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Case histories of earth reinforcement technique in Japan

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ABSTRACT: The soil reinforcement technique has been used in Japan for almost 40 years. The earth reinforcement technique has come to be used for various applications to reinforce soil in this period. The economical efficiency of the earth reinforcement structure has been evaluated in recent years, and the earthquake resistance was proved when the Great Hanshin Earthquake was occurred in 1995. Many earth reinforcement techniques have been introduced as an indicator of the road earthwork in Japan today. This paper describes the kinds of earth reinforcement application that have been used in Japan, the case history, and the statistical analysis.

1 INTRODUCTION

Many methods in filling construction on a soft ground that similar to the reinforcement have come to be used in Japan from around the 1800s. At that time, the structure was built with strictly experiential earth reinforcement. More than 30 years have passed since modern construction method was established and it was used for the structure to secure the stability based on the design system, however, its history is still short.

When a case history of earth reinforcement techniques in Japan is discussed, the following special land features of Japan should be considered carefully. About 60 percent of the land is the mountain ground and unstable foundations, such as landslides and steep slopes. Moreover the soft ground is distributed over the plain parts and the area along the shore. Furthermore, the weather such as heavy rain in the rainy season and snow in winter, and the environmental condition such as volcanic earthquakes influence on the construction works. In order to improve these difficulties, various methods of construction and soil stabilization have already been applied in the public works. From the economical aspect, the curtailment for the costs of construction has been a big subject to discuss since the end of the high economic growth period.

Application of modern earth reinforcement in Japan was started from the sheet method of construction on the soft ground and it was placed on the field of the basal reinforced ground in the 1960s. On the other hand, the first application of the reinforced soil retaining wall was performed in the 1970s. Since then, a large number of constructions by these applications have been built in various areas. Therefore it is presumed that the modern earth reinforcement technique is suitable for the local condition of Japan.

This paper describes the current status and case history of earth reinforcement techniques, which have been applied widely in Japan: firstly, the simplified history on development of the earth reinforcement technique, secondly, the status of application, and thirdly, the statistical analysis about reinforced steep slope embankment and reinforced retaining walls. At the end of this paper, some cases of works in Japan are introduced with figures and photographs.

2 DEVELOPMENT SIMPLIFIED HISTORY OF EARTH REINFORCEMENT TECHNIQUE

As it is mentioned in the introduction, to put the reinforcement in the ground is not new method for constructions. However, new earth reinforcement techniques and reinforcements have been developed gradually in latest 30 years. With these developments, the research from the standpoint of the geotechnical engineering has been performed rapidly. Furthermore, Japanese governmental agencies have accelerated establishment of the indicator of design and the manual about design and construction.

The simplified history on development of the earth reinforcement techniques in Japan is shown in Table-1. Moreover the outline of the change of the

Table 1. Development simplified history (JGS, 1998)

Year	Simplified history in Japan
1959	First application of a spun-bonding geononwoven
1966	Research of the surface processing method by the geonet Research of the reinforced embankment by the weak viscosity ground (slaked lime and filter geosynthetics)
1967	Research of the sheet method on a soft ground
1969	An on-site examination of the surface processing method by the geonet
1972	First construction of Terre Armee reinforced wall
1973	Research of reinforced embankment (railroad embankment)
1977	Development of a pile-net method Development of the surface processing mat method by the water conveying
1981	Development of the sheet method which constructed the bamboo
1982	First construction of soil nailing
1983	First construction of Multi-Anchored reinforced wall
1984	First construction of reinforced steep slope embankment by the geogrid
1986	First construction of reinforced soil retaining wall by the geogrid
1989	A success of Reinforced Railway/Road with Rigid Facing method (RRR)
1993	Investigation about earthquake resistance of reinforced soil structure (earthquake of Kushiro) Development of reinforcement method of ground excavation by the big diameter's reinforcement
1995	Investigation about earthquake resistance of reinforced soil structure (Great Hanshin Earthquake) Activity of the research about the earthquake resistance of earth-reinforcement structure

public designing method of earth reinforcement technique is shown in Table-2.

3 THE STATUS OF APPLICATIONS

The earth reinforcement teclmique is formed by only one element or by more than two elements of the resistance forces of tensile, shear, compression, and bending against the ground by putting the reinforcement in the ground and foundations. Consequently, it has the feature that the stable soil structure doesn't need the following structures; RC retaining walls and sheet piles, pile foundations, ground anchors, and deterrence piles to complement the function that is not in the ground.

The common cases of earth reinforcement used in Japan are as follows; the reinforced ground with soil on the soft ground, the basal reinforced embankment, the reinforced gentle slope embankment with the low quality soil, the reinforced steep slope embankment, the reinforced soil retaining walls and the reinforced natural ground and the excavated ground. And it was replaced the conventional method of construction, and its feature is utilized as a new method of construction. These earth reinforcement techniques are classified into three types, the reinforcement of foundations, the reinforcement of embankment and the retaining walls, and the reinforcement of natural ground and the excavated ground.

Table 2. Changes of the public designing method (PWRC, 1998,1999 and 2000)

Year	Simplified history in Japan
1982	Design and Construction Manual of Reinforced Soil (Terre Armee) Wall Construction Method. (PWRC)
1987	The design method of earth-reinforcement technique of the natural slope by grouting steel rod (Japan highway)
1988	The first revision of Design and Construction Manual of Reinforced Soil (Terre Armee) Wall Construction Method. (PWRC)
1990	Guideline of Geogrid earth reinforcement (Geogrid study group)
1992	Manual of a Rational Design and Construction, Reinforced Soil with Geotextiles (PWRC) The design method of RRR method (Railway Technical Research Institute)
1994	Design and Construction Manual of Multi-Anchored Reinforced Wall Construction Method. (PWRC)
1998	The first revision of Design and Construction Manual of Multi-Anchored Reinforced Wall Construction Method. (PWRC)
1999	A publication of the view of the method of designing in retaining wall method indicator and slope stable method indicator (Road Earthwork / Japan Road Association) The second revision of Design and Construction Manual of Reinforced Soil (Terre Armee) Wall Construction Method. (PWRC)
2000	The first revision of Manual of a Rational Design and Construction, Reinforced Soil with Geotextiles (PWRC)

*PWRC: Public Works Research Center

3.1 *Reinforced ground (basal reinforced ground and basal reinforced low height embankment)*

The range of the reinforced ground is shown in Figure 1 and 2. The geosynthetic is mainly used as the reinforcement of the soft ground.

In the method (a), the single-laid geosynthetic improves the trafficability of the machine during the construction.

In the method (b), the geosynthetic with two or more layers prevents the landslide of the foundations of the embankment on the soft clay.

In the mattress method (c), the geosynthetic with three-dimensional structure distributes the load on the embankment and improve the bearing capacity of foundations.

In the method (d), the geosynthetic with two of more layers is formed in the portion of ground. And it is used to improve the bearing capacity that is insufficient by the method (c).

