Earth Reinforcement Practice, Ochiai, Hayashi & Otani (eds) © 1992 Balkema, Rotterdam. ISBN 90 5410 093 1

Stability analysis for reinforced cut slopes with a rigid facing

M. Muramatsu, K. Nagura, T. Sueoka & K. Suami
Technology Research Center, Taisei Corporation, Yokohama, Japan

T. Kitamura
Taisei Corporation, Tokyo, Japan

ABSTRACT: In order to define various kinds of rigidities of facing structures along with their effects in the case of reinforced cut slopes, small-scale laboratory relief model tests and full-scale field tests were performed using different facing structures, focusing particularly on concrete crib and concrete spraying types. In the laboratory, the small-scale models of reinforced slopes having different types of facing failed due to the relief of the retaining plates. Considering these results, a practical stability analysis method for reinforced cut slopes using various facing types is proposed, which consists of the distribution of the tensile forces of the reinforcement at the relief stress as well as the effects of slope facing. The laboratory tests, field tests and the results obtained by the proposed analysis method are discussed and compared with each other, and the validity of the proposed stability analysis method is then verified by those results.

1 INTORODUCTION

Earth reinforcement of cut slopes has attracted considerable attention in recent years in view of its numerous merits which include economic feasibility, simplicity and minimal destruction of the natural environment. Accordingly, the number of cases in which this technique has been employed have increased correspondingly. However, it appears that the theory behind its reinforcement principle and its design methods are somewhat inadequate. The majority of design methods are based on the research results of destructive testing performed by loading of reinforced slopes, with stability being evaluated in limit equilibrium analyses according to the pull-out resistance of the reinforcements placed at a portion farther back than the latent sliding surface. However, reinforced cut slopes designed according to the above-mentioned methods have proven to be irrational, as the measured results from actual construction have reportedly tended to differ. The primary causes of this are that the stress conditions of actual slope cutting and the stress conditions of experimental loading are different, deformation accompanying stress release of actual slopes is not taken into consideration, and the effectiveness of slope facing is also not taken into consideration.

In this report, a study was conducted regarding the tensile forces acting on reinforcements and the effectiveness of slope facing by conducting a laboratory relief model test which simulated the release of stress by cutting. A new method for stability analysis is proposed which takes into consideration the distribution of tensile forces of reinforcements based on these results, and a quantitative evaluation is attempted in regard to the effectiveness of slope facing. Moreover, a discussion is also presented regarding the validity of this design method based on the measurement results from actual field tests.

2 RELIEF MODEL TEST

The experimental apparatus is indicated in Fig. 1. The test model is 50 cm wide by 200 cm long by 120 cm high. Twelve (12) cm high blocks were stacked in a stack of 9 blocks via bearings on one side forming a flexible retaining wall measuring 108 cm in height. The back of each block was supported by a motorized jack so that each block was able to move independently. In the experiment, excavation and cutting were able to be simulated by filling dried Toyoura sand inside the retaining wall and moving the blocks starting with the top block one at a time to remove the load. Phosphor bronze plates having a thickness of 0.12 mm and width of 5.0 mm were used for the reinforcements embedded in the sand. The reinforcements were then coupled to the slope facing with bolts The surfaces of the reinforcements were covered with sand using an adhesive in order to increase the frictional resistance between the reinforcements and the sand.

In the experimental case described in this report, the reinforcement were placed horizontally, one layer each at the center of each block at a pitch of 12 cm towards the back of the model. In other words, the reinforcements were placed at a 12 cm pitch vertically and horizontally. Testing was performed in the case of a uniform reinforcements length of 25 cm, and in the case only the top two layers measured 50 cm. With respect to the slope facing, the two types of slope facing consisted of a continuous grating crib type and an independent bearing plate type as indicated in Fig. 2, with testing performed by changing the surface areas of each of these types.

