Subgrade stabilization with lattice-frame-reinforced sheet

Stabilisation du sous-grade avec la feuille de treillis à armature renforcée

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ABSTRACT

This paper presents a new type of subgrade stabilization technique, the lattice-frame-reinforced sheet, which consists of a textile sheet and mortar-injected fabric hoses. The special hoses, which are called "Jackets", are installed on the textile sheet with lattice-pattern before mortar injection. This sheet can not only distribute surcharge loads but also work as ground beams and furthermore confine the ballasting material on the sheet horizontally.

In order to investigate the performance of this sheet, a real-scale field test was carried out on the soft ground comprising clayey sand, which could not meet the requirements for subgrade of Japanese standard for railway structures. The developed sheet was laid on the soft ground and then a base-course layer was constructed upon the sheet. As a result of plate loading tests, it showed that the coefficient of vertical subgrade reaction of base course was large enough to satisfy the standard value of the requirements.

Consequently, this sheet was applied to actual temporary road works. By conducting plate loading tests, the effect on increasing the coefficient of subgrade reaction was verified, and compared with 'conventional case', in which only a sheet was laid on the ground and any frames are not placed on it. These test results showed that the developed sheet was able to substantially increase the coefficient of subgrade reaction and therefore effective to improve the quality of base course.

RÉSUMÉ

Ce document présente un nouveau type de technique de stabilisation du sous-grade, la feuille de treillis à armature renforcée, qui se compose d'une feuille de textile et de tuyaux à structure en mortier d'injection. Les tuyaux spéciaux, appellés "Jacket", sont installés en treillis sur la feuille de textile avant l'injection du mortier. Cette feuille peut non seulement répartir des charges supplémentaires mais également fonctionner comme une poutre de sol et en outre peut confiner le matériel de lestage horizontalement sur la feuille.

Afin d'étudier les performances de cette feuille, un test en terrain grandeur nature a été effectuée sur un sol mou comportant du sable argileux, qui ne répondrait pas aux critères pour les revêtements de route selon les normes japonaises pour les structures ferroviaires. La feuille développée a été étendue sur le sol mou et une couche de base en pierres broyées a été placée sur la feuille. Conséquemment aux essais de chargement sur plaque, elle a prouvé que le coefficient de réaction verticale du sous-grade de la couche de base était assez grand pour satisfaire la valeur standard des critères.

En conséquence, cette feuille a été appliquée aux travaux de route provisoires actuels. En effectuant des essais de chargement sur plaque, les effets sur l'augmentation du coefficient de réaction du sous-grade ont été vérifiés, et comparés au "cas conventionnel" dans lequel seulement une feuille a été étendue sur le sol sans qu'aucune armature ne fut posée dessus. Ces résultats d'essai ont prouvé que la feuille développée était capable d'augmenter sensiblement le coefficient de réaction du sous-grade et donc efficace pour améliorer la qualité de la couche de base.

Keywords : surface stabilization, geosynthetics, subgrade, plate loading test, coefficient of subgrade reaction

1 INTRODUCTION

During earthworks in which the surface layer is stabilized by paving sheets on very soft ground, differential settlements are likely to occur because of low flexural strength of the sheet. In such a case, large tensile forces may break the sheet which is usually accompanied by instant loss of earthwork materials. In Japan, to conduct with earthworks on very soft ground successfully, partial solidification of ground surface with cements, or installation of bamboo net made of bamboo stems together with textile sheet, hereinafter called 'bamboo sheet', have been often applied. However, these procedures may not only bring about environmental problems such as highly alkalic impact or logging of bamboo forest, but also reduce the economical performance of earthwork because additional costs and work periods are required. Moreover, the use of bamboo sheet could aggravate the unfavorite aspect in economical performance, for the reason that the cost of bamboo stem has gradually risen up according to losing the farm for it, and that bamboo sheet have been generally constructed in the job site. Hence, the bamboo sheet is supposed to impose a significant burden on the project managers in terms of time and effort.

To resolve these problems, the authors have developed the innovational technique for surface soil stabilization with the geotextile reinforced with a lattice frame, called LFR sheet (Yoshida et al., 2006). The LFR sheet consists of a textile sheet and mortar-injected fabric hoses, which are called 'Jackets' (Fig.1: Kitamoto et al., 2003).