The method (e) is used when the subsidence of the foundations could be happened by the difference in the consolidation. This application has the effect that prevents the difference of the level at the border plane of the bridge pier, or the embankment made by half-bank and half-cut.

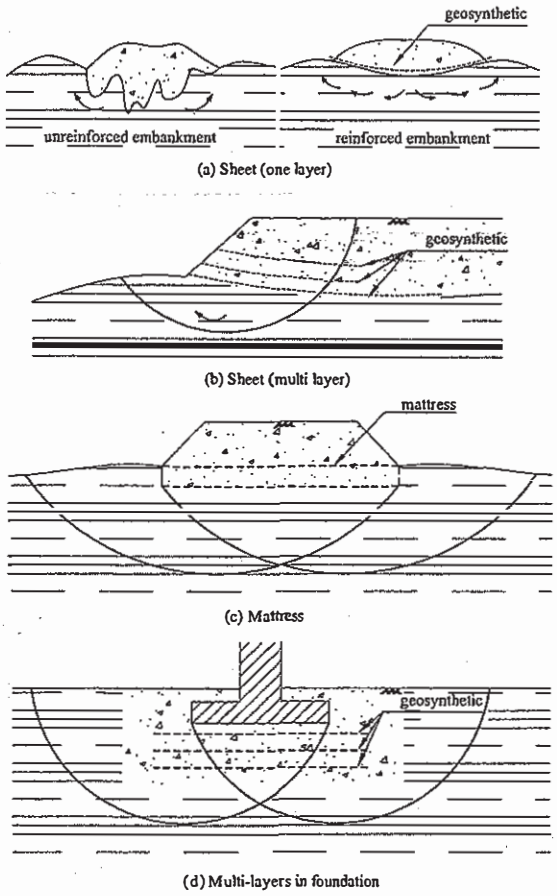


Figure 1. Range of applications where the reinforced ground and foundation (1)

The reinforced steep slope embankment shown in (f) is used as a pre-load method of construction for the limited area. When the wall was built on the soft clay that should be piled, this method is used in order to prevent a lateral flow of the filling load.

(g) and (h) are the typical examples that a few methods of (a) to (f) are used together. They are only used when the piles and the treated soil columns cannot attain the target effect. These methods have the special effect that prevents the differential settlement of the area, a part on piles and a part between piles.

The methods described above are also used by being combined with the other methods in the field of the improvement of soft foundations.

3.2 *Reinforced embankment (reinforced gently and steep slope embankment, reinforced soil retaining wall)*

3.2.1 *Reinforced gently slope embankment*

The range of application with the reinforced gentle slope embankment is shown in Figure 3.

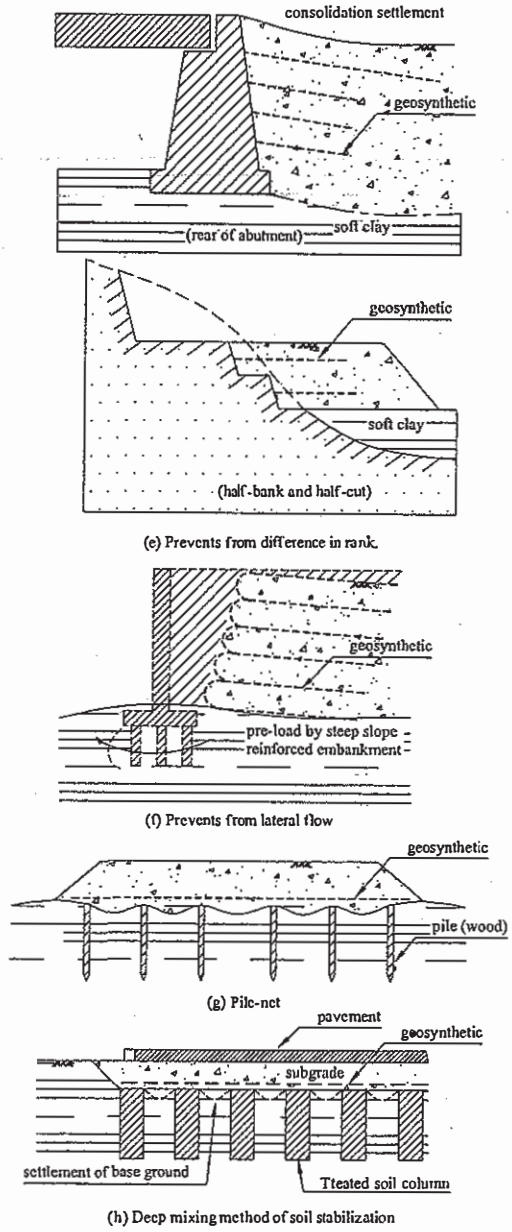


Figure 2. Range of applications where the reinforced ground and foundation (2)

The reinforced embankment method (a) is used when a slope is looser than 45 degrees. It resists the slide of the contained foundations, and tall embankment. In this case, the geosynthetic with short length is laid to prevent the surface of filling from abrasion.

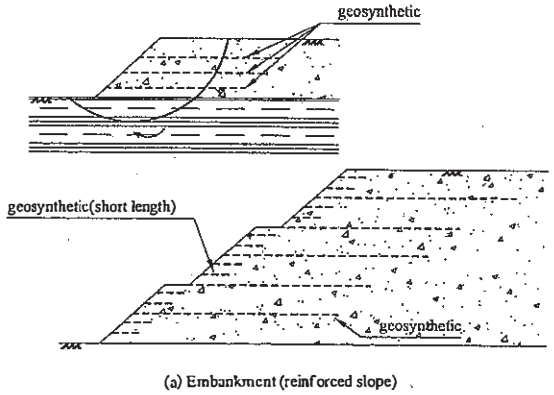
The application (b) and (c) are used in order to dispose of the clay contained much water, created by construction works. The merits of this method are to reduce the amount of the waste created by construction works, and to reuse the clay as the material of the embankment and the site preparation. As it has

been difficult to secure the place to create the waste landfill in Japan, this method has been in the spotlight.

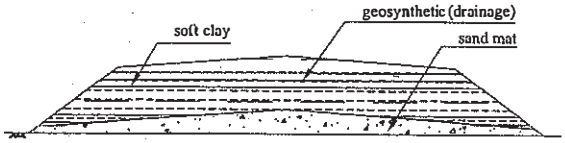
3.2.2 *Reinforced steep slope embankment*

The range of application with the reinforced steep slope embankment is shown in Figure 4.

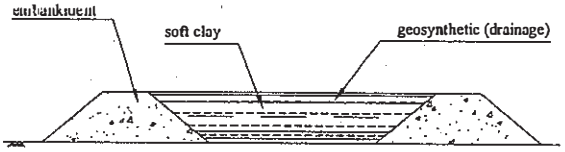
When the steep slope embankment was first introduced to Japan, sand bags involved by geosynthetic were used as a facing of the embankment, shown in (b). Because it was the most suitable for plants to grow up, the slope of the facing was kept being less than 80 degrees. Therefore a large number of cases of construction with this system had been built from the beginning of the1980s to 1995.



