Recent Case Histories of Permanent Geosynthetic-Reinforced Soil Retaining Walls, Tatsuoka & Leshchinsky (eds)
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Geosynthetic-reinforced soil retaining walls for reconstructing railway embankment at Amagasaki

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ABSTRACT: Geosynthetic-reinforced soil retaining walls (GRS-RW) and bridge abutments constructed by rebuilding the existing railway embankment to support tracks of one of the most important and busiest railways in Japan are described. The total length of the wall is about 1,300 m and the average height is 5 m. In place of gravel gabions which had been used for constructing other GRS retaining walls, metal wire-mesh gabions were placed at the shoulder of each soil layer to facilitate construction. The GRS-RW bridge abutments supported directly the load from a bridge girder, exhibiting only negligible deformation. The advantages of GRS-RW system using a continuous rigid facing over the conventional wall construction method and Terre Armee technique, considered when selecting the construction method for this project, are also described.

1. INTRODUCTION

A geosythetic-reinforced soil retaining wall system (GRS-RW system) with a continuous rigid cast-in-place concrete panel has been used to construct permanent and important retaining wall structures by reconstructing railway embankments for more than 7 km (Tatsuoka et al., 1992). **Fig. 1** shows the standard construction method of the GRS-RW system. Namely, first a base RC leveling pad is constructed. Then, the first geosynthetic layer is placed followed by setting gravel bags at the shoulder, over which the geosynthetic sheet is rolled over. The first soil layer is placed on the geosynthetic sheet and compacted very densely. The second layer (geosynthetic plus soil) is constructed similar to the first layer, and this procedure is repeated until the full wall height is completed. After the deformation and settlement of the wall and the supporting ground is ceased, a lightly steel-reinforced concrete layer is cast-in-place directly on the geosynthetic without using a framework for casting concrete on the wall face.

This paper describes the process of selecting the GRS-RW system and the wall construction for Katafuku Line located in Osaka and Hyogo Prefectures. This is a new line connecting JR Takarazuka Line and JR Gakkentoshi Line. The location is shown in

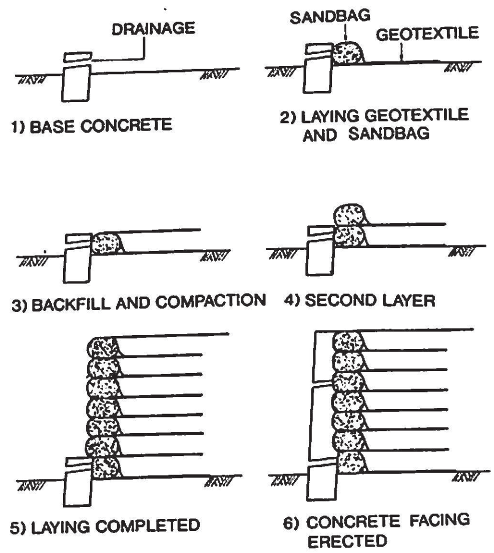


Fig. 1 Standard construction procedure of GRS-RW system

Fig. 2 Location of the site

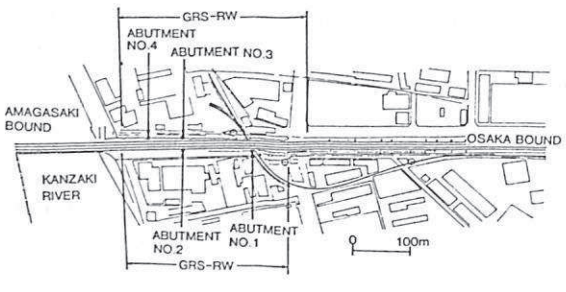


Fig. 3 Description of the site

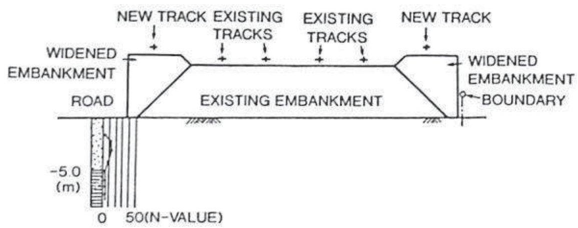


Fig. 4 Cross-section of railway embankment to be reconstructed

Fig. 2. The construction site of GRS retaining walls is located between Amagasaki and Takeshima stations as indicated in **Fig. 3**. The existing railway embankment, which had been supporting four tracks of one of the busiest railways JR Kobe Line, was to be reconstructed to add two new tracks, one on each side of the embankment (**Fig. 4**). The newly constructed retaining walls

