Subgrade stabilization using lattice-frame-reinforced sheet accompanied by compacted crushed-stone layer

T. Yoshida, Y. Kitamoto, M. Okamoto and T. Kawanaka
Kajima Corporation, Tokyo, Japan

A. Okamura
Ashimori Industry Co., Ltd., Osaka, Japan

Keywords: surface soil stabilization, subgrade, base course, differential settlement, K value, plate load test, railroad, road, design

ABSTRACT: The lattice-frame-reinforced (LFR) sheet was developed for surface soil stabilization using geosynthetics, in which a sheet of woven textile is paved onto soft ground and reinforced by a lattice frame consisting of jackets (namely, tubes made of woven textile) filled with mortar. To investigate the performance of the LFR sheet when applied to the stabilization of railroad subgrade, with a cover layer of crushed-stone fill, we carried out full-scale experimental construction on soft clayey sand ground with an N-value of 2, which is below the requirements for railroad subgrade in Japan. In the test, an LFR sheet having a jacket diameter of 10 cm and a lattice interval of 1-2 m was laid on the soft ground, and then a base-course layer of crushed stone was placed on the sheet and compacted up to 30-40 cm thick. By doing so, the coefficient of reaction (K-value) obtained by plate load test exceeded not only the subgrade requirement but also that for the base course, which was not the case for crushed stone compacted without an LFR sheet. These test results, together with finite element analysis, allowed us to compose a set of diagrams that suggest appropriate, economical values for the lattice interval and crushed-stone thickness, according to any given ground conditions (N-value) and required bearing capacity (K-value) as the base course for roads and railroads.

1 INTRODUCTION

The lattice-frame-reinforced (LFR) sheet, or Palace Sheet, is a geocomposite used for surface soil stabilization, in which a sheet of woven textile is paved onto soft ground, accompanied by a lattice frame consisting of jackets (namely, tubes made of woven textile) filled with mortar. As introduced by Yoshida et al. (2006), this method was initially developed for application to extremely soft clayey ground or mud slurry landfill. On this type of ground, differential settlement is likely to occur when the ground surface is subjected to locally concentrated vertical load such as overburden fill layers and heavy construction machinery. The LFR sheet, however, improves the stability of overburden layers as well as the workability and trafficability directly on the soft ground. These advantages are derived from the load distribution effect of the lattice frame. In this type of use, the lattice frame may be placed either beneath or upon the sheet, as illustrated in Fig. 1(a) and (b).

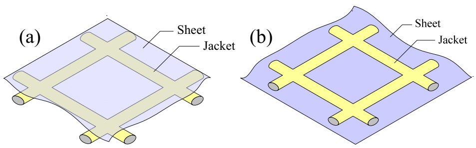


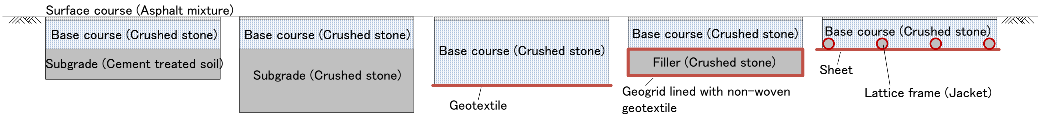
Fig. 1 Illustration of basic features of the LFR sheet: (a) For fillwork on very soft deposit only (Yoshida et al., 2006); (b) For subgrade stabilization (this paper).

Another principal application of the LFR sheet, which is the subject of this paper, is subgrade stabilization, which concurrently forms a base course, for roads and railroad tracks constructed on soft but stiffer ground than in the above case. For this type of use, placement of the LFR sheet is followed by spreading and compaction of a crushed-stone layer. Namely, after allowing a short curing period for the mortar inside the jackets, crushed stone is spread and compacted to form a hybrid base course of LFR sheet and crushed stone. In this application, it is appropriate to place the lattice frame upon the sheet as illustrated in Fig. 1(b); otherwise, the lattice frame will progressively penetrate into the ground and residual settlement may occur as the overburden load increases.

In this paper, we review the merits of the LFR sheet in subgrade stabilization, and present the results of our full-scale field test for railroad construction. Moreover, we introduce a set of design diagrams based on the above test results.

2 EXISTING AND PRESENT METHODS

For stabilization of road and railroad subgrade in Japan, the most common method is cement stabilization, as illustrated in Fig. 2(a). This method significantly increases the subgrade bearing capacity. However, the stabilized layer without tensile reinforcement may result in propagation of cracks, leading to differential settlement. Moreover, the construction period tends



(a) Cement stabilization (b) Replacement (c) Single geotextile (d) Geogrid cover + filler (e) LFR sheet

Fig. 2 Schematic figures of existing method for surface stabilization and LFR sheet (for roads).

to be lengthy due to the required mixing tests beforehand and the curing period for the mortar. Furthermore, removal of the stabilized layer, if necessary, may disturb nearby residents with the noise from destruction, and would incur extra costs especially in terms of waste disposal. Dust pollution from the cement may be another problem.