(a) Embankment (reinforced slope)



(b) Embankment (accelerated consolidation)

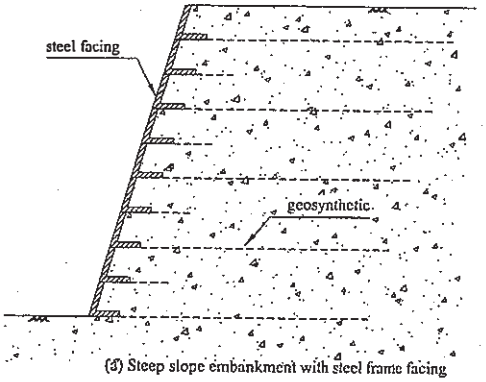


(c) Site preparation (accelerated consolidation)

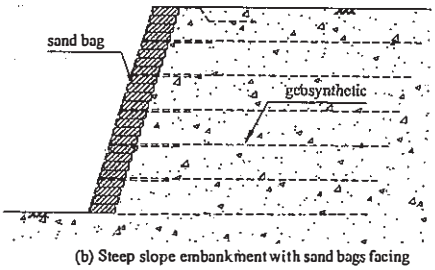
Figure 3. Range of applications where the reinforced gently slope embankment

After 1995, the facing with steel frames, shown in (a), replaced to sand bags. It saved the labor of workers to make many sand bags. Now, the facing with steel frames has formed numbers of steep slope embankment with geosynthetic.

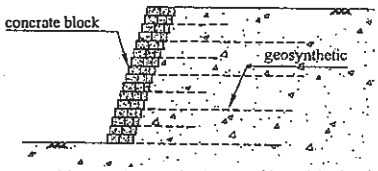
And the facing with modular blocks, shown in (c), has been used to keep the scenery of the urban area.



(a) Steep slope embankment with steel frame facing



(b) Steep slope embankment with sand bags facing



(c) Steep slope embankment with modular block facing

Figure 4. Range of applications where the reinforced steep slope embankment

3.2.3 *Reinforced soil retaining wall*

The range of application with reinforced soil retaining walls is shown in Figure 5.

Concrete panels and mechanically stabilized earth walls are used as the facing of retaining walls. The facing of retaining walls have various types. And metal strips, steel bars connected with anchor plates, and geosynthetic such as geogrid are used as the reinforcement. The Terre Armee retaining wall system, shown in (a), and the Multi-Anchor retaining wall system, shown in (b) are the typical examples of this method.

3.2.4 *Reinforced Railroad/Road with Rigid Facing Method (RRR)*

The range of the application with the reinforced Railroad/Road with Rigid Facing method (RRR) is shown in Figure 6.

The reinforced Railroad/Road with Rigid Facing Method (RRR) is used to deform the facing and to settle the filling materials which are further smaller than the materials used for the reinforced soil retaining walls has been described above. The fundamental structure of this method is completed

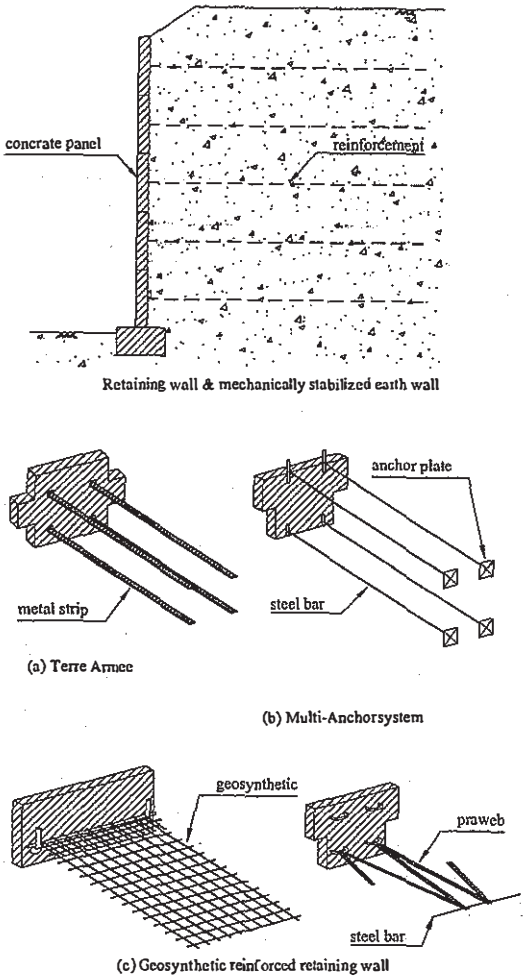


Figure 5. Range of applications where the reinforced retaining wall

with the following procedures. At first, the filling of the reverse side of the facing is built with the sand bags or the steel frames involved by the geosynthetic and forms the perpendicular steep slope embankment. After the filling materials settled several times deformed the facing, the rigid facing is attached. Now many constructions are built with this method especially the railroad in Japan.

3.3 *Soil nailing and excavation*

The range of the application with the soil nailing and the excavation with the reinforcement is shown in Figure 7.

The method (a) is used in order to maintain the stability of slopes. The excavation by this method has been performed for many years. Steel rods coated by grout are used as the reinforcement.

In the method (b), sheet piles and simple retaining walls are used as the reinforcement. And in order to insert the reinforcement, the excavation is performed with the open cut method.

In the method (c), the materials with high strength

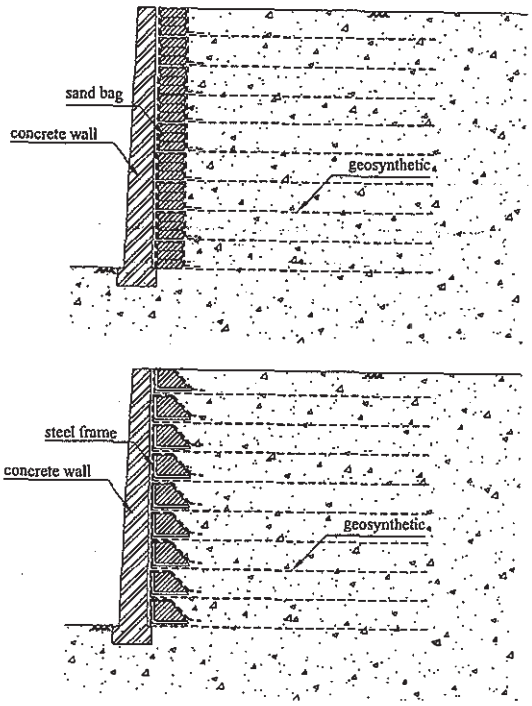


Figure 6. Range of applications where the reinforced Railroad/Road with Rigid Facing Method (RRR)

such as fiber-reinforced plastics are used as the reinforcement. The reinforcement is placed at the set-up angle in the embankment. This method can make the slope embankment being perpendicular.