Plate 1 A view of the embankment before reconstruction

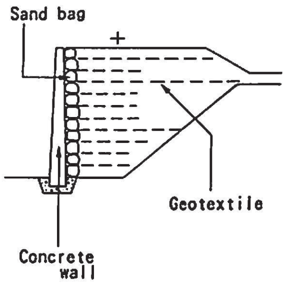
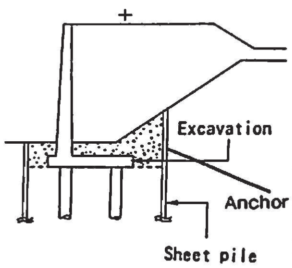
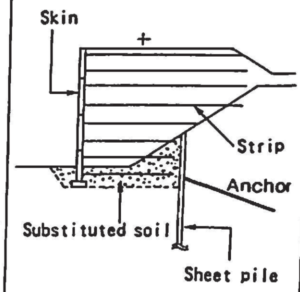
were planned to support two of the four tracks of JR Kobe Line, while the two tracks of the new line were planned to occupy two of the existing four tracks. A new land should be purchased when the width of the embankment is increased, keeping the same slope as the previous one. Since the site is located in an extremely congested city area, the limited budget for this project did not allow this solution (as in most of the similar cases in urban areas in Japan), as seen from **Plate 1**. The only practical solution is, therefore, to steepen the existing slope to a near vertical wall. Another design condition considered is the relatively poor supporting ground condition, as the site is located next to the present river bed of Kanzaki River. A typical soil profile near the abutment No. 3 is shown in Fig. 4.

2. SELECTION OF CONSTRUCTION METHOD

Table 1 was prepared for the purpose of selecting the most appropriate method for the construction of retaining wall for this project. First, the following three options were selected: GRS retaining walls, conventional cantilever RC walls (so-called L-shaped RC wall), and Terre Armee retaining walls.

The cantilever walls is a technique for which the most experience exists. Therefore, the construction of reliable structures can be safely expected. However, this type of relatively rigid RC structure is needed to be supported by a pile foundation due to the relatively poor

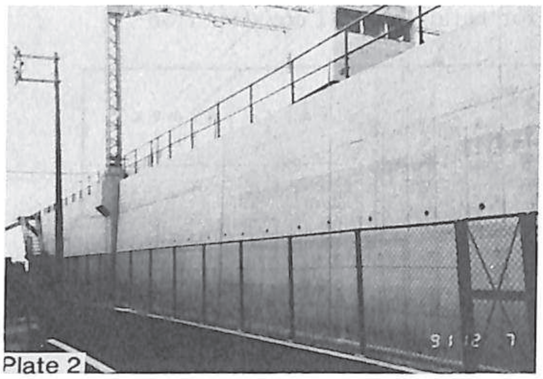
Table 1 Comparison of three methods for retaining wall construction