Replacement with crushed stone, as shown in Fig. 2(b), is another major method for subgrade stabilization. This method is free of the problems associated with using cement, but is not free from differential settlement, due to the lack of bending rigidity of the crushed-stone layer. In addition, a large amount of excavated surplus soil must be removed from the site.

To reduce the thickness of replacement with crushed stone, geosynthetics have been effectively applied. In Fig. 2(c), a geotextile is placed at the bottom of a crushed-stone layer, and in Fig. 2(d), a crushed-stone layer is covered with a geotextile similar to a mattress. In both cases, the geotextile as a tensile member contributes to providing bending resistance of the combined body of crushed-stone layer and geotextile. However, these combined bodies can hardly resist shear deformation, which may lead to differential settlement of the ground.

On the other hand, the LFR sheet, shown in Fig. 2(e), overcomes this problem by reinforcing the geotextile with a rigid lattice frame. Namely, the lattice frame can significantly resist both bending and shear forces. Moreover, the lattice frame may have the effect of reducing the differential settlement under a concentrated vertical load, by resisting local deformation of the crushed-stone layer, and thus successfully reduce the total thickness of the crushed-stone layer.

3 EXPERIMENTAL CONSTRUCTION

As part of a renewal project for an existing railroad, the construction of a temporary railroad track for passenger service required subgrade stabilization. Hence, to investigate the performance of the LFR sheet accompanied by crushed stone, full-scale experimental construction was conducted locally (Okamoto et al., 2006).

3.1 *Ground condition*

The surface soil profile was observed at the site of boring to a depth of 4 m and at an adjacent excavated pit, and is shown in Fig. 3. The total thickness of soft layers, namely clayey sand of N=2 and clayey sand with gravel of N=4, was 1.65 m. No subsoil water was found within the boring depth. The coefficient of reaction K_{30} (obtained from a plate load test using a loading plate 30 cm in diameter) at the ground surface was only 24 MN/m^3, while the subgrade requirement was 70 MN/m^3 (Railway Technical Research Institute, 1992). In other words, this surface layer should have been properly stabilized before placing a base course.

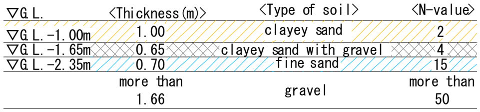


Fig. 3 Ground profile.

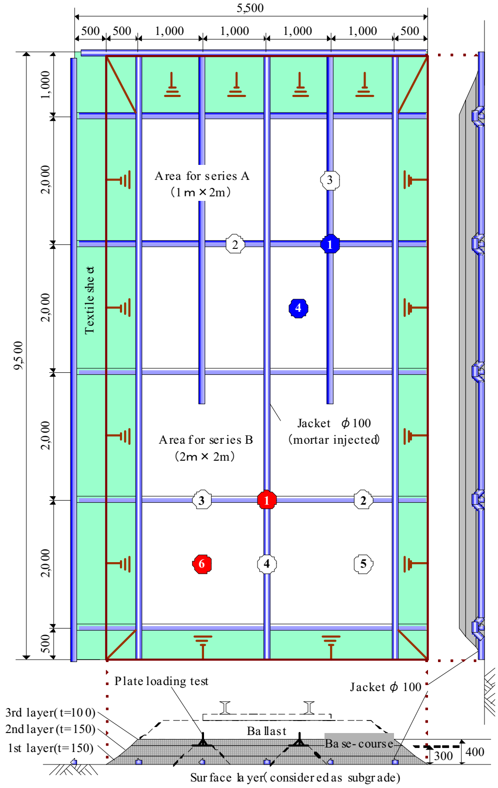


Fig. 4 Configuration of the field test (Unit: mm).

(a) Initial state (b) After installation of mortar

Fig. 5 Structuring of lattice frame with mortar.

3.2 *Scheme of experiment*

The arrangement of the experimental embankment is illustrated in Fig. 4. The LFR sheet and jacket used were both made of woven polyester textile, and the jacket diameter was 10 cm (Yoshida et al., 2006). Two types of lattice interval, 1×2 m (Series A) and 2×2 m (Series B) were employed. Figure 5 shows the LFR sheet before and after filling the jackets with mortar. After 3 days of curing the mortar, crusher-run stone with a maximum particle diameter of 40 mm was spread and compacted, as a base course. The required value of the coefficient of reaction K_{30} on the base course was 110 MN/m^3 (Railway Technical Research Institute, 1992). The thickness of the base course was 30 cm and was compacted every 15 cm, conforming to the Railway Technical Research Institute (1992). Compaction was conducted using a roller to obtain more than 90% of the maximum dry density of the modified Proctor method. Hence, a series of plate load tests were conducted to measure K_{30} values at selected points as indicated with number symbols in Fig. 5. Moreover, a 10-cm-thick additional crusher-run layer was placed and the K_{30} values were measured again at points indicated by colored solid symbols with white numbers. An adjacent base course layer was constructed without an LFR sheet, and a plate load test was performed for a comparative study. The ballast, the sleeper and the rail were not placed in this experimental work. The uniaxial compressive strength at 1 day before placing the crusher-run stone and on the day when the plate load tests were conducted was 32.8 and 38.6 N/mm^2, respectively.