4 THE CURRENR STATUS OF REINFORCED STEEP SLOPE EMBANKMENT AND REINFORCED SOIL RETAINING WALL

The statistical data about the reinforced steep slope embankment and the reinforced retaining walls are described in this chapter. Figure 8 shows the percentage of the past application with the earth reinforcement technique in Japan. The reinforced steep slope embankment and the reinforced retaining walls are 65%. Furthermore, the statistic data were taken according to the following scales; the number and the purpose of past applications, the area and height of walls, the length of reinforcement, the type of facing, the angle of slopes, the type of fill materials, and the condition of foundations.

4.1 *Case of past application in Japan*

Figure 9 shows the number of the applications in Japan with reinforced steep slope embankment and reinforced retaining walls. The Terre Armee method has been used before 1980, the Geogrid method since 1984, and the Multi-Anchor method since 1985. The number of all methods has been increased since each method was started to use. The increase

of the number of each method is closely related to the publication of the public design manual described in Chapter 3. Especially after the indicator was revised in 1999, the increase in the number of the cases is remarkably. In 2000, about 2,200 cases of reinforced retaining walls were made by the Terre Armee method and the Multi-Anchor method, and 1,100 cases of reinforced steep slope embankment were made by the Geogrid method.

Figure 10 shows the percentage of the purpose of the construction that was performed with three methods. The construction for the road is over 80%. The construction for the expressway road, the national road, and the railway are performed since it needs to be maintained eternally. The five types of applications shown in Figure 10 hold the majority of the purpose.

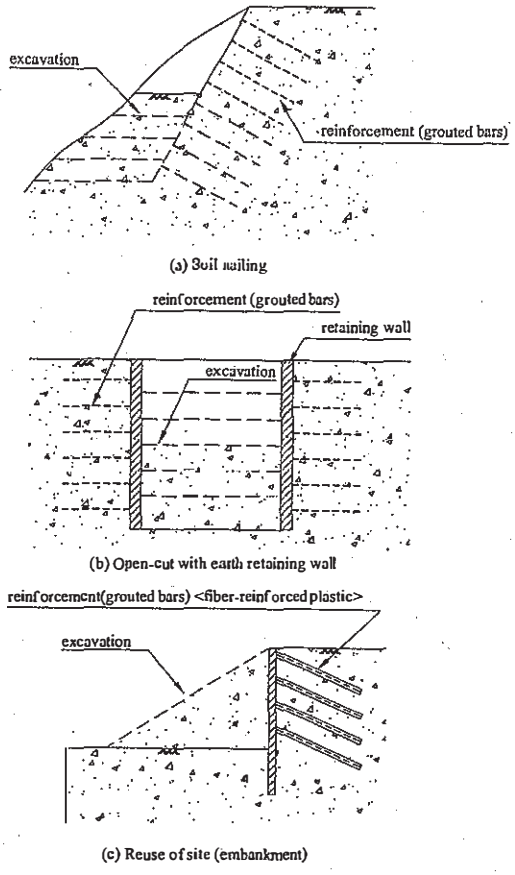


Figure 7. Range of applications where the soil nailing and excavation

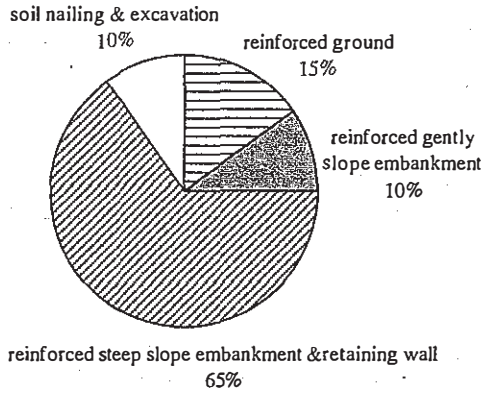


Figure 8. Percentage of application

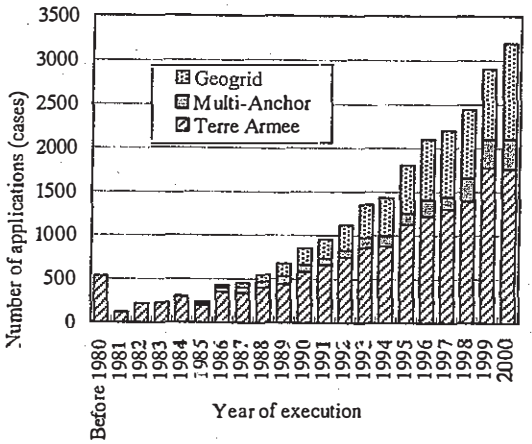


Figure 9. Number of applications of reinforced steep slope embankment and reinforced retaining wall

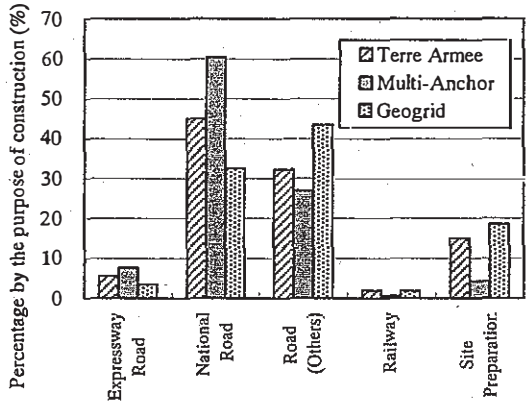


Figure 10. Percentage by the purpose of construction

4.2 *Scales of application in the past*

The distribution of the area of walls shown in Figure 11 is one of the most useful ways to measure the scale of the earth reinforcement structure. The area of walls, which is smaller than 1,000 m^2 is over 90%. Moreover the construction works are performed from 100m^2 to 400m^2 most frequently with the three methods that have mentioned above. However, the large walls exceeded 1,000 m^2 have been made recent years.

Figure 12 shows the distribution of the height of reinforced retaining walls and reinforced steep slope embankment. The structure which height is from 5 to 9m are built by the three major methods. The rate from 5 to 15m is over 60%. The Geogrid method are