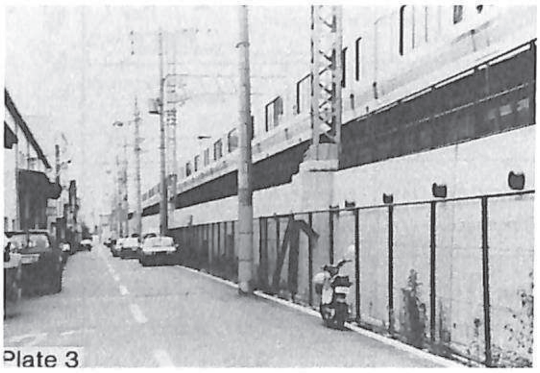
	Reinforced embankment	L-shaped RC wall	Terre Armee
SKETCH			
PLUSES	Piles are not needed. Any soil materials can be used	Because of long piles, structure has good stability	Piles are not needed.
MINUS -ES	Much man power is needed to set sand bags at the shoulder	It is hard to construct piles at such a narrow space.	Long strip is needed. Only good soil can be used.
PERIOD	Relatively short	Relatively long	Relatively long
RATIO OF COST	0.44	1.00	0.55
	○	×	△

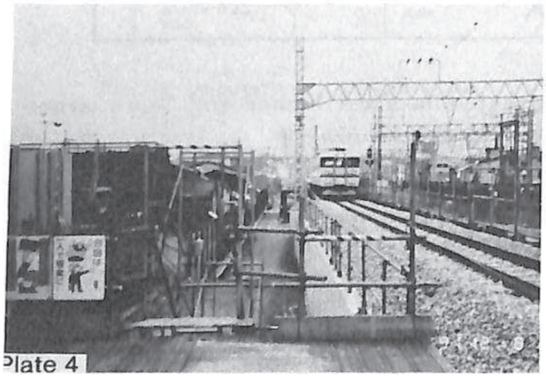
supporting ground condition. In addition, the construction of this type of wall needs excavation into the existing slope, requiring the installation of sheet piles anchored to the embankment. Both constructions described above need heavy construction machines, the use of which is very difficult in such a congested area. Furthermore, the total construction cost becomes highest among these three methods.

Both Terre Armee walls and GRS retaining walls before casting-in-place concrete facing are flexible enough to accommodate the settlement of the ground. Thus, the use of pile foundation is unnecessary. It was considered, however, that for Terre Armee walls, some excavation may be required, since a relatively long strip reinforcement should be used. This condition also leads to the use of sheet pile anchored into the embankment. Accordingly, the total cost estimated becomes higher for Terre Armee than for GRS-RW system.

The two disadvantages envisioned for the GRS-RW system are that the construction would be most labor-intensive combined with construction inexperience when compared with the other two methods. Conversely, the following important advantages of GRS-RW system were considered during the selection process. First, the total construction cost was lowest. Second, the Terre Armee needs a relatively high quality cohesionless soil for the backfill soil, while GRS-RW system can use a much lower quality soil. Third, the construction period was estimated to be shortest primarily since sheet piles are not necessary due to the use of relatively short reinforcement. Lastly, but not least, continuous rigid facing can support load transmitted from the foundation of the steel frame structure for electric







Plates 2, 3 and 4 Some views of completed walls

supply to trains, constructed directly on the top of facing and in the reinforced zone behind the facing as described later. This arrangement is not possible for Terre Armee walls.

Based on the above considerations, the GRS-RW system was considered as the most

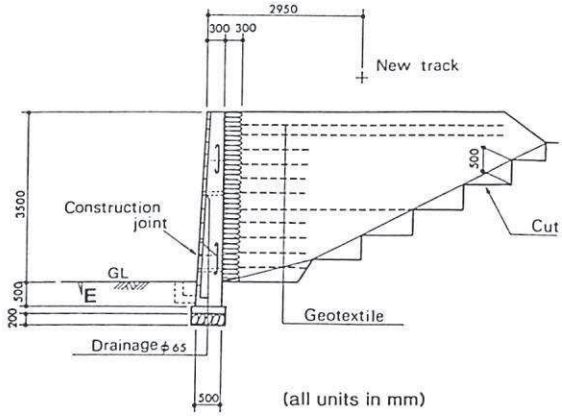


Fig. 5 Typical cross-section of the GRS retaining wall

suitable method for this project, and was therefore selected.