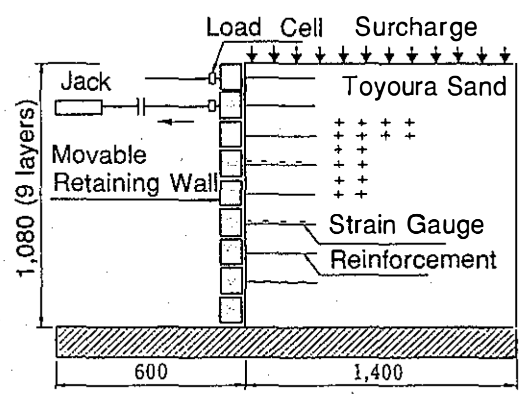

Fig. 1 Experimental Relief Model

3 MODEL TEST RESULTS

Fig. 2 indicates typical test results in the case of using a square bearing plate measuring 3 cm on a side, and the case of using a grating crib having a width of 2 cm for the slope facing. The displacements indicated in the diagram represent the distribution of displacement of the slope surface at the points each of the blocks were released. In addition, the forms of the sliding surfaces that were produced are also shown. While the reinforcing patterns of the reinforcements are completely identical in both cases, the deformation modes are clearly different. In comparison with the case of using a bearing plate, deformation that is constrained overall is observed in the case of using a grating crib, thus indicating promotion of integration of the reinforced region. The location where the sliding surface is produced as well the height are also different. However, in all cases, the sliding surface passed through the reinforced region, occurring linearly at nearly the active failure. In other words, simulated retaining wall-like behavior was not demonstrated. Fig. 3 is a plot of the ratio of the area occupied by the slope facing on the slope surface versus the self-standing height of the slope. The placement patterns of the reinforcement were naturally all the same. A clear relationship was observed between both factors