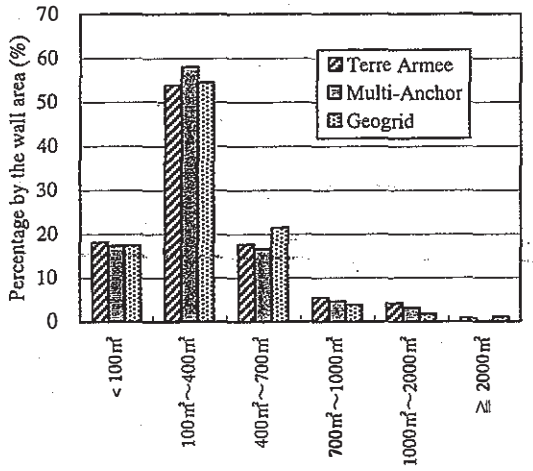


Figure 11. Percentage by the wall area

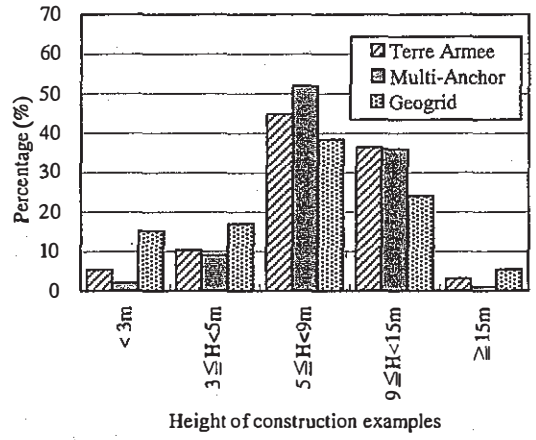


Figure 12. Wall height of construction examples

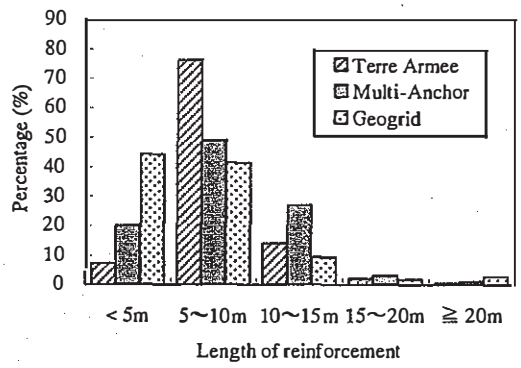


Figure 13. Length of reinforcement of construction examples

used most frequently in the three methods to build the structures which height is lower than 5m. And the rate of the structures over 15m is only 1to 5%.

Figure 13 shows the distribution of the length of the reinforcement. Metal strips, steel rods and geogrid are used as the appropriate reinforcement for the three methods. The reinforcement, which length is shorter than 15m are common used. Metal strips which length is 5 to 10m are most used for the Terre Armee method and the rate is over 75%. For the Geogrid method, the reinforcement which length is shorter than 5m is most used.

4.3 *Appearance of application in the past*

The kind of facing and inclination of facing are the typical information to recognize the geometric form of reinforced retaining walls and reinforced steep slope embankment.

Table 3 shows the distribution of the types of the facing. Concrete panels are mainly used for the Terre Armee method and the Multi-Anchor method. The rate of steel frames for the Geogrid method is about 70%. The facing of steel frames has the various kinds such as the one that was welded by steel rods, and that was processed with expand metal and so on.

Figure 14 shows the distribution of the inclination of the facing of geogrid reinforced steep slope embankment and geogrid reinforced retaining walls. The rate added to slope 1:0.3 and 1:0.5 is about 60%, however, the rate of plumbs is only 5.6%.

Table 3. Kind of wall's facing

Kinds of facing	Terre Armee	Multi-Anchor	Geogrid
Concrete Panel	97.1%	98.2%	8.4%
Metal Wall	2.9%	1.8%	0.0%
Sand bag			16.8%
Steel Frame			72.0%
Others			2.8%

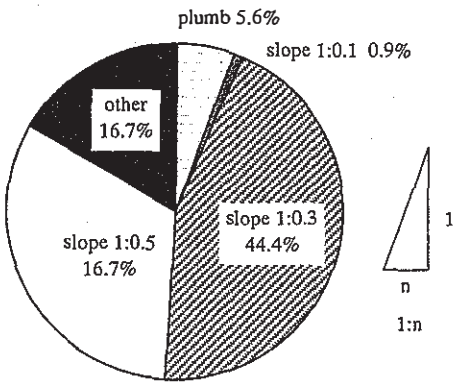


Figure 14. Inclination of the geogrid reinforced steep slope embankment & the geogrid reinforced retaining wall

4.4 *Earth material of application in the past*

In the earth reinforcement techniques, it is very important to recognize the materials which have been used for the applications in the past, and the materi-

als of the foundations which is under the embankment structure.

Figure 15 is the distribution of filling materials used for the applications. It should be referred that sand and gravel material used most frequently as the fill materials. Cohesive soil is used for the Multi-Anchor method and the Geogrid method but it is rarely used for the Terre Armee method. Rocks are used for the Multi-Anchor method and the Terre Armee method but are rarely used for the Geogrid method.

Figure 16 is the distribution of the materials of the foundation which is under the earth reinforcement structure. The rate of the soil and bedrock occupies over 70%. However, the applications on the soft ground and soil-improved ground have been carried out.

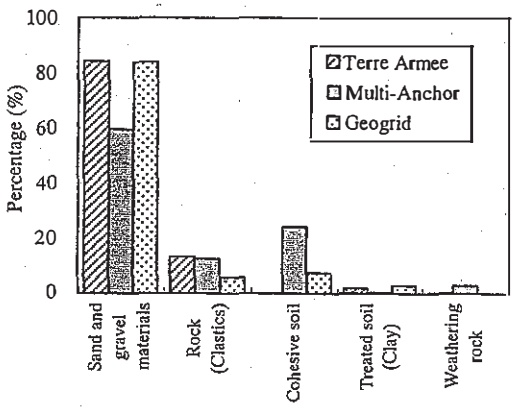


Figure 15. Fill material of construction examples

5 CASE HISTORIES IN JAPAN

Some cases of works in Japan are introduced with figures and photographs. The cross-section profile of the each method and the height of walls are indicated above each photograph.

5.1 *Terre Armee reinforced wall*

Figure 17, 18 and 19 are the typical examples of the reinforced retaining walls built by the Terre Armee method.

5.2 *Multi-Anchored reinforced wall*

Figure 20, 21 and 22 are the typical examples of the reinforced retaining walls built by the Multi-Anchored method.

5.3 *Geosynthetic reinforced steep slope embankment and retaining wall*

Figure 23, 24, 25 and 26 are the typical examples of the reinforced retaining walls built by the geosynthetic reinforced steep slope embankment and retaining walls.

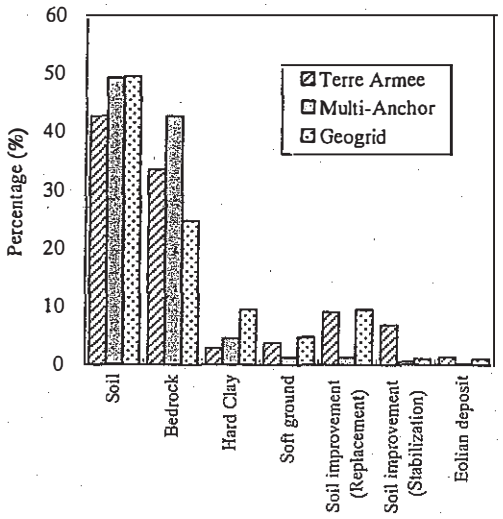


Figure 16. Foundation condition of construction examples

5.4 *Geosynthetic reinforced embankment on soft ground*

Figure 27 is the example of the web-shaped geosynthetic reinforced embankment on soft ground.