3. CONSTRUCTION

3.1 General

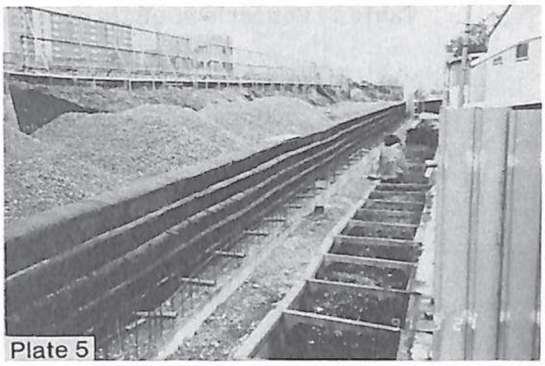
Fig. 5 shows the typical cross-section of the GRS retaining wall. The average wall height was 5 m and the total wall length was 1,300 m. The construction of GRS retaining walls was started in October 1990, and ended in August 1991. The tracks were open for traffic in December 1991. **Plates 2, 3** and **4** show some views of the completed walls under service. It may be seen that the appearance of the walls are the same with that of conventional RC wall structures. Part of the construction at the initial stage has been reported in Tatsuoka et al. (1992).

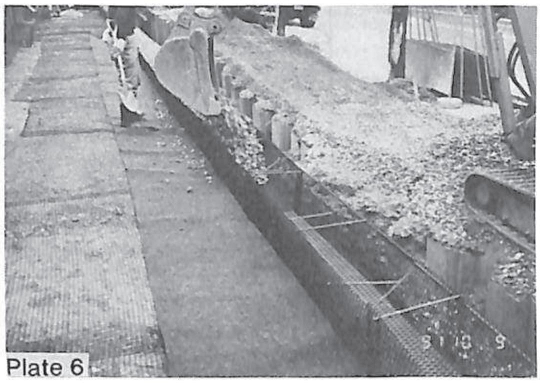
Soil used for the backfill is mostly borrowed sand for the ordinary retaining wall sections, while a well-graded gravel of crushed sandstone having D_{50}= 10.8 mm and a uniformity coefficient U_c= 12.5 was used for the bridge abutments. The backfill soil was mechanically compacted to a dry density of around 2.0～2.1 gf/cm^3.

A Vinylon grid, which has been verified to have very strong resistance against high pH and the presence of calcium from concrete, was used, since fresh concrete was cast-in-place directly on the grid to form a full-height rigid concrete facing. The diameter of the member of grid was 0.2 cm and the aperture was 2.0 cm. For the ordinary walls, a grid having an ultimate rupture strength of 3.8 tonf/m obtained from tensile rupture tests at a strain rate of 5 %/min was used, while a grid having a doubled strength of 7.6 tonf/m was used for the bridge abutments (n.b., the design strength was 3.0 tonf/m and 6.0 tonf/m respectively).

3.2 Metal-wire mesh gabions

In place of the ordinary type of sand bags made of steel grid, metal-wire mesh gabion (bag) as shown in **Fig. 6** was used to minimize labor. The length of one unit bag is 1.8 m. A metal-wire mesh bag was first placed on the shoulder of each soil layer, in which subsequently gravel was placed. Then, a non-woven geotextile sheet was wrapped around each bag to protect the geosynthetic reinforcement, which was then wrapped around the bag. **Plates 5** and **6** show the views during construction.





Plates 5 and 6 Views during construction

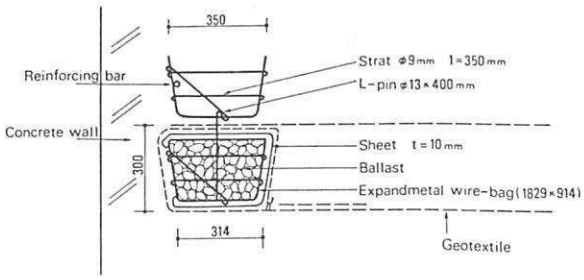


Fig. 6 Metal-wire mesh gabions used at the shoulder of each soil layer

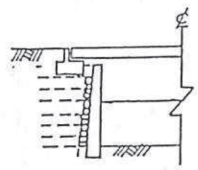
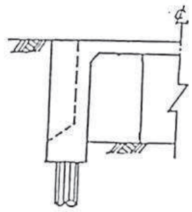
4. GRS RETAINING WALLS SUPPORTING FOUNDATIONS OF STRUCTURES

