The construction of geosynthetic-reinforced soil (GRS) integral bridge

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ABSTRACT: Concrete structures such as bridges are also prone to damage during earthquakes. In order to improve their earthquake-resistance, a new type of bridge is being considered. The concept of this idea is to combine the above-mentioned RRR embankment construction system with an integral concrete bridge. That is to say, backfill of the integral bridge will be built using the RRR construction system with abutments instead of rigid facing. This concept is called the geosynthetic-reinforced soil (GRS) integral bridge.In this paper, the construction of a GRS integral bridge as a full-scale test prototype is detailed, along with the monitoring installations for future testing. The test site is the place where the RRR construction system was developed and tested about 25 years ago. At the test site, two embankments (each about 5 m high) built using the RRR construction system were still in place, and available for use as the location of the latest test structure. The distance between two existing embankments is about 15 m. The GRS integral bridge with 15 m span (3 m wide) was constructed after removing a part of each embankment.

1 INTRODUCTION

Strong earthquakes, particularly those affecting developed areas, cause extensive damage to the infrastructure. Reinforced concrete abutments often suffer considerable damage, including settlement and displacement of the backfill.

Highways and railways are key components of the transport distribution system. Damage to highway and railway structures during a severe earthquake not only causes substantial property damage, but also has an adverse effect on the subsequent rescue and relief operations. It is preferable therefore that transport links are able to withstand the effects of earthquakes whenever possible, and for the infrastructure design to allow for quick and simple repairs to restore the operation of the transport links as quickly as possible after the earthquake.

This study focuses on bridge abutments and girders as highway and railway facilities, and reports on the results of a full-scale construction test for an GRS integral bridge, which is expected to provide greater resistance to earthquakes.

2 GRS INTEGRAL BRIDGE

Gravity, T-shaped abutments have generally been used in bridge construction.

Problems with conventional bridge abutments include the need for pile foundations, deformation or settlement of the backfill and the soils supporting bridge abutments over time, stability during earthquakes, and maintenance of bearing zones. In order to solve these problems, new types of abutments have been developed and constructed as described below.

(i) Reinforced soil bridge abutments
These abutments provide geotechnical engineering solutions for the problems involved in conventional abutments. Small abutments are installed on top of the rigid facing retaining walls with geotextile-reinforced soil constructed with RRR system(Fig. 1).

Reinforcing the backfill with geotextile and integrating the wall with the rigid facing of the wall is effective for controlling the settlement of the backfill during an earthquake and for controlling the deformation of the backfill after a prolonged period of operation. Problems with the bearings still remain, however, such as those related to seismic damage and maintenance.

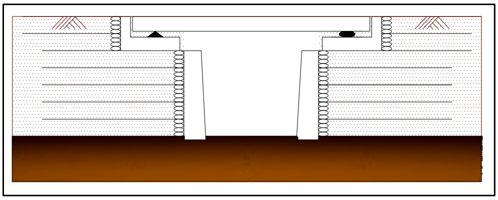

Figure 1. Reinforced soil bridge abutments

(ii) Integral bridges
In integral bridges, the girder is connected to the abutments to solve the problems involved in conventional bridges from a structural mechanics point of view (Fig. 2). Benefits of integral bridges include the elimination of bearings, reduction of maintenance costs, elimination of sections vulnerable to earthquakes, and smaller abutment structures. A new problem, however, occurs. Thermal movement of the bridge girder induces additional stresses in the abutment backfill and embedded items.

Figure 2. Integral bridge

(iii) GRS integral bridge
The above two methods are expected to be more effective when combined. Integral bridges with the RRR are the product obtained by integrating the two types of abutments. The embankment behind the integral bridge that connects the bridge girder to abutments is reinforced with geotextile. The bridge girder, abutments, and the embankments behind the abutments are formed into a single structure by integrating the reinforced soil to the abutments (Fig. 3).

Integral bridges with reinforced soil have proved to be highly resistant to earthquakes in laboratory model tests.[1)] No data has, however, been collected by observing full size integral bridges. In order to develop this type of bridge, it has been considered necessary to construct a full-scale structure, and to conduct long-term field monitoring of earth pressure, temperature, displacement, stress of reinforcement and other parameters, for establishing the design method and for identifying post-construction problems. To that end, a full-scale structure has been constructed for testing in a joint research.