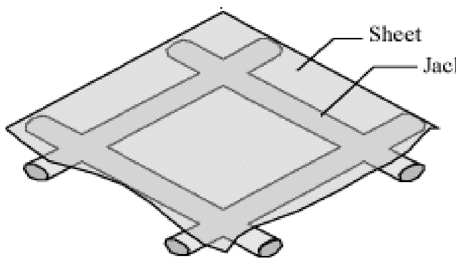

Figure 1. Basic features of the LFR sheet

M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2378

The installation steps of LFR sheet are described as follows.
(1) Weaving fabric hoses into lattice-pattern and fixing the hoses to textile sheet in the factory.
(2) Spreading the textile sheet out on the ground.
(3) Structuring of lattice-frame by injecting high liquidity mortar into the hoses.

In this procedure, what is necessary in the actual field should be only spreading of the sheet and mortar injection, which implies that installation of LFR sheet requires relatively lower efforts than bamboo sheet.

Yoshida et al. (Yoshida et al. 2006) previously reported stabilization effect of the LFR sheet on very soft ground comprising swamps and marshy soils, with the conclusions that the lattice-frame taking shape from the jacket, could improve the flexural strength of textile sheet, so that the LFR sheet could significantly decrease the differential settlement due to the load distribution effect.

In Japan, it is not necessarily true that only the very soft ground requires the improvement. Surface solidification with cement treatment or replacement with aggregates, are often applied in road or railway construction on relatively soft ground, when the surface layer does not meet the requirements for subgrade. The main objective of this paper is to report the application of the LFR sheet for improvement of subgrade stabilization.

2 FIELD TEST

2.1 *Objective*

To estimate the applicability of LFR sheet to subgrade stabilization, a field test was carried out (Okamoto et al. 2006). In this test, the LFR sheet was installed upon the subgrade surface of railway to satisfy the required intensity of the Japanese standard for railway construction.

2.2 *Condition of base foundation*

The stratigraphic profile of the test site, obtained from soil explorations with a test-pit, is shown in Fig.2. The surface layer as thick as 1.0m, which consisted of clayey sand and stiff layer was distributed from the depth of 2.35m of depth. In the test-pit whose depth is 4.0m, no subsoil water was found.

Vertical coefficient of subgrade reaction K_{30} observed in the surface layer by conducting plate loading test using 300mm diameter of loading plate, was less than $24MN/m^2$. In accordance with the railway standard, intensity of surface layer was insufficient in comparison with a requirement for a subgrade, identified as $70MN/m^2$ in the Japanese construction standard for railway (Railway technical research institute 1992). Hence, it was considered that the surface layer should be properly improved to construct a railway base-course on it. It was because the stiffness of base-course is significantly associated with that of subgrade.

2.3 *Testing procedures*

For the reasons mentioned above, the testing procedures were configured as follows.

- Subgrade surface was obtained by removing 200mm-thick of top soil.
- LFR sheet was spread out on subgrade surface.
- Railway base-course was constructed upon the LFR sheet.
- The performance of this system was estimated by vertical coefficient of subgrade reaction measured on the railway base-course, in comparison with the requirement for base-course (K_{30}>$110MN/m^2$) identified in the standard.

Fig.3 shows the formation of base-course that was constructed for the field test. To investigate the effect of lattice size on the stiffness of base-course, two lattice sizes were employed (series-A and B). The injected mortar (Fig.4) was made of early-strength cement with fluidizer. Its compression strength observed at 28days after injection was $45.6N/mm^2$. After a lapse of 3days from mortar injection, construction of base-course with a total thickness of 300mm, was carried out by placing crusher-run (D_{max}=40mm, Maximum dry density ρ_{dmax}=$2.17g/cm^3$) with 150mm-thick spreading layer. Compaction was conducted by hand-guide-roller on each spreading layer. Compaction degree of base-course, observed by in-situ density test, was more than 90%. For a comparison, another base-course was constructed upon the non-improved subgrade adjacently.