As described in detail in Fig. 6.16 in the related text in Tatsuoka (1992), one of the advantages of using a rigid facing is that a structure can be constructed on the top of facing or in the reinforced zone immediately behind the facing. For this project, relatively large foundation for an electric frame for six tracks was constructed in the reinforced zone immediately behind the rigid facing (**Fig. 7**). **Plates 7, 8** and **9** show the foundation during and after construction, respectively. When Terre Armee walls were used, the foundation should have been constructed to be independent of the wall while being supported by a pile foundation.

5. BRIDGE ABUTMENTS BY GRS-RW SYSTEM

At three locations, the railway has an over-bridge over a road (see Fig. 3). **Table 2** was prepared for selecting the method for the bridge abutment construction. The conventional RC structure supported with a pile foundation and Terre Armee walls were not selected basically because of the same reasons for which the conventional cantilever RC wall structures were not adopted for the ordinary retaining wall part. Terre Armee bridge abutment was not adopted either. In particular, it was considered that the facing of metal skin or discrete panels of Terre Armee walls is not adequate for supporting a concentrated

Table 2 Comparison of three methods for bridge abutment construction

	GRS-RW System	RC Frame structure
SKETCH		
PLUSES	Large construction equipment is not used	Negligible settlement
MINUSES	Possibility of settlement when the backfill is not well compacted	Piles are needed, which makes the construction work difficult in a limited area
PERIOD	Relatively short	Relatively long
COST	Relatively low	Relatively high

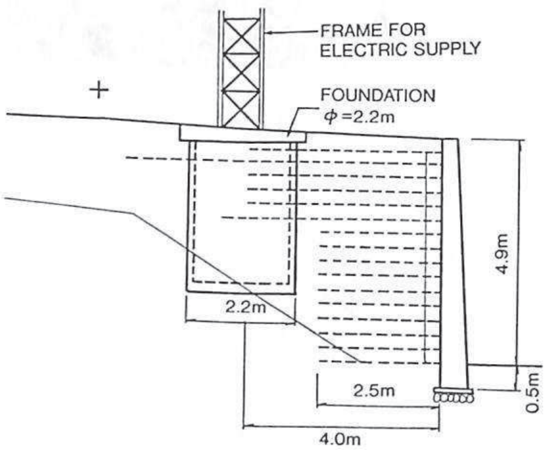


Fig. 7 Foundation of electric supply frame constructed in the reinforced zone immediately behind the rigid facing

Plate 7 Foundation of electric supply frame constructed in the reinforced zone immediately behind the rigid facing during construction

load from bridge load. The fact that Terre Armee walls have not been used for major bridge abutments in Japan was also considered. It was finally decided to adopt the GRS-RW system for constructing the bridge abutments while using a selected well--graded sandstone gravel heavily compacted, and a relatively stronger reinforcement; at one site, in addition to the above, the vertical spacing between reinforcement layers was reduced to 15 cm from the standard value of 30 cm.

Fig. 8 shows the GRS-RW bridge abutments at Takeshima BV (Bridge Viaduct). It was estimated that the cost was reduced to about a half when compared with that for the conventional RC structure. **Plates 10,**

Plates 8 and 9 Foundation of electric supply frame constructed in the reinforced zone immediately behind the rigid facing after construction

