Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-1757

Deformation characteristics of railway asphalt roadbed under a moving wheel load

Les caractéristiques de déformation de couche de base d'asphalte ferroviaire sous une roue mobile chargent

Y. Momoya & E. Sekine
Railway Technical Research Institute, Tokyo, Japan

ABSTRACT
For the purpose of a basic study to develop a relevant performance-based design method for railway asphalt roadbed, resilient and residual deformation characteristics of roadbed and subgrade were evaluated by means of scale model tests. In this study, moving-wheel loading tests were carried out, because the deformation characteristics under fixed-point loading were substantially different from that under traveling trainloads. This paper discusses the effect of the stiffness and thickness of roadbed on the resilient and residual deformation of roadbed and subgrade under the moving-wheel loads.

RÉSUMÉ
Pour développer une méthode de conception appropriée pour le trottoir d'asphalte pour le chemin de fer, des caractéristiques résilientes et résiduelles de déformation le trottoir d'asphalte ont été évaluées par les essais modèles. Dans cette étude, des essais roue mobile chargent ont été effectués, parce que les caractéristiques de déformation sous le chargement à point fixe étaient essentiellement différentes de celle sous les trainloads. Cet article discute l'effet de la rigidité le trottoir d'asphalte sur la déformation résilientes et résiduelles de couche de base le roue mobile chargement.

1 INTRODUCTION

Asphalt roadbed (asphalt concrete roadbed), cross section of which is shown in Fig.1, is widely laid under ballasted railway tracks in Japan, primarily to support ballasted tracks firmly and reduce the track irregularities. Furthermore, asphalt roadbeds are designed to reduce the load level in subgrade so that the subgrade is not excessively deformed. In the current design standards of railway asphalt roadbed, the thickness of asphalt roadbed is determined to limit the maximum resilient settlement at the top of the roadbed evaluated by the elastic half-space theory to 2.5mm (Sunaga and Sekine, 1994). This current design standard does not take into account the number of train passings. To alleviate this drawback and to develop a more rational performance-based design method that can reduce the total life cycle cost, the design method of asphalt roadbed is now being revised. A performance-based design method has been applied to asphalt concrete pavement for highways, in which the service life of the asphalt concrete layer is determined based on a fatigue criterion. It is considered that the new performance-based design of railway asphalt roadbed should also be based on a similar fatigue criterion for asphalt concrete. For the basic study to introduce fatigue criterion of asphalt concrete, deformation characteristic of railway asphalt roadbed was thoroughly investigated in this study.

In the design of pavement for highways, a fatigue criterion of asphalt concrete is specified in terms of maximum resilient tensile strains that are evaluated by multi-layer elastic analysis. However, railway roadbeds are subjected to complicated load conditions due to complicated track structures, composed of rails, sleepers and ballast. In order to apply fatigue criterion of asphalt concrete, it is necessary to clarify resilient deformation characteristics of asphalt roadbed coincide with residual deformation under repeated loading.

To investigate the deformation characteristics of railway track structures, fixed-point loading tests have frequently been conducted by applying a repeated load to the same point of a rail (Momoya et al., 2002). However in fixed-point loading tests, there is an inevitable problem in that the settlement of the sleeper beneath the loading point becomes greater than that of adjacent sleepers (Hirakawa, 2002). As a result, maximum load applied to the sleeper beneath the loading point gradually decreases with repeated loading. Therefore, fixed point loading cannot evaluate resilient deformation characteristic of railway roadbed properly. To alleviate this drawback, a moving-wheel loading method was developed to move a wheel on the rail at a constant load, simulating the traveling trainload on railway track. Moreover, under moving-wheel loading, the continuous rotation of the direction of principal stress has a certain effect on the residual deformation (Wong and Arthur, 1985; Towhata et al., 1994). In the present study, the whole (resilient and residual) deformation characteristics of railway asphalt roadbed in the moving- wheel loading tests were discussed.

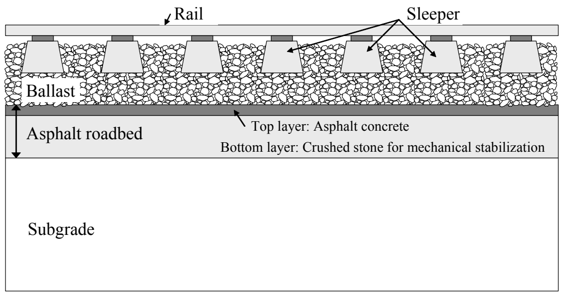


Figure 1. Typical cross-section of railway asphalt roadbed.

