Settlement of geogrid-reinforced railroad bed due to cyclic load

Étude de l'effet d'une charge périodique sur le tassement du sol d'une voie de chemin de fer qui a été renforcé par une géogrille

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ABSTRACT: Results of large-scale laboratory model tests conducted to determine the permanent settlement due to cyclic load of the railroad bed for a proposed high-speed train route extending from Seoul to Pusan in South Korea are reported. The maximum anticipated speed of the train is likely to be 385 km/hr. The possibility of using geogrid layers as reinforcement to reduce the permanent settlement of the subbase layer was investigated. Based on the present test results, it appears that practically all permanent settlement due to cyclic load is completed after application of 100,000 cycles of load.

RÉSUMÉ: Cet article présente les résultats d'une étude, basée sur un modèle de laboratoire, sur l'effet qu'une charge périodique a sur le tassement du sol d'une voie de chemin de fer. Cette étude à grande échelle avait pour but de déterminer le tassement du à une charge périodique sur le sol de la voie d'une ligne de chemin de fer à grande vitese allant de Séoul à Pusan en Corée du Sud. On prévoit que la vitesse maximum sera de l'order de 385 km/hr. L'utilisation de couches de geogrille pour réenforcer le sol et rééduire le tassement a été étudiée. Les résultats obtenus semble indiquer que presque tout le tassement due to a la charge périodique est terminé aprés 100.000 cycles de charge.

1 INTRODUCTION

In order to reduce ever-increasing highway traffic in South Korea, a new high-speed train service is being planned between Seoul, the capital, and Pusan, the second largest city. The maximum anticipated speed of the train is about 385 km/hr. It is expected that the high-speed train will transmit cyclic load to the sleepers that will induce permanent settlement of the railroad tracks primarily due to the compression of the subbase and the compacted *in situ* soil. More recently results of several studies have been published which related to the permanent settlement of foundations due to the application of cyclic load (e.g., Yeo et al., 1993; Das and Shin, 1993; Das et al., 1998). In designing the railroad, it was essential to estimate the magnitude of the possible permanent settlement of the soil below the ballast and subballast due to cyclic loading. Attempts were also made to evaluate the possibility of reducing settlement by reinforcing the soil with layers of geogrid. The results of these model tests are presented.

2 CONSIDERATIONS FOR CYCLIC LOAD ON SLEEPERS

Figure 1 shows a schematic diagram of the layout of the railroad track. To consider the load transfer mechanism from the wheel to the ground supporting the sleepers, the present Japanese standard (RTRI, 1996) was used, according to which the load is not uniformly distributed by a sleeper. Figure 2 shows the load transfer mechanism assumed by the Japanese standard. For the present case, the area of a sleeper carrying uniformly distributed load on each side is $A = 2aB = (2)(53.8)(27.54) \approx 2963\ \text{cm}^2$. The magnitude of the actual design wheel load (static) of the high-speed train is estimated to be 83.4 kN. According to the Japanese standard (RTRI, 1996) which was used for this design, dynamic effects and the uneven surface contact between the wheels and rails should be considered, or:

$$P'_w = P_w\left(1+\frac{V}{100}\right)(1+C) \quad (1)$$

where P'_w = equivalent dynamic load for each wheel; P_w = static wheel load (= 83.4 kN in this case); V = maximum velocity in km/hr; C = a coefficient ≈ 0.3.

With V = 385 km/hr and P_w = 83.4 kN, Eq. (1) yields P'_w = 236.6 kN. Again, a part of the load on a sleeper will be transmitted to the adjacent sleepers, and it is between 40 to 60%. Conservatively, assuming that the equivalent dynamic load to be carried on each side of a given sleeper is $0.6P'_w$, the intensity of the maximum cyclic load [$q_{d(\max)}$] on an actual sleeper in the field would be

$$q_{d(\max)} = \frac{0.6P'_w}{A} = \frac{(0.6)(236.6)}{2963\times10^{-4}} \approx 479\ \text{kN/m}^2$$