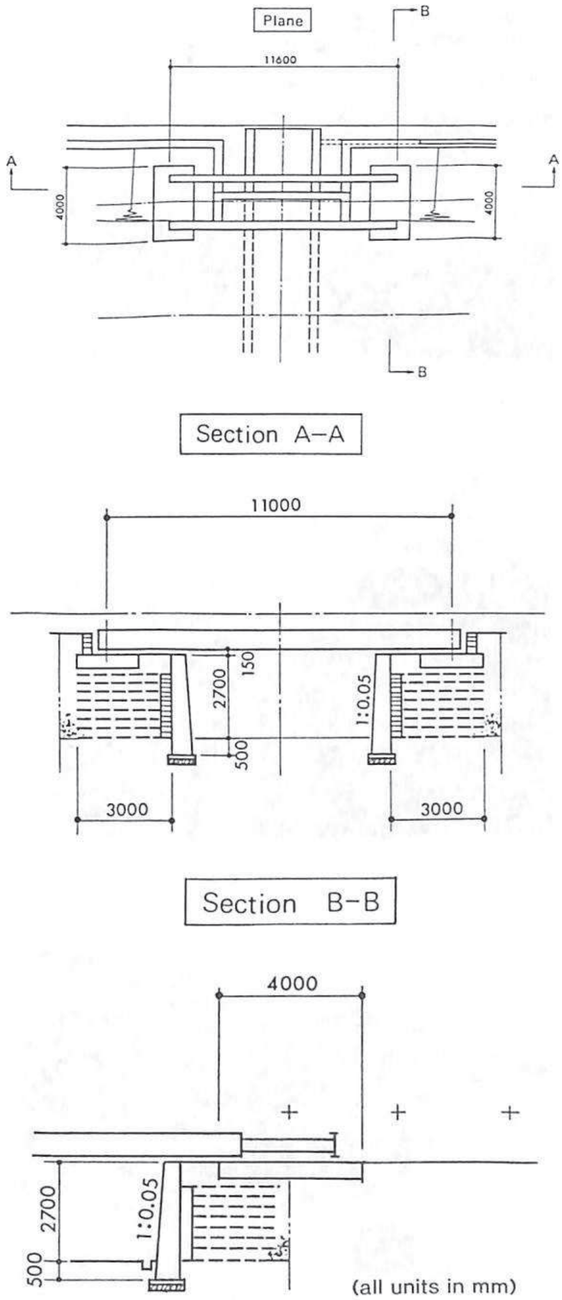


Fig. 8 Plans and cross-sections of GRS-RW bridge abutments at Takeshima BV (No.1 in Fig. 3)

11 and **12** show the bridge abutment under construction, while **Plates 13, 14** and **15** show the completed bridge abutments.

Since the GRS-RW bridge abutments are the first ones constructed in Japan to support a very busy and important railway, the behaviour during and after construction was carefully monitored (**Fig. 9**). Some observations are reported in Tateyama and Murata (1993). **Fig. 9** shows the arrangements of instrumentation at one of the two GRS-RW abutments (No.3 in Fig. 3).

Fig. 10 shows the increase in the vertical earth pressure and the axial strain in reinforcement recorded at the moment when the heaviest wheel load was above the abutment during passage of the first train. The maximum acceleration observed at the top of the abutment was about 0.2g and 0.1g in the vertical and horizontal directions. Relatively large strains were observed in the first and second reinforcement layers from the top. The maximum tension recorded was only about 0.05 tonf/m, which is far below the tensile rupture strength.


Plate 10

(No.3 in Fig. 3)

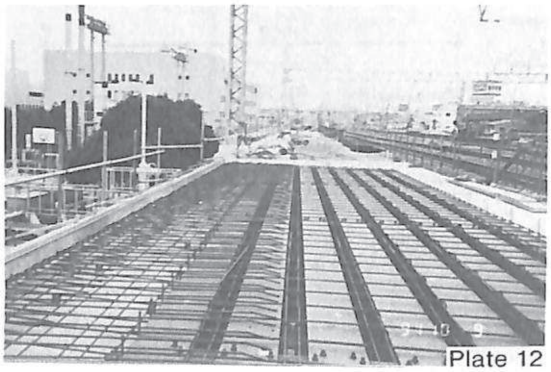


Plate 12

(No.3 in Fig. 3)