2 MOVING WHEEL LOADING TEST METHOD

Fig. 2 shows the model test apparatus developed for moving-wheel loading test, in which a loading wheel moves back and forth repeatedly at a speed of 60 cm/min between the ends on a pair of rails. The wheel load was applied by using air cylinder. The model scale was 1/5, which was composed of two rails, fifteen sleepers, an asphalt roadbed and subgrade.

Fig. 3 shows the longitudinal cross section of the scale model in detail. In a prototype track, an asphalt roadbed is composed of an asphalt concrete top layer and a crushed stone bottom layer. In this scale model, the asphalt roadbed was made of CA (cement asphalt) mortar for the asphalt concrete layer and sandy gravel for the crushed stone layer. The subgrade was made of gravelly sand, which is used in the construction of railway embankment. Grain size distributions and physical properties of sandy gravel and gravelly sand are described in Fig. 4. In the scale model test, the effect of asphalt concrete layer (CA mortar layer in the scale model) and asphalt roadbed thickness was investigated. The thickness of asphalt roadbed was controlled by the thickness of bottom layer (crushed stone for mechanical stabilization), because the asphalt concrete layer of asphalt is constant value of 5 cm (1 cm in the scale model) in

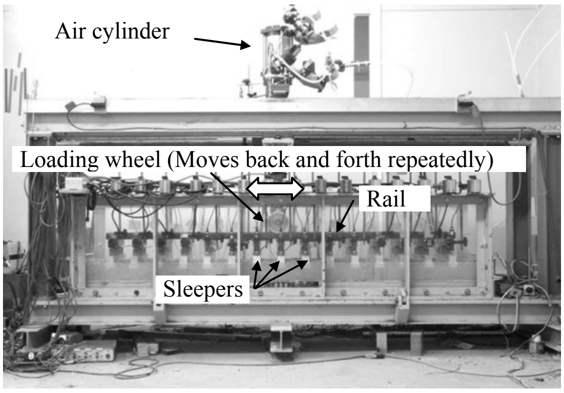


Figure 2. Moving-wheel loading test apparatus.

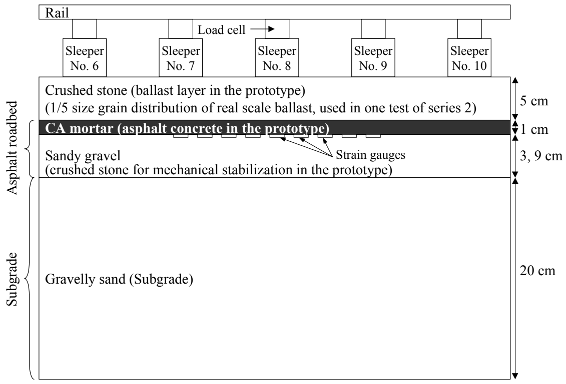
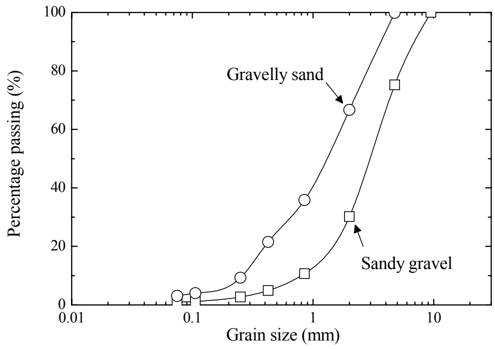


Figure 3. Longitudinal cross-section of scale model.



	Gravelly sand	Sandy gravel
D_{50} (mm)	1.32	2.97
U_c	6.48	4.35
G_s	2.664	2.710
ρ_{dmax} (g/cm^3)	1.956	2.205
w_{opt} (%)	10.5	7.8

Figure 4. Grain size distributions and physical properties of sandy gravel and gravelly sand.

the prototype track. The thickness of the subgrade was 20 cm. The length of the scale model was 2 m and the width was 30 cm.

While the scale model tests were basically carried out without ballast layer to avoid the scattering of the test result, one case with 5 cm-thick ballast layer was performed to investigate the effect of the existence of that.