3.3 *Results of experiment*

For convenience, the planar offset distances of the plate load test points from the nearest jackets are summarized in Fig. 6. The relationship between planar offset distance and K_{30} value at a base-course thickness of 30 cm is shown in Fig. 7. In Series B, with lattice interval of 2×2 m, the minimum K_{30} value was observed at the center of the lattice (B-6) as expected, while in Series A with lattice interval of 1×2 m, such a tendency was not obvious. The K_{30} values at A-4 and B-5, which were both 0.5 m away from the jacket, showed relatively larger K_{30} values together with A-3, B-3 and B-4, which were located just at the jacket.

On the other hand, at intersecting points (A-1, B-1) and their closest neighbors (A-2, B-2) located at the jackets but only 0.5 m away from the intersection, the K_{30} values were apparently smaller. As observed in Fig. 5(b), one of the two intersecting jackets was inevitably upheld at an intersection and thereby the base course materials placed beneath the upheld jacket would have been relatively difficult to compact, which likely led to the reduced K_{30} value just around the intersections.

Nevertheless, at all test points, the K_{30} values exceeded the required 110 MN/m^3 for the base course. In contrast, the K_{30} value for the base course without the LFR sheet was only 63.0 MN/m^3, failing to satisfy the requirement. This indicates that the LFR sheet successfully improved the stiffness of the subgrade that was insufficient by itself.

Figure 8 shows the effect of base-course thickness on K_{30}. It is obvious that the K_{30} value became larger with increasing base-course thickness. However, since the K_{30} values observed

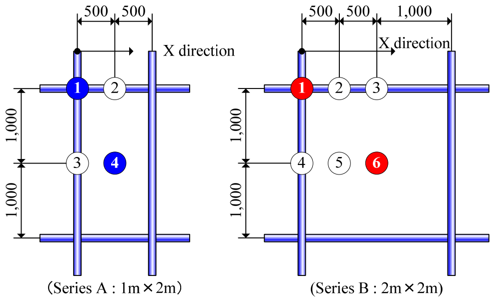


Fig. 6 Planar offset distance of test points from jacket.

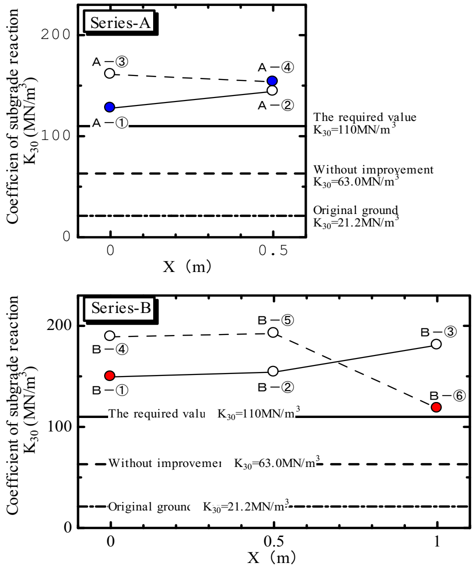


Fig. 7 Effect of offset distance on K_{30}.

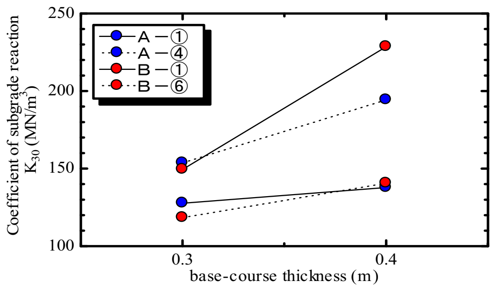


Fig. 8 Effect of base-course thickness on K_{30}.

at the 300-mm thickness were sufficiently large to meet the requirement, 300 mm was considered to be more appropriate at this site.

4 NUMERICAL ANALYSES

In applying the LFR sheet to a road or railroad, the proper lattice interval and crushed-stone thickness must be determined

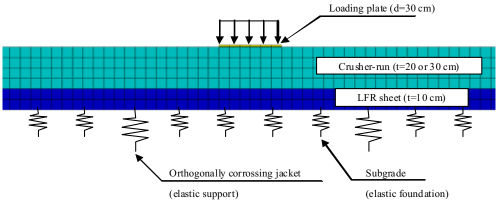


Fig. 9 Numerical model for load test simulation.

according to the ground conditions and required performance of the base course. To facilitate this, we built a set of diagrams to provide an economical design, based on the results of the plate load tests described in Section 3.