Figure 3.GRS Integral Bridge

3 OUTLINE OF FULL-SCALE TEST

The integral bridge with reinforced soil constructed for this study is outlined in Table 1 and Fig. 4.

Table 1. Outline of GRS integral bridge

Length	15m
Width	3m (A single railway track)
Height	5m
Foundation type	Spread foundation
Embankment behind the abutment(1)	Crushed stone for mechanical stabilization enhanced by cement mixing and reinforced with geotextile
Embankment behind the abutment(2)	Crushed stone for mechanical stabilization reinforced with geotextile
Geotextile	Main material: Vinylon Design tensile strength:Tk Tk = 74 kN/m

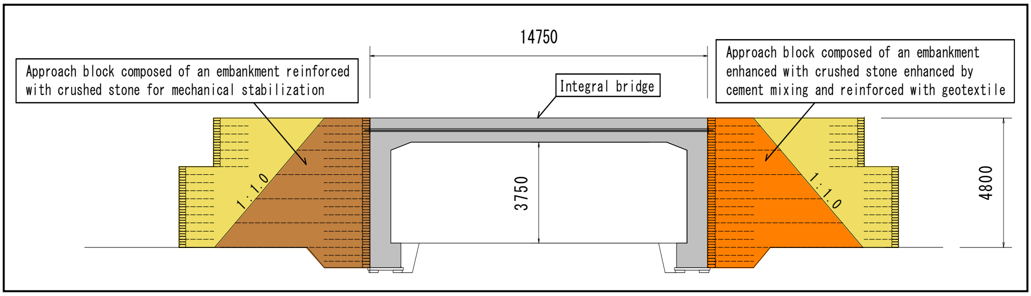

Figure 4.Construction plan for full-scale bridge

4 CONSTRUCTION

The test site is the place where the RRR construction system was developed and tested about 25 years ago. Two embankments (each about 5 m high) built using the RRR construction system, and which still remained, were utilized to form the full-scale test structure.

Part of the two existing RRR embankments was removed, and a new GRS integral bridge was constructed in its place. Given the space limitations on the site, this method was considered the most practical for the construction, and for applying loads in the loading tests (Fig. 5).

During excavation of the RRR embankments, some of the reinforcing materials were collected to investigate their properties after being in place for 25 years.

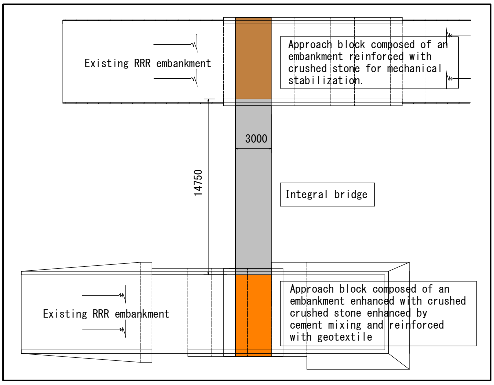

Figure 5. Plan view of full-scale bridge

Tensile tests and other tests are now being conducted to examine their deterioration over time. The test results will be separately reported upon completion. A flowchart of construction steps is given in Fig. 6.

4.1 *Preparation: Removal of existing embankment and construction of temporary earth retaining structure*

Prior to removing the sections of the existing embankments, two rows of steel sheet piles were driven into each embankment.

The ends of the sheet piles were prepared to ensure that they could be driven through the materials in the old embankments, including the layers of geotextiles installed at vertical intervals of 300 mm.

The preparation of the sheet piles is shown in Fig. 7.

The condition after the removal of the existing embankment is shown in Fig. 8.

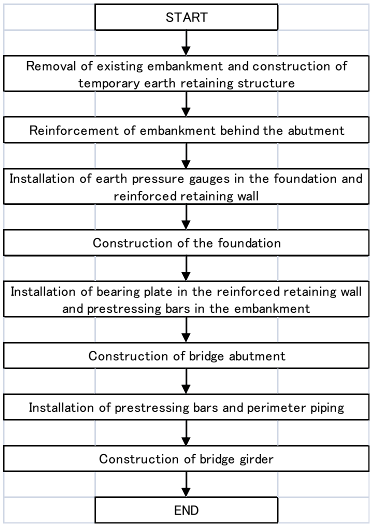

Figure 6. Flowchart of construction steps

Figure 7. Photo of the tip of the steel sheet-pile

Figure 8. Photo of completion of embankment removal

4.2 *Reinforcement of embankment*

4.2.1 *Installation of lubrication layer*

When reinforcing the embankment, a lubrication layer was installed parallel to the bridge axis, to reduce the friction expected to occur at the interface between the steel sheet pile and the embankment fill material (Fig. 9). The lubrication layers were formed using faced plywood and general-purpose industrial cup grease.

