainfalls while protecting the geogrid layers against the degradation by UV. It is planned to spray seeds of relevant grass types on a 5 cm-thick layer of substrate medium placed in advance on the slope face.

4.3 *Long-term monitoring of the behavior of geogrid-reinforced steep slope*

To confirm whether the tensile strains that will develop in the geogrid-reinforced steep slope is kept far below the tensile rupture strain, equal to about 10 %, the tensile strains of geogrid will be observed for a long period after the completion of the slope. The deformation of the slope will also be monitored for some long period. This monitoring is necessary also to confirm that the stability design of the fill is reasonably on the safe side.

5 CONCLUSIONS

To ensure a sufficiently high seismic stability of an existing earth dam for a very important reservoir for water supply to Tokyo with a densely-populated residential area in front, on the downstream slope of the dam, a counter-weight fill with a17 m-high steep slope reinforced with HDPE geogrid layers was constructed. A 1:1 steep slope was adopted to alleviate a space restraint while to ensure a high seismic stability. The total area of the geogrid layers was 28,500 m^2. As this project is the first case of reinforcing an existing earth dam by means of geogrid-reinforcement, the grading characteristics of the backfill was strictly controlled while a high degree of compaction was ensured. The long-term post-construction behavior of the geogrid-reinforced steep slope will be monitored while ensuring a long-term durability of the geogrid in the steep slope.

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