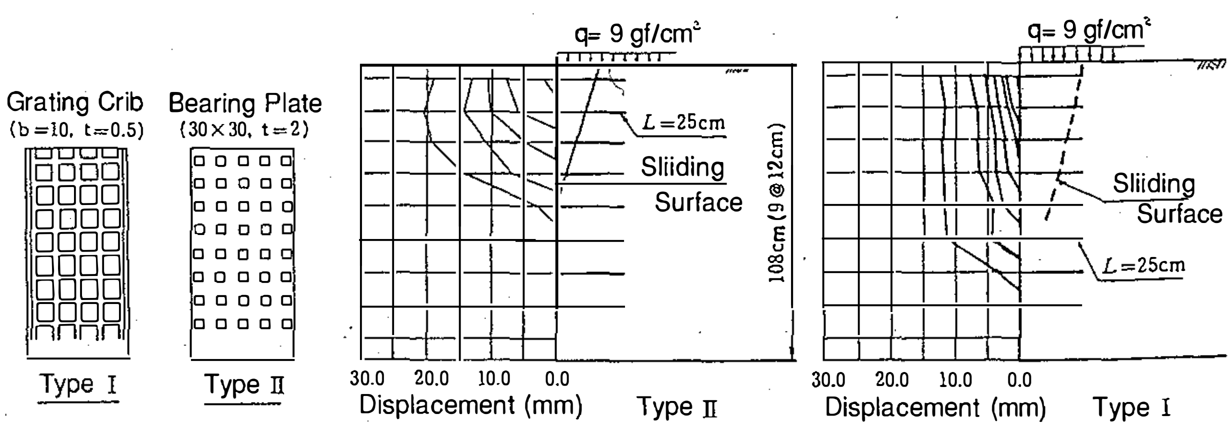

Fig. 2 Slope Facing Types and Reinforced Slope Deformation Modes

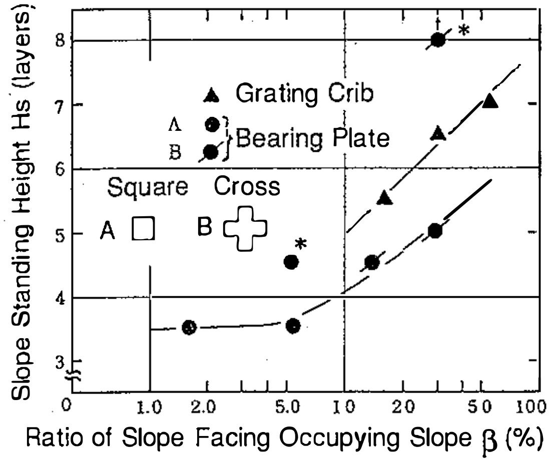

Fig. 3 Ratio of Slope Facing Occupying Slope vs. Slope Standing Height

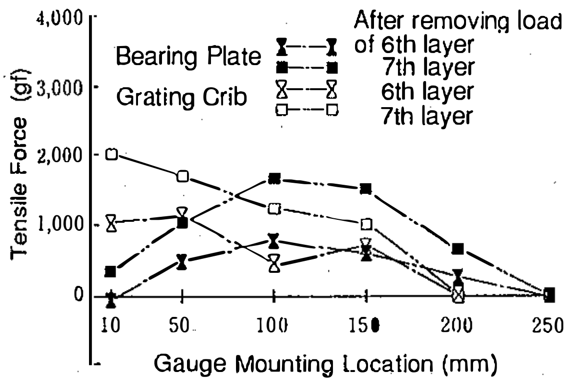

Fig. 4 Effect of Slope Facing on Distribution of Reinforcement Tensile Forcc. Distribution of Tensile Force in 6th Layer Reinforcement.

from which it can be clearly understood that the stability of reinforced slopes is strongly influenced by the ratio of slope facing which occupies the slope surface.

The following considers the tensile force produced in the reinforcements. Fig. 4 compares the distribution of tensile force that was produced in the 6th layer of reinforcement with respect to the cases of using a bearing plate and a grating crib for the slope facing. In contrast to a symmetrical distribution being demonstrated in the center of the reinforcement in the case of the bearing plate having a low level of slope facing effects, in the case of the grating crib, it can be seen that the shape of the distribution has changed to that in which the maximum value of tensile force is biased towards the slope surface. A similar trend was observed in reinforcements of other layers and in other

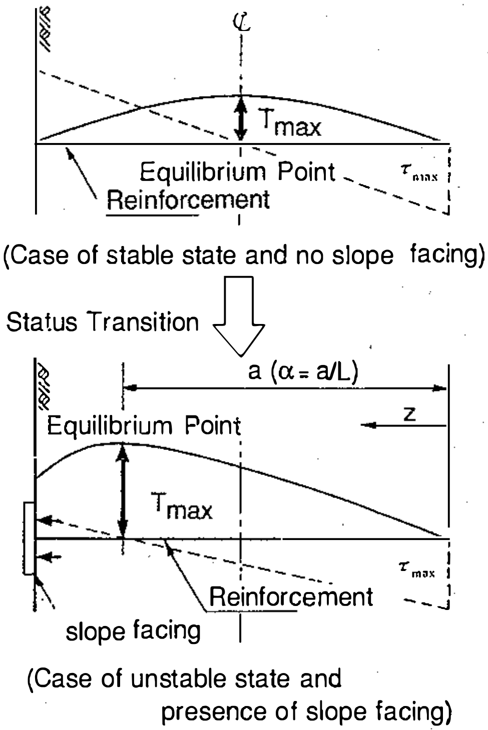

Fig. 5 Mechanism of Occurrence of Tensile Force in Reinforcements

cases as well. As a result of further studies summarizing these experiment results, it was determined that the distribution of tensile force produced in reinforcements can be schematically expressed as in Fig. 5. Firstly, friction τ between the reinforcements and the ground is approximately represented with a triangular distribution as shown in the diagram. Next, in the case of slope facing, the equilibrium point of friction τ shifts toward the slope surface according to the degree of the burden of earth pressure. As a result, differences in the distribution form of tensile force are believed to occur as indicated in the diagram. In other words, friction τ, which acts on the reinforcements, and reinforcement tensile force T can be determined from the following equation:

$$\tau = \tau_{max}(1-z/\alpha) \quad (1)$$

$$T = \pi DLz(1-z/2\alpha) \quad (2)$$

where,

- τ_{max} : Maximum friction between reinforcemets and ground
- D : Diameter of reinforcements
- L : Length of reinforcements
- α : Constant which fluctuates according to the ratio of facing occupying the slope surface

4 STABILITY ANALYSIS

Rather than the conventional method based on the pull-out resistance at depths at or below the sliding surface, the limit equilibrium method was employed for stability analysis by setting the distribution of the tensile forces of the reinforcements according to the method described in the previous section. Although the following equation itself is not different from that used in the past, its application differs from conventional use in that Ti is set in advance.

$$F_s = \frac{\Sigma[cl+\{W_i\cos\alpha_i + T_i\sin\theta_i\}\tan\phi]}{\Sigma[W_i\sin\alpha_i - T_i\cos\theta_i]} \tag{3}$$

where,

- c, ϕ : Ground cohesion and internal friction angle
- T_i : Reinforcement tensile force
- θ_i : Reinforcement placement angle (with respect to horizontal)

Fig. 6 indicates the results of comparison with the test results with respect to two cases using bearing plates in which the length of the reinforcements are different. This diagram indicates the fluctuation in the safety factor Fs for each load removal step of each block. The favorable correlation of the calculated results and the experiment results indicates the validity of the above-mentioned analysis method.