▽G. L.	<Thickness(m)>	<Type of soil>	<N-value>
▽G. L. -1. 00m	1. 00	clayey sand	2
▽G. L. -1. 65m	0. 65	clayey sand with gravel	4
▽G. L. -2. 35m	0. 70	fine sand	15
	more than 1. 66	gravel	more than 50

Figure 2. Stratigraphic profile of field test area

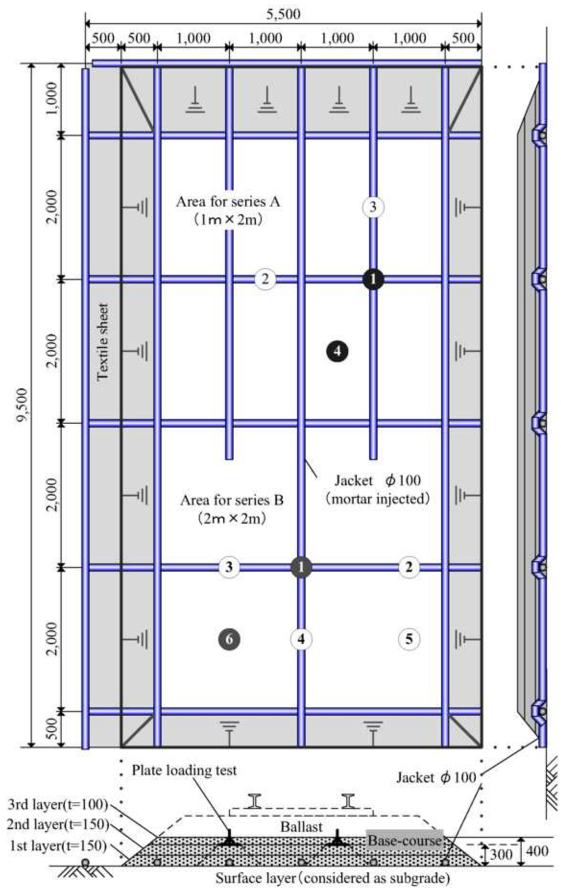

Figure 3. Configurations of field test (Unit: mm)

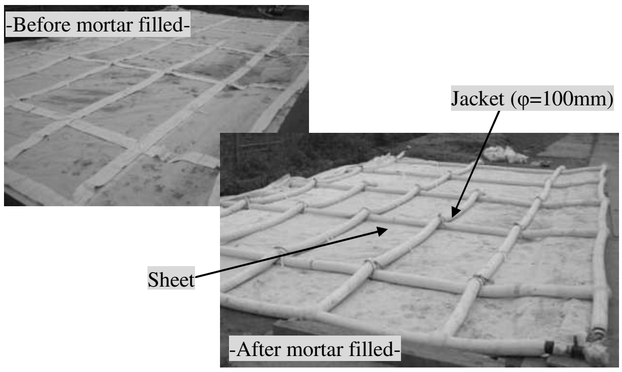

Figure 4. Structuring of lattice frame by mortar injection

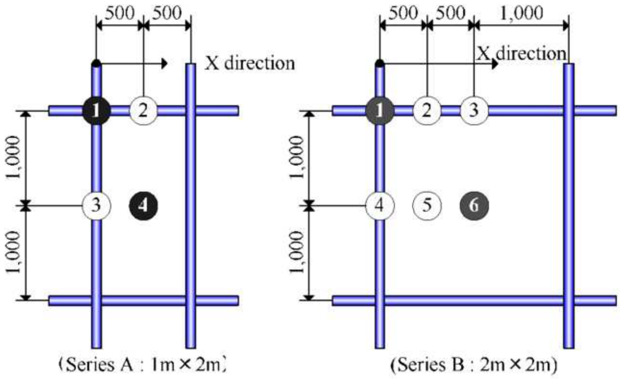

Figure 5. Integrated arrangement of test points (Unit: mm)

To estimate the performance of constructed base-course in terms of K_{30} value, plate loading tests with a diameter of 300mm for loading plate were carried out. It was expected that K_{30} should be influenced by the offset distance between the test point and the jacket, test points were selectively arranged as shown in Fig.5. In Fig.3 and 5, the number symbols indicate the points of plate loading test. To avoid interference between each test, each test point was actually arranged in a sufficient distance from the neighboring one, as shown in Fig.3.

After a series of tests, an additional 100mm-thick layer of base-course was placed to verify the effect of base-course thickness. At the points indicated by white colored symbols in Fig.3 and 5, plate loading tests were performed once again on the surface of the additional layer.