The faced plywood was fixed to the exposed surface of the sheet piles in heights of 900 mm, equivalent to the combined height of three layers of embankment. The plywood was fixed to prevent it from moving when the embankment material was compacted, and grease was applied before embankment filling started.

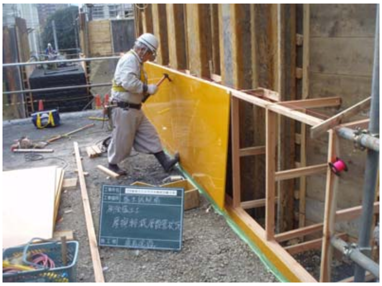

Figure 9. Photo of Installation of a lubrication layer

4.2.2 *Application of geotextile*

Geotextile was expected to be subjected to tensile forces. Deformations on the surface of the geotextile, such as extraordinary projections or indentations, and bending were likely to increase deformation before tensile forces acted and reduce the geotextile's effectiveness in the reinforced embankment. The surface of the embankment was therefore levelled to avoid an uneven surface before applying geotextile (Fig . 10).

Strain gauges were installed at some points in the geotextile. In order to prevent the gauges and related cables from being damage by compaction, cables were routed to provide adequate allowance for movement, and the cables and gauges were covered with fine sand for protection during filling.

Figure 10. Photo of application of geotextile

4.2.3 *Spreading and compaction of embankment materials*

The facing of the embankment was temporarily restrained using sandbags.

Sandbags were likely to move outward during filling and compaction, thus reducing the bridge length as they intruded the location of the concrete frameand also reducing the concrete cover. Sandbags were therefore installed about 10 millimetres behind the design location of the concrete frame so that the wall surface of the reinforced embankment after compaction could be positioned at the design location (Fig. 11 and 12). Embankment materials were spread manually and tampers were used for compaction because construction took place in a narrow space.

Embankment materials were spread and compacted for a thickness of 150 mm per layer. Geotextile was applied at intervals of 300 mm.

Figure 11. Photo of Compaction of temporary retaining materials (sandbags)

Figure 12. Photo of temporary retaining

4.2.4 *Embankment materials*

For embankment materials, ordinary crushed stone for mechanical stabilization (M-40) and crushed stone for mechanical stabilization enhanced by cement mixing with a relative weight of 4% were used to verify the effects of varying backfill embankment materials (e.g. settlement of the section behind the abutment due to thermal contraction of the bridge girder). Crushed stone for mechanical stabilization enhanced by cement mixing was produced in accordance with the guidelines related to railways in Japan.

4.2.5 *Field compaction test*

Field compaction tests were conducted for each material to determine the time required for compaction using tampers to achieve $Dc \geq 95\%$, the control level of compaction for the embankments. Fig. 13 shows a plan view of compaction test locations. The embankment materials were compacted for 0.5, 1.0 and 2.0 minutes/m^2 in three different blocks, respectively.

As a result of the test, it was confirmed that the standard value of Dc ≥ 95% was achieved for crushed stone for mechanical stabilization enhanced by cement mixing at a compaction time of two minutes/m2. For crushed stone for mechanical stabilization, no standard value was achieved at a compaction time of two minutes/m2. A test was conducted again at a compaction time of three minutes/m^2 and the achievement of the standard was confirmed.

Fig. 15 shows the results of compaction test for crushed stone for mechanical stabilization enhanced by cement mixing.