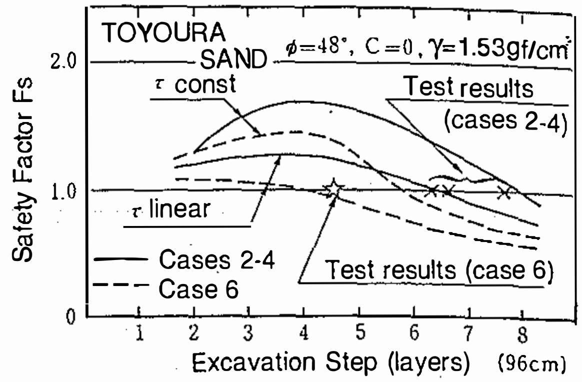

Fig. 6 Results of Slope Stability Analysis

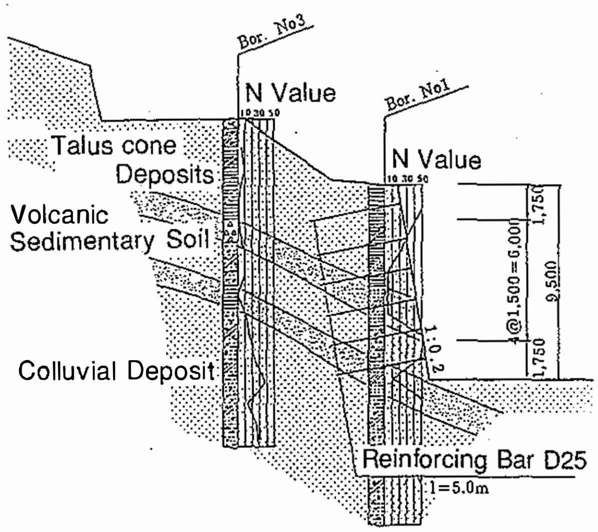

Fig. 7 Construction Work Cross-Section

5 FIELD TEST

Earth reinforcement was actually applied on a cut slope in the field, changing the types of slope facing employed at that time in order to observe the resulting behavior. A summary of that work is described below. The soil profile at the site was comprised of talus cone type deposits consisting primarily of loamy gravel containing large amounts of boulders measuring 10-30 cm in diameter as indicated in Fig. 7. This type of ground was cut to a height of 9.5 m at a gradient of roughly 80 degrees. The reinforcement method consisted of driving in D25 reinforcing bars measuring 5 m in length downward at an angle of 10 degrees and at a vertical and horizontal pitch of 1.5 m. Slope facing was divided into two areas, with one area consisting of conventional concrete spraying (t = 10 cm) and the other area consisting of a sprayed concrete crib (beam width: 20 cm, grating pitch: 1.5 m) as indicated in Fig. 8.

Fig. 9 indicates the measured values of horizontal buried displacement gauges placed in the second layer from the top. The fixed point of displacement is taken to be a point 10 m from the slope face, and it can be seen from the shape of the distribution that in the case of using a concrete crib, the integration of the reinforced area is maintained. This trend was similar to that observed in the relief model test. Next, Fig. 10 indicates the tensile forces that were produced in the reinforcing bars. The diagram also shows the results of simulation analysis using the two-dimensional elastic finite element method. The calculated values, measured values as well as the results from the laboratory relief model test all demonstrate a similar trend. More specifically, in contrast to maximum tensile force occurring near the center of the reinforcement in the case of slope facing by concrete spraying, maximum tensile force