2.4 *Test results*

The relationships between the K_{30} value and offset distance from the jacket are shown in Fig.6. The minimum K_{30} value that was observed at B-6 in series B was not less than the required value of 110MN/m^2. In contrast, the K_{30} value observed on the base-course constructed upon subgrade without improvement failed to fulfill the requirements. This apparently denotes that the LFR sheet can improve the stiffness of base-course upon the subgrade that exhibits insufficient capability. The improving effect of the LFR sheet is recognized that jackets confine the materials placed in the lattice frame, so that the confining effect reduces the shear deformation. Furthermore, it could be said that jackets control the lateral displacement of base-course material during compaction, which facilitates a desirable compaction quality.

The observed K_{30} values at A-4 and B-5, which were both 0.5m away from the jacket, appeared almost the same as the K_{30} observed upon the jacket (e.g. A-3, B-3, 4). This result indicates that the improving effect of the LFR sheet is expected to be constant within the range of 0 to 0.5m away from jacket. Also, it should be noted that the observed K_{30} value at B-6 was generously 60 percent as much as the ones observed at adjacent points (B-4, 5).

The K_{30} values observed at intersecting points of jackets (A-1, B-1) were slightly smaller than those of adjoining points (A-2, B-2). Because as shown in Figure 4, two jackets were piled at every intersecting point, one of the jackets was inevitably upheld and thereby unable to be on contact with the textile sheet. The base-course materials placed beneath the upheld jacket were difficult to be compacted, which might lead to reduction of the dry density of base-course and the K_{30} value observed on the top of the intersecting points.

Fig.7 shows the effect of base-course thickness on K_{30}. It is obvious that the K_{30} values became larger with the increase of base-course thickness. Although, it was foreseen that the K_{30} values on 400mm-thick base-course would be influenced by the preceding tests, appropriate result that indicated dependency of K_{30} on base-course thickness was obtained. On the other hand, since the K_{30} values observed on 300mm-thick base-course app-

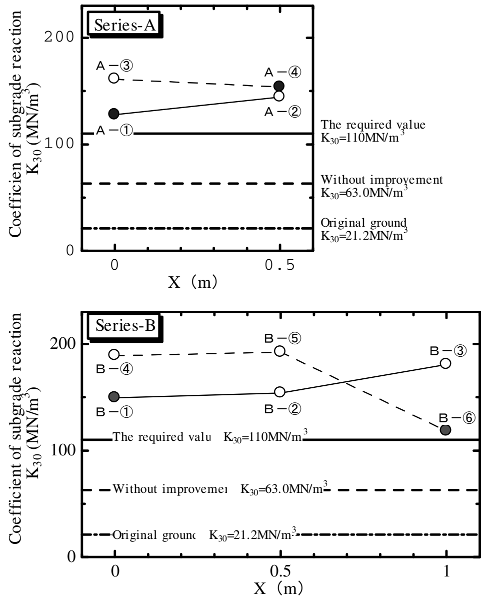

Figure 6 Effect of offset distance on K_{30}

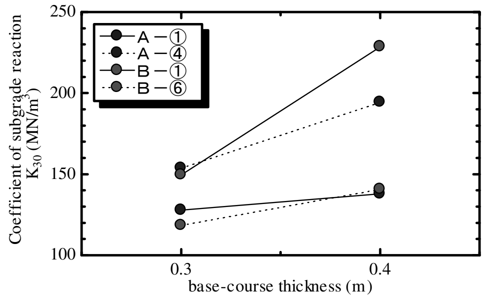

Figure 7. Effect of base-course thickness on K_{30}

-eared to be large enough to meet the requirement, 300mm of thick was considered to be adequate for base-course constructed in this site.

3 ACTUAL APPLICATIONS

3.1 *Application in a temporary road work*

3.1.1 *Back ground*

As described in the chapter.2, the field tests have confirmed the improvement performance of the LFR sheet. Consequently, employment of this sheet was decided in an actual temporary road work. The road work presented in this section was associated with a renewal work of road-bridge. The LFR sheet was installed for improving subgrade of approach roads to the temporary bridge that was in service during the renewal work. The approach roads to the temporary bridge was located in a paddy fields, where a very thick layer of peat (N=1~2) was distributed beneath the agricultural soil layer.