In these tests, measurements were taken for the vertical load on the sleepers, the vertical and shear stresses at the bottom of the subgrade, the strain at the bottom of the CA mortar layer, and for sleeper displacement. The wheel load and position were simultaneously monitored. These values were recorded and stored in a computer at intervals of 0.1 seconds. To observe the deformation in the subgrade, image processing was adopted. Black circular markers, 1.5 mm in diameter, were arranged in a 1 cm-interval grid pattern on the latex membrane placed with silicone grease at the inside of transparent acrylic side wall of the sand box. From the digital images of those markers, the stain distribution in the asphalt roadbed and subgrade was obtained by image processing program in computer.

3 RESIDUAL DEFORMATION CHARACTERISTICS

Fig. 5 shows the vertical load activated at sleepers under moving-wheel loading in the case with 10-cm thick asphalt roadbed. Although respective sleepers applied vertical load sequentially, magnitudes of the vertical loads are different between sleepers due to the setting condition of sleepers that were connected to the rigid rail. This difference of vertical sleeper load in respective sleepers was almost same during repeated moving-loading through the tests. Fig. 6 shows residual settlement of each sleeper after 100 cycles by 1.5 kN wheel load, after 50 cycles by 3 kN and after 1000 cycles. It seems that the sleepers settle almost uniformly under the moving-wheel loading, although the

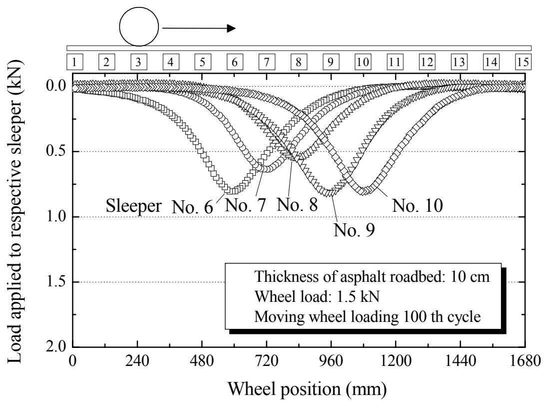


Figure 5. Vertical load applied to respective sleepers.

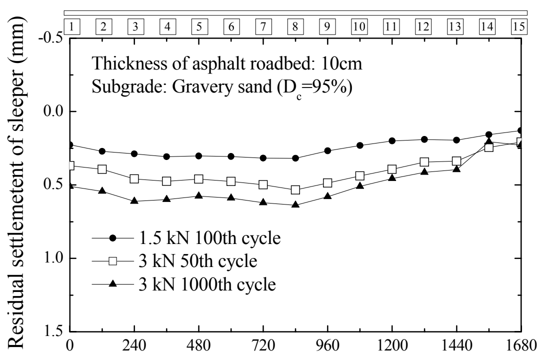


Figure 6. Residual settlement of respective sleepers.

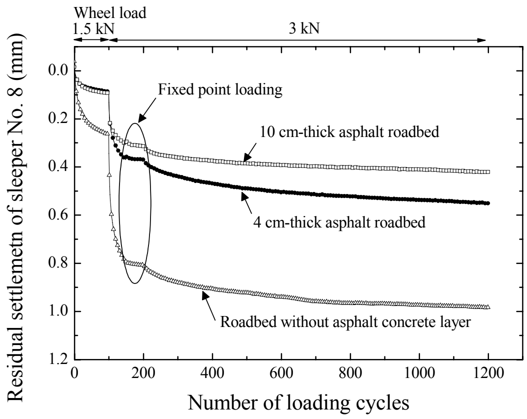


Figure 7. Residual settlement of sleeper No. 8.

magnitudes of vertical loads on respective sleepers were different.

Fig. 7 shows the residual settlement of sleeper No. 8, which located in the center of the scale model. In those tests, the wheel load was 1.5 kN for the first 100 loading cycles, which was subsequently increased to 3 kN. During otherwise moving-wheel loading at a wheel load of 3 kN, cyclic loads between zero and 3 kN were applied to a fixed-point on the rails above the center of sleeper No. 8. Moving-wheel loading at a wheel load of 3 kN was carried out for 1,000 times. With the increase of wheel load from 1.5 kN to 3 kN, the increment of the residual settlement significantly increased. By contrast, the residual settlement rate became suddenly much smaller, by a factor of 1/6 – 1/4 once fixed point loading was commenced. From these results, it is clear that the deformation characteristics under moving-wheel loading fixed-point loading becomes quite different.