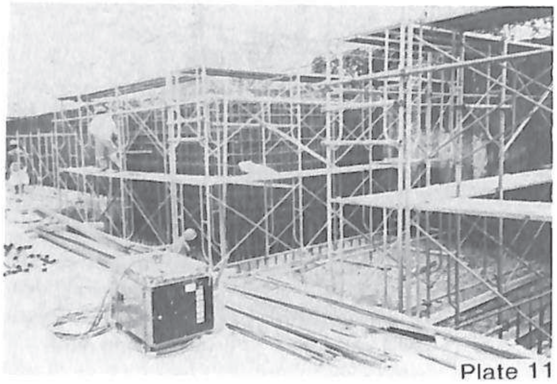


Plate 11

(No.4 in Fig. 3)

Plates 10, 11 and 12 GRS-RW bridge abutment under construction (a RC bridge girder is used only at abutment No.4)

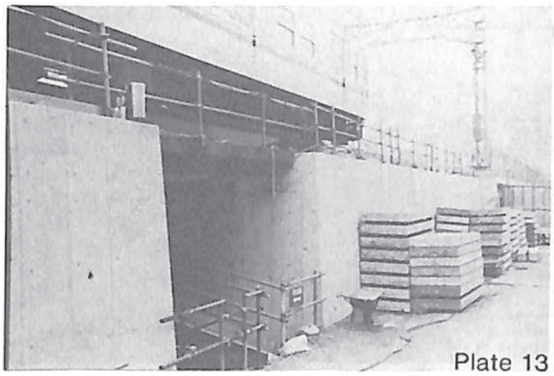


Plate 13

(No.3 in Fig. 3)

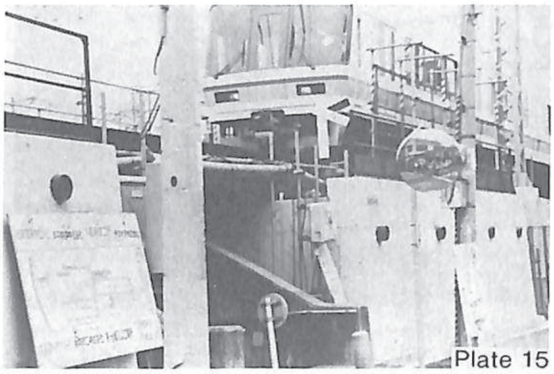


Plate 15

(No.3 in Fig. 3)

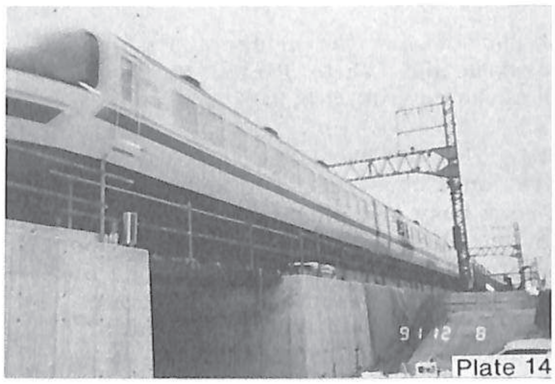
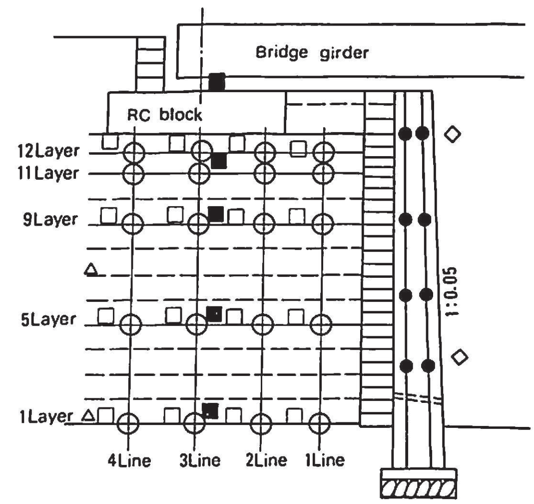


Plate 14

(No.1 in Fig. 3)