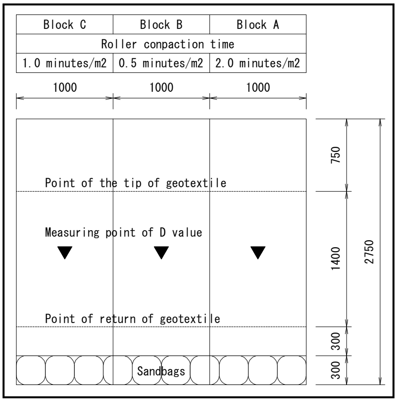

Figure 13. Plan view of test construction

Figure 14. Photo of blocks in test construction

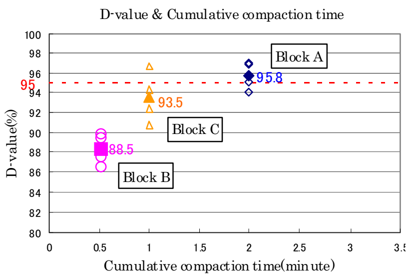

Figure 15. Results of field compaction test

Figure 16. Photo of Completion of reinforced embankment

4.3 *Construction of framework*

The concrete foundations, bridge abutments and bridge girders were constructed using standard methods for reinforced concrete.

The specifications for the concrete and reinforcement used for the framework are listed in Table 2.

Table 2. The specification for the concrete and reinforcement

Design concrete strength	fck=27N/mm^2
Slump of concrete	80mm
Max grain size of coarse aggregate	20mm
Main reinforcement in fundation	D19mm@150mm (mean pitch)
Main reinforcement in bridge abutment	D19mm@150mm (mean pitch)
Main reinforcement in bridge girder	D22mm@150mm (mean pitch)

The abutment has a smaller width and requires less reinforcement than conventional abutments because the backfill is reinforced and the integral bridge structure is adopted.

When placing concrete, the wall surface of reinforced embankment is used as formwork without using any formwork between the backfill concrete and crushed stone, and concrete is placed direct unto the surface of the reinforced wall. Thus, the abutment is integrated with the reinforced embankment wall.

Construction work in various phases is shown in Fig. 17 through 19.

Figure 17. Photo of Construction of foundation

Figure 18. Photo of construction of bridge girder

Figure 19. Photo of Completion of construction

5 MEASUREMENT

Field observations are to be conducted for approximately year after the construction of the concrete framework, to examine the effects of temperature changes on the body of the bridge and on the embankment behind the bridge abutment. The design method will be established by analyzing the results of the test during the one year monitoring period.

Measurement instruments were installed as described below (Fig. 20)

Earth pressure gauges: Installed at six locations. Measuring earth pressure from reinforced embankment

Geotextile strain gauges: Installed at 66 locations. Measuring stress occurring in the geotextile installed in the reinforced embankment

Reinforcement stress gauges: Installed at 18 locations.Measuring stress occurring in the reinforcement in the framework

Thermometers: installed at three locations. Measuring outdoor temperature and the temperature in the concrete

Relative displacement transducers: Installed at four locations.Measuring displacement due to thermal contraction in the bridge girder section

Prestressing bars: Five are used.Prestressing bars are installed in the reinforced embankment and bridge girder for conducting loading tests at the end of one-year field observation.

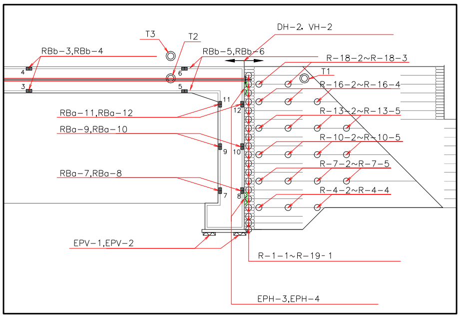

Figure 20. Measurement plan

6 CONCLUSIONS

This paper reports the construction of a full-scale GRS integral bridge.

It was confirmed to be able to construct the GRS bridge without trouble in this full-scall test.

Field monitoring of the full-scale model will be conducted for approximately one year. The results are expected to confirm the results of the laboratory tests, and identify problems that would not be readily apparent in laboratory tests.

This paper does not describe results of the field monitoring since number of data obtained has not been enough so far. The monitoring result is to be presented taking another opportunity in future.

In the future, the design method will be established for the bridge construction method based on the knowledge obtained in the monitoring and loading tests, and design and construction manuals will be prepared for the bridge for practical application.

The bridge construction method should be effective for constructing bridges for railways, and other locations, and may enable the reduction of construction and maintenance costs, as well as providing considerable improvement to the resistance of seismic forces when compared with conventional methods.

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Reference

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