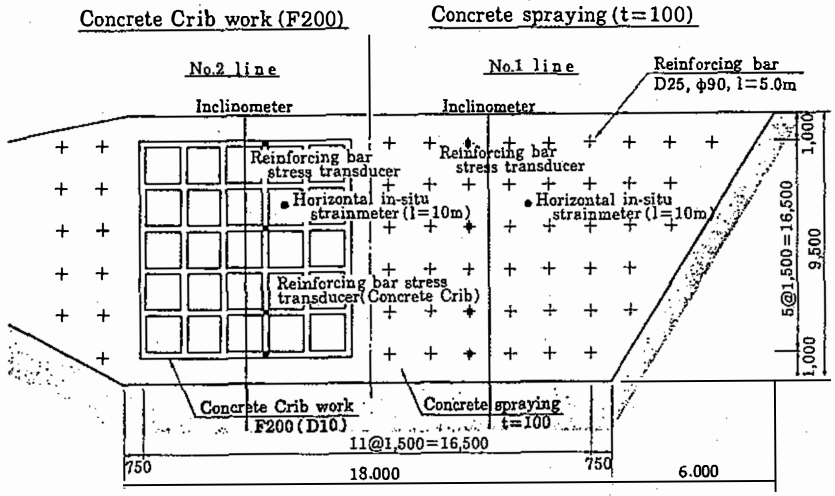

Fig. 8 Slope Frontal View and Instrument Placement

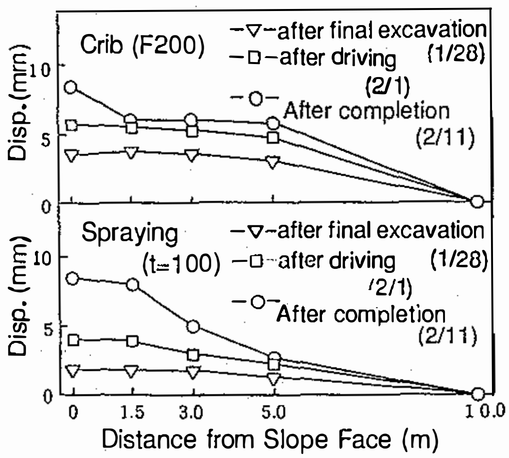

Fig. 9 Distribution of Internal Displacement

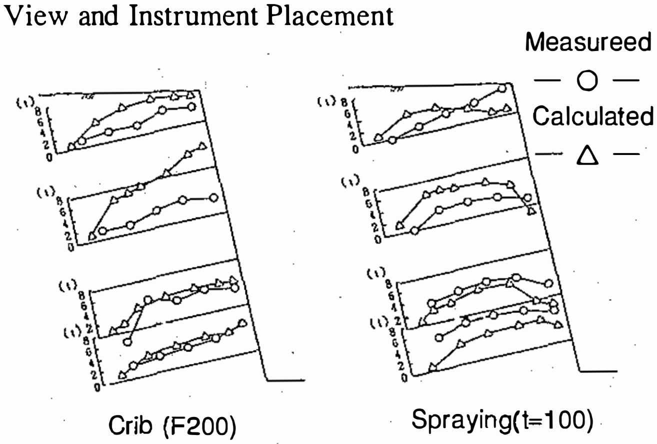

Fig. 10 Distribution of Tensile Force in Reinforcing Bars

occurs on the side of the slope surface in the case of a concrete crib. When viewed together with the results of the laboratory relief model test, this fact means that slope facing by concrete spraying alone does not adequately contribute to improvement of the overall stability of the slope, while also indicating that the employing of slope facing wherein the slope face becomes a rigid, integrated structure in the manner of a crib is able to contribute to improvement of the stability of the slope .

It has been previously discussed that the effects of slope facing on the stability of reinforced cut slopes are intimately related to the ratio of the area of the slope facing occupying the slope, and Fig. 11 indicates the relationship between the ratio of slope facing occupying the slope and the shape of the distribution of reinforcements tensile force. The ordinate axis in the diagram represents the ratio of the