Plates 13, 14 and 15 Completed GRS-RW bridge abutment



INSTRUMENTATION	NUMBER	LEGEND
Soil pressure	16	□
Acceleration	4	■
Void water pressure	2	△
Inclination	2	◇
Strain of geotextile	10	○
Strain of steel bar	8	●

Fig. 9 Arrangements for measuring the performance of GRS-RW bridge abutment at Takeshima BV (No.1 in Fig. 3)

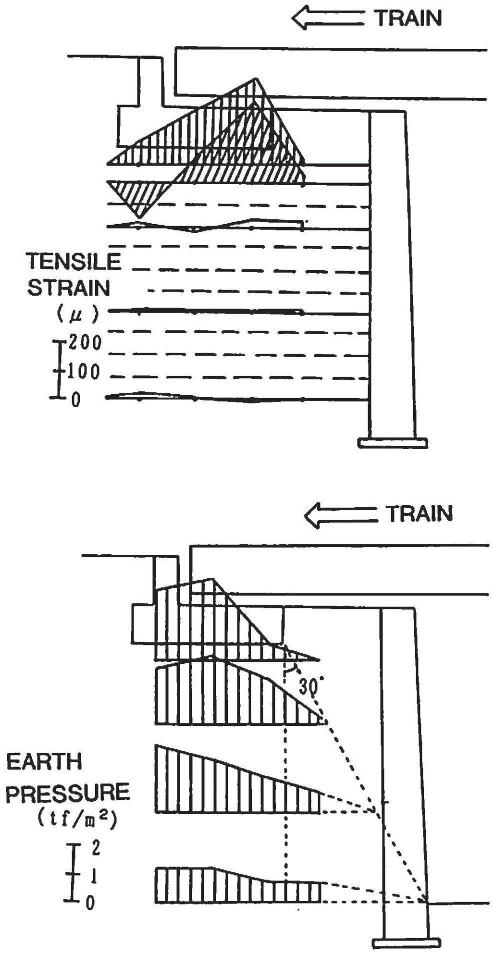


Fig. 10 Increase in the strain in reinforcement and the earth pressure at several levels in GRS-RW bridge abutment

The earth pressure due to the train load decreased with depth, while suggesting spreading at an angle of about 30° relative to the vertical. The distribution patterns of reinforcement force and earth pressure show that the reinforcement helped in supporting the train load. The observations obtained so far indicated that all the GRS-RW abutments at the sites have been very stable.

Fig. 11 shows the time history of the settlement at the concrete blocks supporting the railway girder placed on GRS-RWs. The location is No.2 in Fig. 3, which is different from that described in Figs. 9 and 10. The result is typical at this site. The number of passing trains is, on average, about 250 times a day, while each train consists of about 8 ~ 12 cars with about 48 tonf per car (n.b., about 12 tonf per wheel). It may be seen from Fig. 11 that after some initial settlement, developed during several days after the start of train passing, it virtually stopped increasing. The settlements due to train load observed at all the GRS-RW abutments have been far less than the allowable limit.

6. CONCLUSIONS

The GRS retaining walls and abutments which were constructed to support tracks of one of the most important and busiest railways in Japan have been described. To the best of the authors' knowledge, these structures are the first large-in-scale

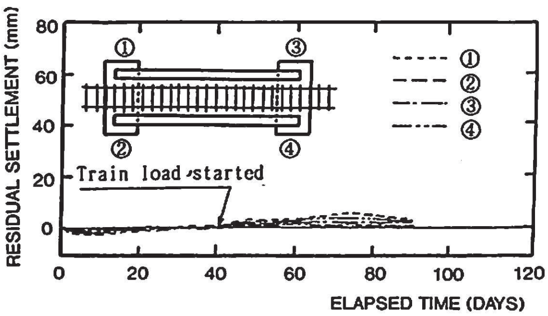


Fig. 11 Time history of the settlement at the concrete block supporting the rail girder

geosynthetic-reinforced soil walls used to support high-speed busy railway tracks in the world. It is believed that the use of a continuous rigid facing contributed to this very successful application. The performance of the structures have been extremely satisfactory.

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