Figure 9 shows a two-dimensional finite element model that simulates the plate load test for the experimental construction. This model consists of a loading plate, crusher-run stone, LFR sheet, subgrade modeled as elastic foundation, and orthogonally crossing jackets modeled as elastic supports. The physical parameters of the model are listed in Table 1. Elastic parameters for the foundation and supports were determined following Yoshida et al. (2006) and based on the N-value of the subgrade. The LFR sheet, having a thickness of 10 cm, was integrated with the crusher-run stone inside the lattice frame. Young's modulus of the lattice spacing of the LFR sheet (1×2 or 2×2 m) was determined inversely so that the calculated K_{30} values at N=2 correspond to those of the actual plate loading denoted by hollow markers in Fig. 10(b) and (c). Thus, calculations were conducted to obtain the relationship between the subgrade N-value and K_{30} for the base course, with base-course thickness ranging from 0.2 to 0.4 m, as summarized in Fig. 10(a) to (c). In these diagrams, K_{30} values without the LFR sheet (namely, crusher-run stone only) indicated by solid circles were obtained by multiplying the computed K_{30} values by a constant, to agree with the test value, denoted by a hollow circle in Fig. 10(b).

Since the diagrams in Fig. 10 were composed referring only to the field experiment reported in Section 3, they must be verified through further application in the near future. However, plate load test results from recent road work (Okamoto et al., 2009), denoted by hollow markers in Fig. 10(a), indicate the reliability of these diagrams.

5 CONCLUSIONS

The following conclusions were drawn from this study:

- The LFR sheet is applicable for constructing a base course for roads and railroads on subgrade of insufficient bearing capacity.
- The K_{30} value on the base course consisting of the LFR sheet and crusher-run stone increases as the lattice interval decreases and the thickness of the crusher-run layer increases.
- In a full-scale experiment on subgrade of clayey sand with an N-value of 2, a sufficient K_{30} value as a railroad base course was achieved at a crusher-run layer thickness of 30 cm for a lattice interval of 2×2 m.

Table 1 Physical parameters in the numerical simulations

	Young's modulus (MN/m^2)	Poisson's ratio
Loading plate	10000	0.2
Crusher-run layer	100	0.4
LFR sheet (1×2 m)	2500	0.4
LFR sheet (2×2 m)	500	0.4
	Coefficient of reaction	
N-value of subgrade	Elastic foundation (kN/m^2)	Elastic support (kN/m)
1	2300	8700
2	4500	14500
3	6700	19300

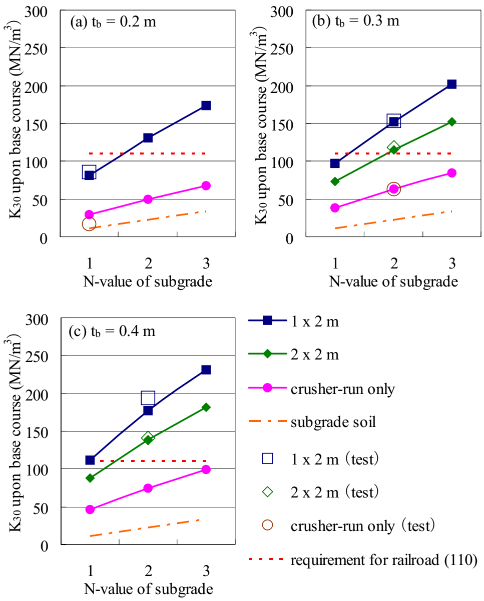


Fig. 10 Design diagrams of LFR sheet for base course. (t_b: thickness of base course including LFR sheet)

ACKNOWLEDGEMENT

We are grateful to East Japan Railway Co., Ltd. for their suggestions and support in the experimental construction.

REFERENCES

Okamoto, M., Yoshida, T. and Kitamoto, Y. (2009): Subgrade stabilization with lattice-frame-reinforced sheet, Proc. of 17th Int. Conf. of Soil Mechanics & Geotechnical Engineering, Alexandria (in press).

Railway Technical Research Institute (1992): Standards for railway structure construction, earth structures (in Japanese).

Yoshida, T., Kitamoto, Y., Shimada, Y., Kuronuma, I., Shibata, K., Karasaki, K., Goto, J. and Yagi, I. (2006): Effects of surface soil stabilization by a lattice-frame-reinforced sheet, Proc. of 8th Int. Conf. on Geosynthetics, Yokohama, pp. 843-846.