When the wheel load was 1.5 kN, the effect of the asphalt roadbed thickness was not significant. The effect became significant when the wheel load became 3 kN. Finally, in the case with 10 cm-thick asphalt roadbed, the residual settlement of the sleeper was approximately 30 % smaller than in the case with 4 cm-thick asphalt roadbed after 1,000 times 3 kN loading.

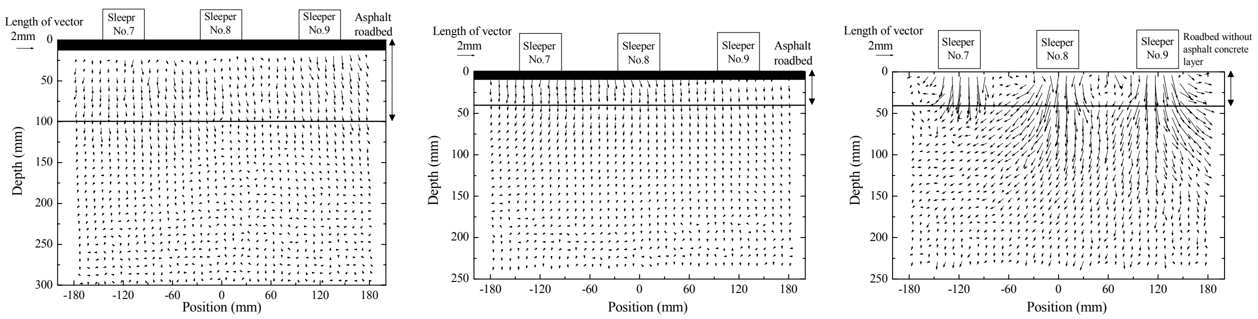
The effect of the existence of 1 cm-thick asphalt concrete layer (CA mortar layer in the scale model) was rather larger than the total thickness of asphalt roadbed. In the case without CA mortar layer, the settlement of the sleeper became approximately as twice as the case with it.

To clarify the function of asphalt concrete layer, deformation in the roadbed and subgrade was investigated visually on the image processing results. Fig. 8 shows the residual deformation in roadbed and subgrade at the end of the tests and Fig. 9 shows residual shear strain of those. In the cases with asphalt concrete layer, roadbed deformed uniformly while in the case without asphalt concrete layer, the deformation significantly concentrated beneath the sleepers. In the case without asphalt concrete layer, shear strain concentrated beneath the edges of sleepers while in the cases with asphalt concrete layer, the magnitude of shear strain was much smaller. The results showed that the 1-cm thick thin stiff layer of asphalt concrete had significant effect to reduce the concentration of deformation in the asphalt roadbed. Because asphalt concrete layer serves significant role for the function of asphalt roadbed to reduce the residual deformation in the roadbed and subgrade, it is important to estimate the life of asphalt concrete accurately in the design of asphalt roadbed.

4 RESILIENT DEFORMATION CHARACTERISTICS

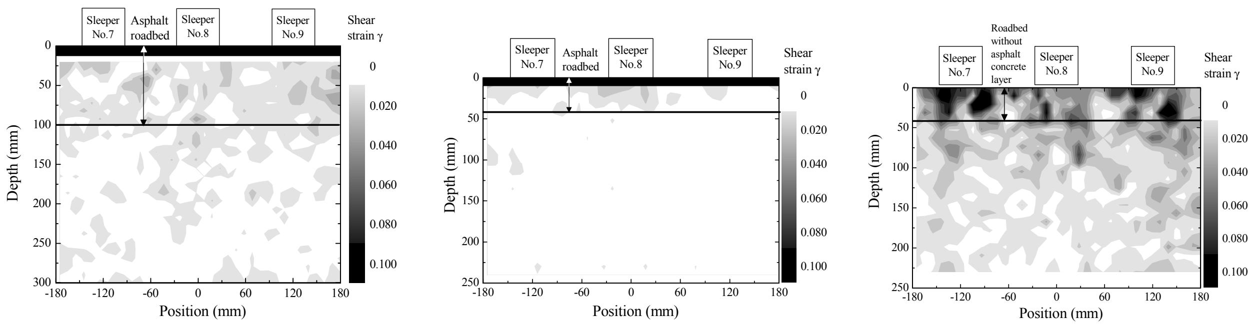
It is important to clarify the resilient deformation characteristics of asphalt roadbed because the fatigue criterion of asphalt concrete is specified in terms of maximum resilient tensile strains. To introduce this method, it is necessary to investigate the resilient deformation characteristics of railway asphalt roadbed coincide with the accumulation of residual deformation.