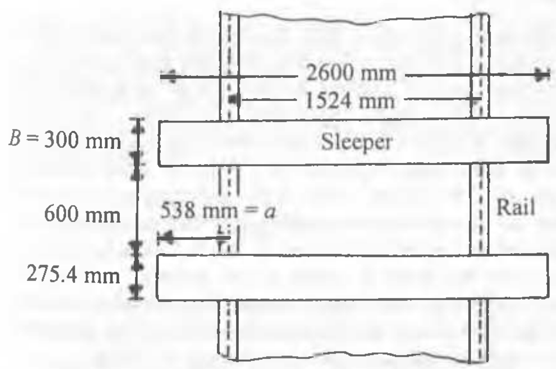

Figure 1. Proposed layout of the railroad track

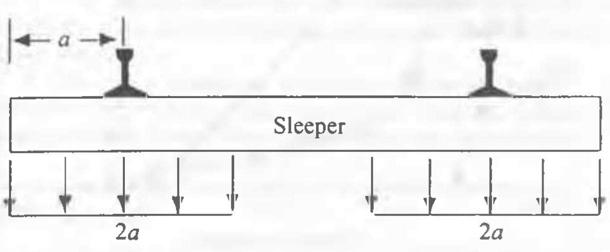

Figure 2. Load transfer mechanism assumed by Japanese standard

3 LABORATORY MODEL TESTS

The model test box was made out of steel plates which were 8 mm thick. The inside dimensions of the box measured 1.4 m (length) × 1 m (width) × 2 m (height). For the laboratory model tests, it was decided to use a test plate with a = 400 mm and B = 270 mm, which gives an effective area A = (2)(40 cm)(27 cm) = 2160 cm^2, which is about 73% of the area under actual field condition. Thus the model sleeper used for the laboratory testing measured 800 mm (length) × 270 mm (width) × 33 mm (thickness) and was made from steel.

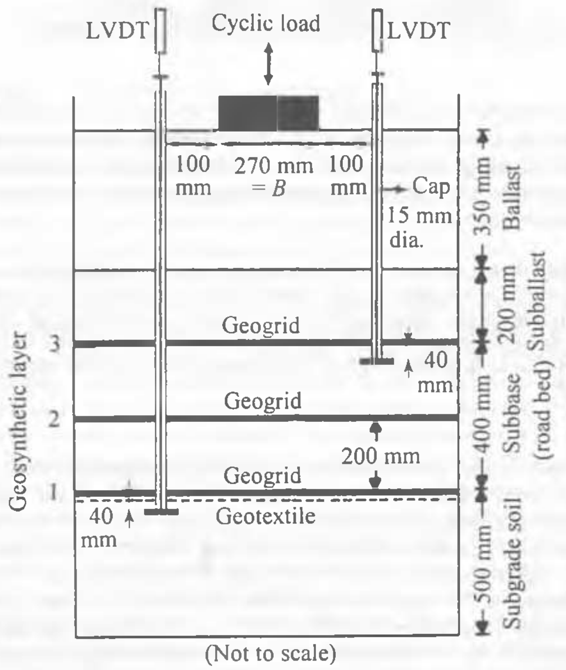

Figure 3. Model test arrangement

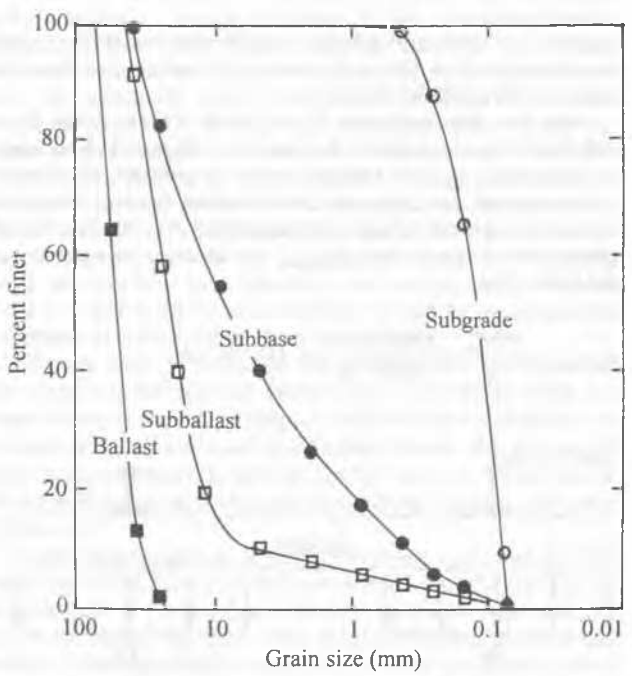

Figure 4. Grain-size distributions of subgrade soil, subbase soil, subballast, and ballast