In such cases, surface treatment with chemicals or replacement with aggregates would be the resolution. But, after the bridge renewal works finished, the temporary bridge and the approach roads must be dismantled for restore the function of the paddy field. It was, however, expected that the perfect removal of solidified ground or scattered aggregates were extremely difficult. With installation of the LFR sheet, material of base-course (or upper subgrade) was physically isolated from the original ground by the textile sheet and this feature of the LFR sheet was recognized to ease the removal works. For this reason, the employment of LFR sheet was decided by the project manager.

3.1.2 *Observations and results*

Fig.8 shows the paved LFR sheet. And the pavement structure is shown in Fig.9. After the removal of agricultural soils, the LFR sheet mounted the lattice frame of series-A (as shown in Fig.5) was directly spread out on the top of peat layer. Both of the base-course and upper subgrade were made of aggregates (crusher-run: D_{max}=40mm). After the base-course was completely constructed, plate loading tests were conducted at the same points as indicated in Figure 5. The requirement for this base-course was more than 34.5MN/m^2 in K_{30} value. As shown in Table.1, all of the results on improved case complied with the requirement and K_{30} of another base-course made with conventional sheet (without lattice frame) which was constructed in co adjacent place indicated insufficient intensity. From this result, it was confirmed that an acceptable base-course was able to be constructed with using the LFR sheet.

And it should be noted that K_{30} of A-1 (jacket cross point) was the lowest in all result. This was expected to be associated with the same reason, as mentioned in section 2.4. To resolve this problem, a new method of jackets crossing is being developed.

Figure 8. The paved LFR sheet

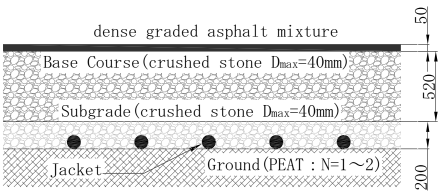

Figure 9. Pavement structure (Unit: mm)

Table 1. Results of plate loading tests

Test Location (in Fig.5)	Coefficient of subgrade reaction K_{30}
A-1	67.1 MN/m^2
A-2	101.2 MN/m^2
A-3	125.5 MN/m^2
A-4	86.2 MN/m^2
Conventional Sheet (Without Lattice-Frame)	16.8 MN/m^2

3.2 *Other cases of installation*

Fig.10 is the case of installation to temporary road for construction machinery which was directly established upon the wet paddy field. In such a disadvantageous condition, the LFR sheet can provide certain performance (Goto et al. 2006).

Fig.11 also shows the case of installation to temporary road for a river improvement work. In this case, temporary road located in the reed community. By the installation of the LFR sheet, removal of subsoil stems became to be prevented. After a half year from the removal of temporary road, resurgence of the reed community could be confirmed (Okamura et al. 2007).

Figure 10. Installation for temporary approach in wet paddy field

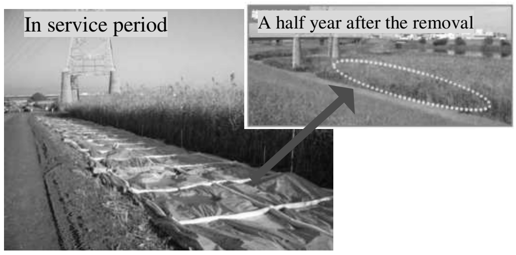

Figure 11. Installation for protection of the subsoil stems of reeds

4 CONCLUSIONS

The improvement performance of the LFR sheet was confirmed empirically by the investigations described in this paper. In the next stage, the designing system which makes it possible to estimate the effect of lattice size and material confining effect of the jacket should be developed.

ACKNOWLEDGEMENT

The LFR sheet was developed jointly by Ashimori Industry Co., Ltd. The authors appreciate the cooperative members of Ashimori Industry for their grate efforts and cooperation. And the authors are grateful to East Japan Railway Company for their suggestion and support in the field test mentioned in chapter.2. The authors also would like to acknowledge Suwa construction office of Nagano prefecture, Moriya Corporation and Chouhou Construction Co., LTD, for their provision of the information about installation of the LFR sheet described in chapter.3.

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