5.5 *Reinforced slope and ground (soil nailing, root pile)*

Figure 28 and 29 are the examples of the reinforced slope and ground by root pile method.

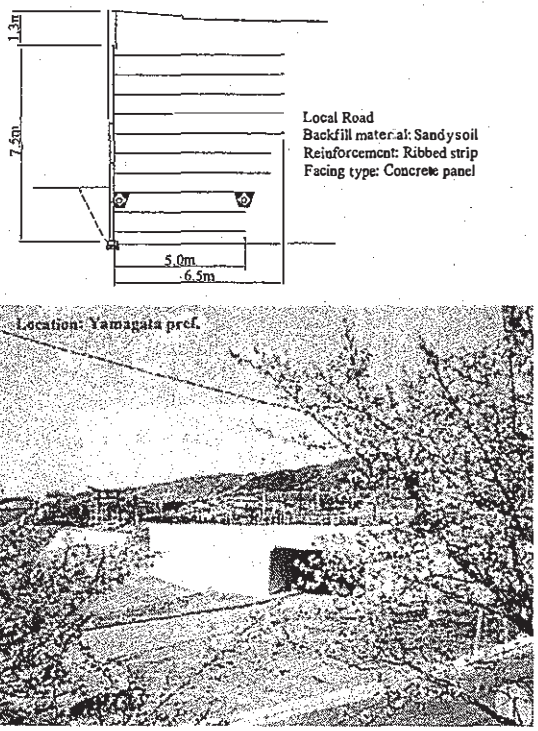


Figure 17. The Terre Armee reinforced wall currently used for local road

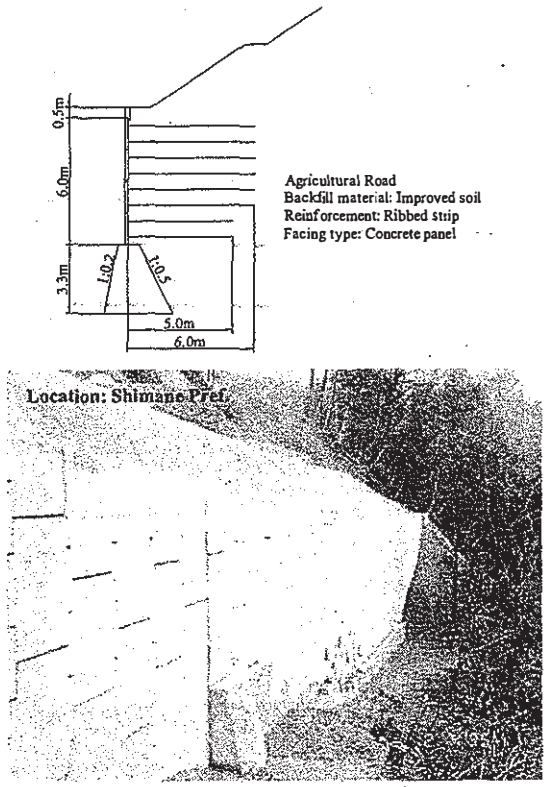


Figure 18. The Terre Armee reinforced wall currently used for agricultural road

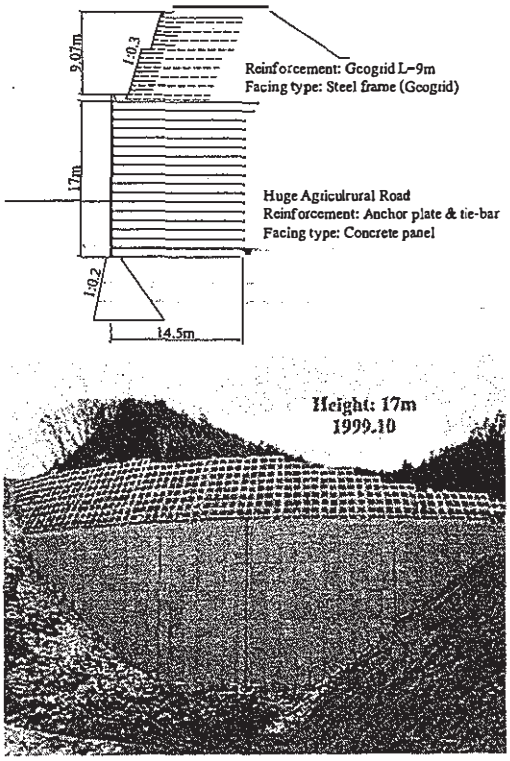


Figure 20. The Multi-Anchored reinforced wall currently used for huge agricultural road

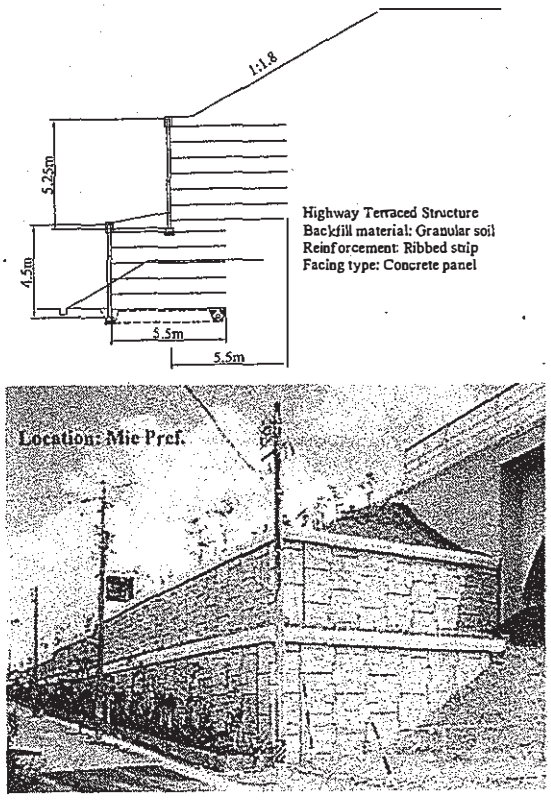


Figure 19. The Terre Armee reinforced wall currently used for highway-terraced structure

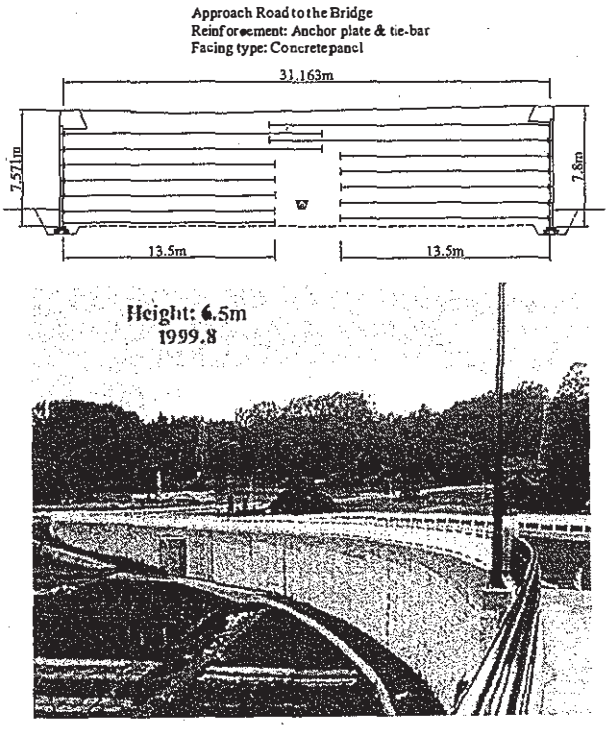


Figure 21. The Multi-Anchored reinforced wall currently used for approach road to the bridge