Table 1. Physical Properties of geosynthetics used for soil reinforcement

Property	Geogrid	Geotextile
Polymer type	Polypropylene	Polyester
Manufacturing type	Bi-axial	Nonwoven
Thickness (mm)	6.5 (junction)	4.5
Yield point elongation (%)	MD: 10.1; CD: 12.4	50-120
Tensile strength at 2% elongation (kN/m)	MD: 20.2; CD: 14.1	--
Aperture size (mm)	34 (MD) × 27 (CD)	--

Note: MD—machine direction; CD—cross-machine direction

Table 2. Sequence of model tests

Test No.	Reinforced/ unreinforced	Reinforcement details (see Figure 3)
1	Unreinforced	—
2	Reinforced	Layer 1 only (geotextile and geogrid)
3	Reinforced	Layers 1 and 2
4	Reinforced	Layers 1, 2, and 3

Figure 3 shows a schematic diagram of the model test arrangement. The materials used for the ballast, subballast, subbase (road bed), and the subgrade soil are representative of those in actual field conditions. The grain-size distributions of these materials are shown in Figure 4. The thicknesses of the ballast, subballast, and the subbase (road bed) layers in the model test box were kept the same as would be encountered in the field. Laboratory compaction tests were conducted on the subbase soil and the subgrade soil with the following results:

Subbase soil: Maximum dry unit weight = 21.1 kN/m^3
Optimum moisture content = 9.14%
Test method: ASTM D-1557 (Method D)

Subgrade soil: Maximum dry unit weight = 15.5 kN/m^3
Optimum moisture content = 8.6%
Test method: ASTM D-698 (Method A)

The subgrade soil and the subbase (road bed) coarse materials were mixed with the desired amount of water to reach the optimum moisture levels. These soil, subballast, and ballast materials were compacted in 100-mm lift thicknesses to the average maximum dry unit weights. To compact the soil, a hand-held vibrator with a flat bottom plate (135 mm × 117 mm) was used. The geotextile and geogrid layers were placed at desired depths. Physical properties of the geotextile and geogrid used for the tests are given in Table 1. Two LVDTs were placed along the center line and 100 mm away from the edges of the model sleeper—one for measuring the settlement near the top of the subbase course and the other for measuring the settlement near the top of the subgrade soil (Fig. 3). The model sleepers were placed centrally on the top of the ballast. Load to the sleeper was applied by an altreator. The sequence of the model tests is given in Table 2.

4 LOADING CONDITIONS FOR THE MODEL TESTS

In the laboratory, the cyclic load applied on the model sleeper which measured 270 mm × 800 mm provided maximum [$q_{d\max}$] and minimum [$q_{d(\min)}$] stresses of 545 kN/m^2 and 45 kN/m^2, respectively. The load application sequence is shown schematically in Figure 5. It included two step loads raising the intensity of static load to 295 kN/m^2. A cyclic load having an amplitude of 250 kN/m^2 was then superimposed, thereby providing the desired magnitude of $q_{d(\max)}$. The maximum cyclic stress applied in the laboratory test is about 13.8% higher than anticipated in the field. It needs to be pointed out that the frequency of cyclic load was increased gradually with the application of 10 cycles at 0.01 Hz followed by 1000 cycles at 2 Hz, after which the frequency was maintained at 3.5 Hz.