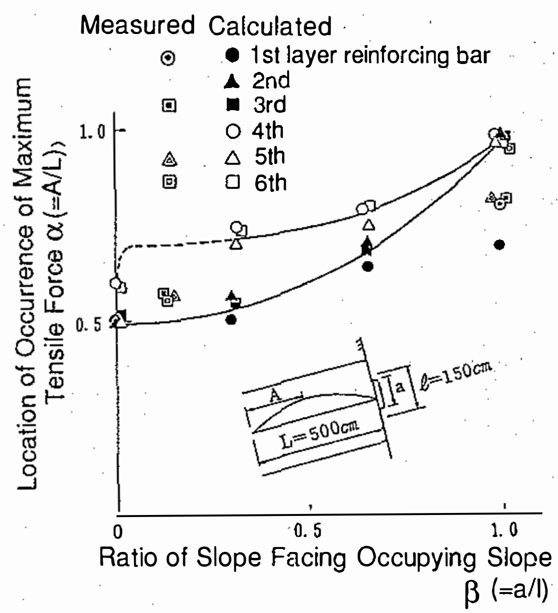

Fig. 11 Location of Occurrence of Maximum Tensile Force

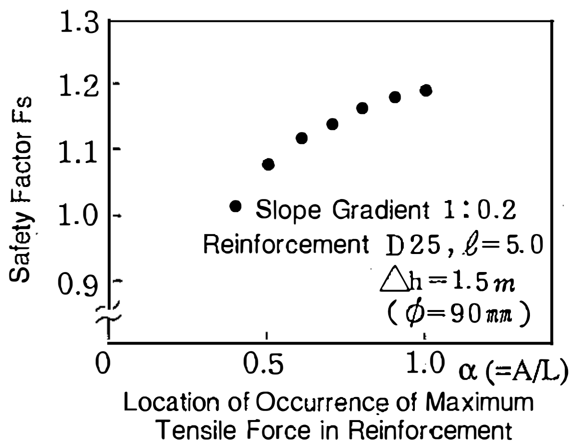

Fig. 12 Effect of Location Maximum Tensile Force on Stability Analysis

location of maximum tensile force with respect to the total length of the reinforcements. In the case of actual slopes, the ratio of slope facing occupying the slope is considered to be a area ratio of slope facing which can be expected to demonstrate adequate structural rigidity. As adequate rigidity cannot be anticipated in the case of concrete spraying alone, it is not evaluated in terms of an occupation ratio. It has been demonstrated that the location of occurrence of maximum tensile force in reinforcements shifts towards the slope face accompanying an increase in the ratio of slope facing occupying the slope.

Analysis of the stability of reinforced cut slopes is performed by determining the shape of the distribution of reinforcement tensile force as was indicated in section 4, and the shape of the distribution of tensile force can be determined according to differences in slope facing by utilizing the relationship of Fig. 11. Fig. 12 indicates the results when a stability analysis is performed by fluctuating the location of occurrence of maximum reinforcement tensile force from the center of the reinforcements towards the slope surface in the field test slope. Accompanying the shift of the location of maximum reinforcement tensile force towards the slope surface, or in other words, accompanying an increase in the ratio of slope facing occupying the slope, the safety factor of reinforced cut slopes can be seen to increase. This finding makes it safe to say that the effects of slope facing are evaluated by the safety factor of reinforced cut slopes.

6 CONCLUSION

A study was conducted regarding methods for evaluating the stability of reinforced cut slopes through the conducting of a relief model experiment taking into consideration the release of stress by cutting. As a result, it was indicated that the tensile forces that occur in reinforcements are effected by deformation of the slope accompanying stress relief as well as slope facing irrespective of the sliding surface. In addition, it was also indicated that the shape of the distribution of reinforcement tensile force as well as stability are effected by the ratio of the area of the slope facing occupying the slope. Based on these results, a method involving the determination of the distribution of reinforcement tensile force in advance followed by the performing of a stability analysis using the limit equilibrium method was proposed. By using this method, it is possible to make a quantitative evaluation of the effects of slope facing on slope stability. In addition, results similar to those described above were obtained in actual work performed in a field test. These results verified the effects of rigid, integrated slope facing, such as a concrete crib, on the stability of reinforced cut slopes.

REFERENCES

Sano, N., Kitamura, T. and Matsuoka, K. 1988. Proposal for design and construction of reinforced cut slope with steel bars, Proc. International Symposium on Theory and Practice of Earth Reinforcement, Fukuoka Japan: 347-352

Muramatsu, M , Suami, K. and Nagura, K. 1991. Reinfored cut slope stabilization with reinforcing bars, Taisei Technical Reserch Report, Taisei corp. ,Yokohama Japan: 215-222

Tatsuoka, F., Tateyama, M. and Murata, O. 1989. Earth retaining wall with a short geotextile and a rigid facing, Proc. 12th ICSMFE, 2: 1311-1314.

Tatsuoka, F., Murata, O. and Tateyama, M. 1991. Permanent geosynthetic-reinforced soil retaining walls used for railway embankments in japan, Proc. International Symposium on Gyosynthetic-Reinforced Soil-Retaining walls,Denver.