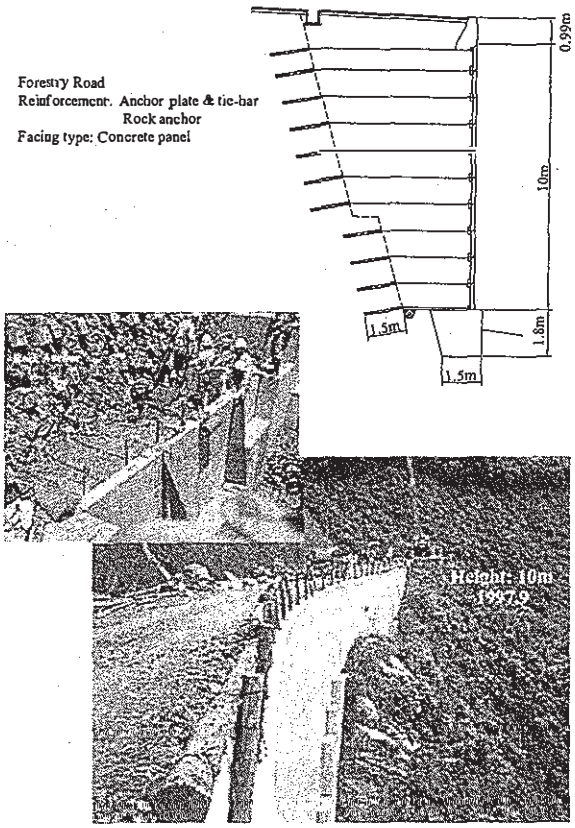


Figure 22. The Multi-Anchored reinforced wall currently used for forestry road

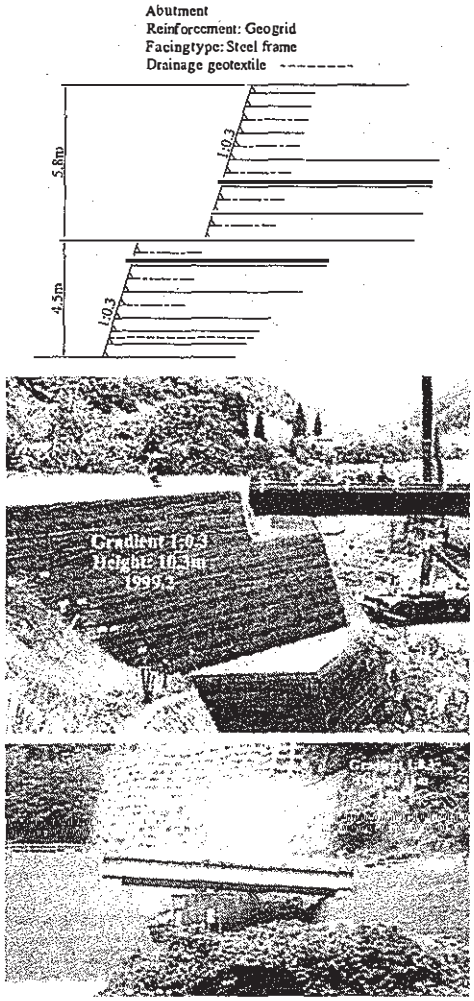


Figure 23. The Geosynthetic reinforced steep slope embankment currently used for abutment of bridge pier

6 SUMMARIES

The reinforced soil structures have been used for almost 30 years in Japan. And some issues still remain to be resolved. The reinforced soil techniques are expected to be developed, and it will bring a bright future to not only Japan but also Asian countries and around the world.

7 ACKNOWLEGRMENTS

Most of the contents presented in this paper are based on the activities of sub committee 1 (SC1) and sub committee 5 (SC5) of technical committee 9 (TC9) supporting committee setup in Japanese Geotechnical Society (JGS). The author wishes to express sincere thanks for sub committee members except of the authors; Dr. H. Abe (Kajima Corporation), Assoc. Prof. J. Kuwano (Tokyo Institute of Technology), A. Yamamoto (Obayashi Corporation) and S. Tayama (Japan Highway Public Corporation).

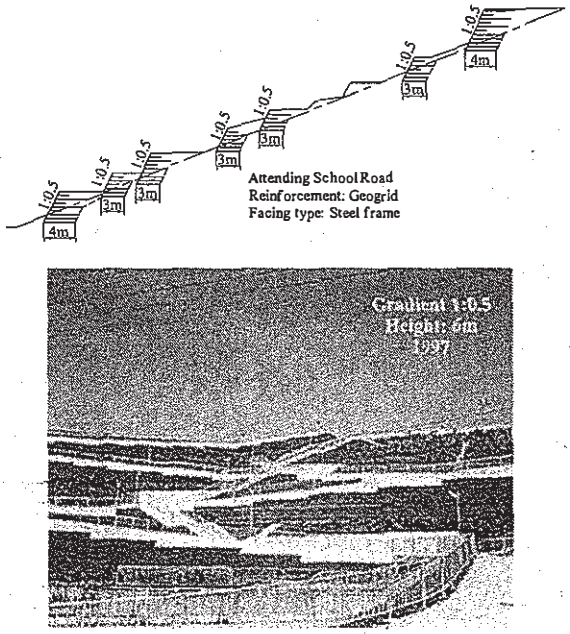


Figure 24. The Geosynthetic reinforced steep slope embankment currently used for attending school road

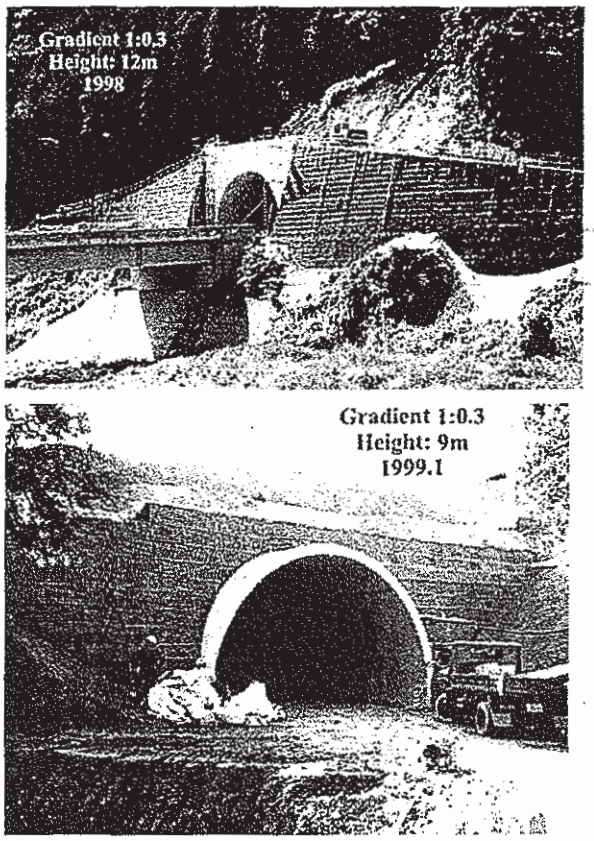


Figure 25. The Geosynthetic reinforced steep slope embankment currently used around tunnel