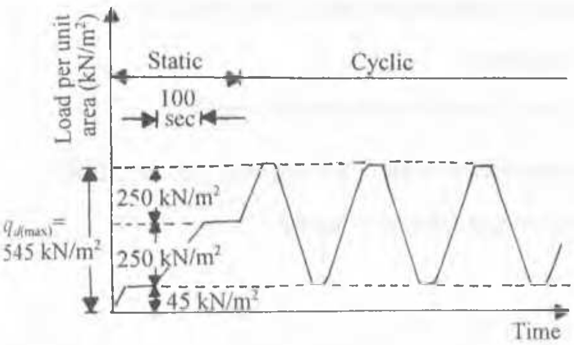

Figure 5. Load application sequence

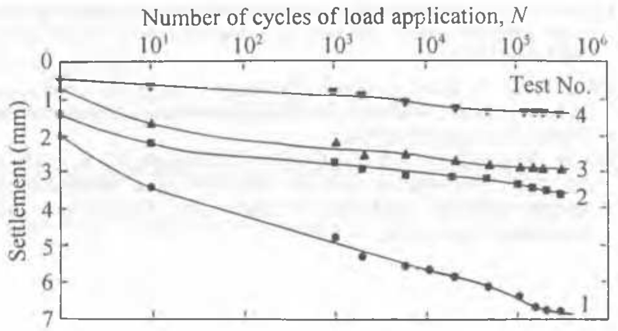

Figure 7. Settlement of subgrade soil

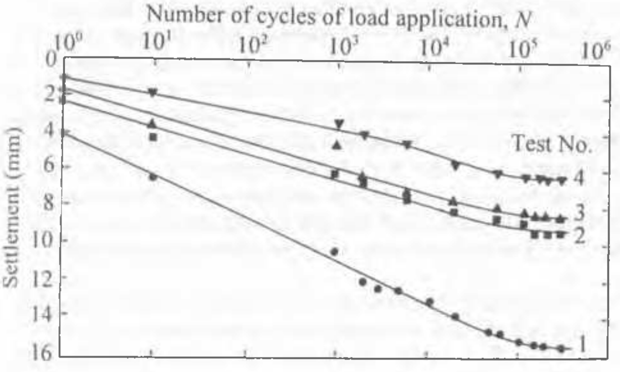

Figure 6. Total settlement of subgrade soil and subbase (measured at the top of the subbase course)

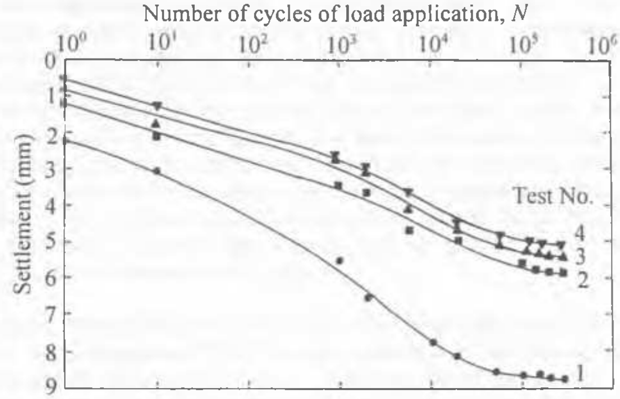

Figure 8. Settlement of subbase (road bed)

5 MODEL TEST RESULTS

Figures 6 and 7 show plots of the variations of the settlements measured with number of load cycles, respectively, at the top of the subgrade soil layer and subbase course. The settlement measured at the top of the subgrade soil represents the settlement of that layer only (S_d). The settlement measured at the top of the subbase course (S_t) is the total settlement of the subgrade soil and the subbase course. Thus, the net settlement of the subbase course (S_t) can be estimated as

$$S_s = S_t - S_d \tag{2}$$

Using Eq.(2) and the experimental results shown in Figures 6 and 7, the variation of S_s with the number of load cycles was calculated and is shown in Figure 8. From Figures 6, 7, and 8, several observations can be made, and they are described below. For all tests, the permanent settlements (S_t, S_s, and S_d) increased with the number of load cycle applications (N) up to about 0.7×10^5 to 1×10^5 cycles. For N greater than about 0.7×10^5 to 1×10^5 cycles, the settlement remained practically constant. This value of N may be called N_{cr} (critical number of load cycles). Assuming that the maximum permanent settlement occurs at N_{cr}, the reduction of permanent settlement due to reinforcement, R, can be calculated as:

$$R = \frac{S_{\text{unreinforced}} - S_{\text{reinforced}}}{S_{\text{unreinforced}}} \times 100 \tag{3}$$

Based on the results shown in Figures 6 and 8 and using Eq. (3), the magnitudes of the reduction of total settlement (R_t) and the reduction of settlement of the subbase course (R_s) were calculated, and these values are given below:

Test No.	R_t (%)	R_s (%)
2	47	33
3	58	38
4	80	43

Based on the values of R_t and R_s given above, the most significant effect in decreasing the permanent settlement is due to the inclusion of the geogrid and geotextile layers at the interface of the subbase and subgrade soil layers (test No. 2). At the same time, minimal effect on the values of R_t and R_s is realized when the geogrid layer is placed at the middle of the subbase layer, and it is probably not cost effective.

6 CONCLUSIONS

Four large-scale laboratory model tests were conducted to estimate the permanent settlement of the railroad bed due to the application of cyclic load developed during the movement of a proposed high-speed train from Seoul to Pusan (South Korea). The effect of using geogrid reinforcement for settlement reduction was investigated. Based on the present model test results, the following conclusions can be drawn:

1. The critical number of cyclic load applications beyond which the permanent settlement remains practically constant is about 100,000.
2. The most beneficial effect of settlement reduction is realized when a layer of geotextile and a layer of geogrid are placed at the interface of the subbase layer and the dredged soil.

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