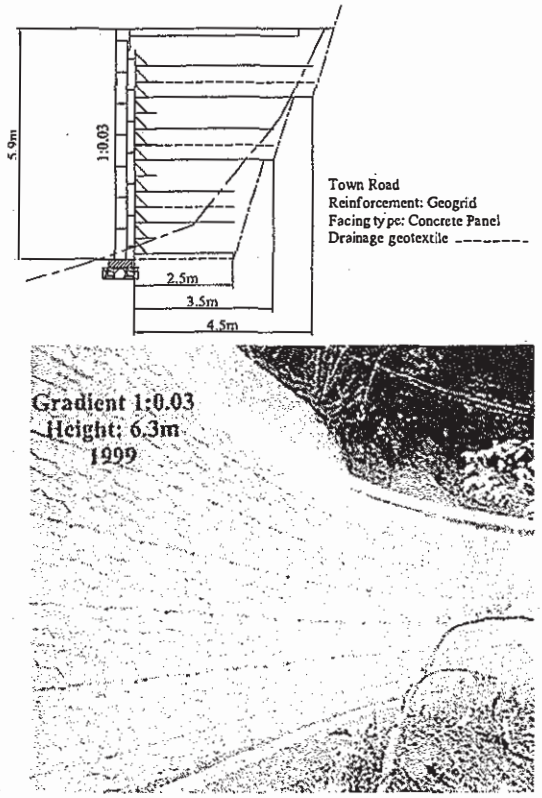


Figure 26. The Geosynthetic reinforced retaining wall used for town road

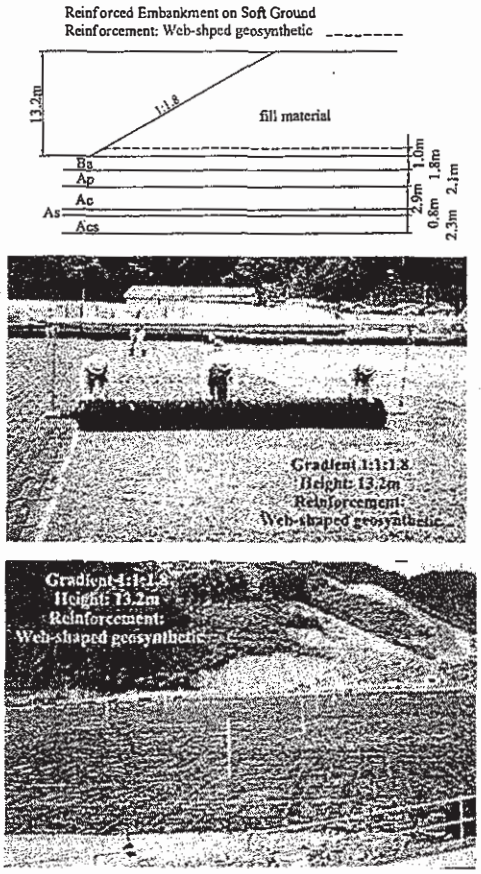


Figure 27. Web-shaped geosynthetic reinforced embankment on soft ground

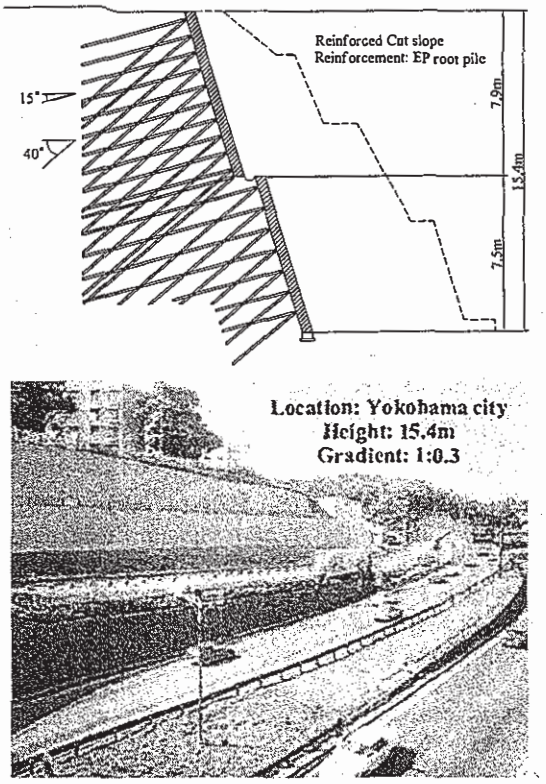


Figure 28. Reinforced cut slope by root pile method

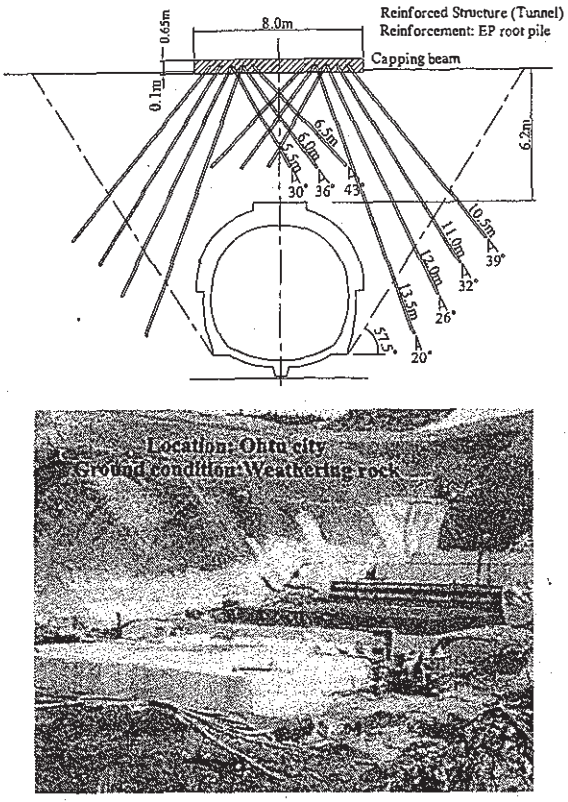


Figure 29. Reinforced ground structure for tunnel

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