Fig. 10 shows the transition of sleeper vertical load amplitude of sleeper No. 8 by the number of loading cycles. At the beginning of the 1.5 kN moving-wheel loading, the sleeper vertical load amplitude slightly increased and converged to a constant value. With the increase of wheel load to 3 kN, the sleeper vertical load amplitude increased to approximately twice value linearly. Immediately after the increase of wheel load, the sleeper vertical load amplitude slightly increased again and co



(a) 10 cm-thick asphalt roadbed (b) 4 cm-thick asphalt roadbed (c) Roadbed without asphalt concrete layer

Figure 8. Residual deformation in the roadbed and sugrade at the end of the moving-wheel loading tests.



(a) 10 cm-thick asphalt roadbed (b) 4 cm-thick asphalt roadbed (c) Roadbed without asphalt concrete layer

Figure 9. Residual shear strain in the roadbed and sugrade at the end of the moving-wheel loading tests.

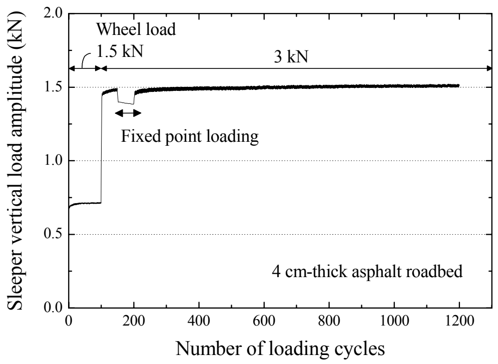


Figure 10. Sleeper No. 8 vertical load amplitude.

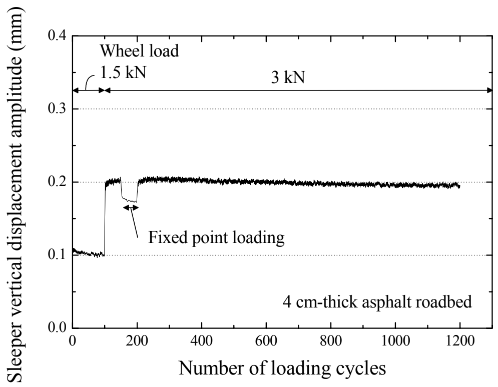


Figure 11. Sleeper No. 8 vertical displacement amplitude.

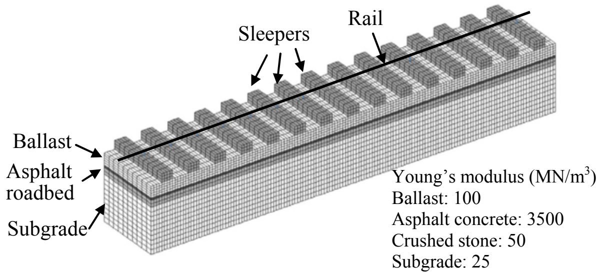


Figure 12. Three dimensional FEM model.

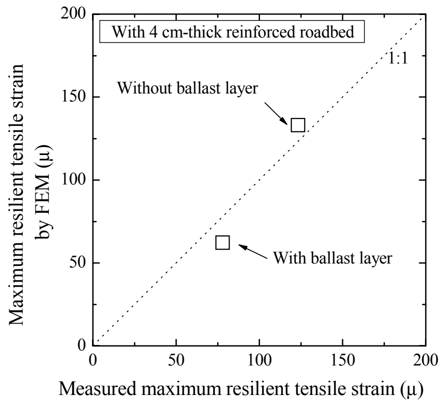


Figure 13. The maximum resilient strain of asphalt concrete layer in the scale model test and FEM, with and without ballast layer.

converged to a constant value. Those slight transitions are due to the increase of stiffness of roadbed and subgrade during the repeated moving wheel loading. A sleeper just beneath the wheel sustained approximately 50 % of the wheel load in this scale model, and that ratio slightly increased with the increase of the stiffness of roadbed and subgrade and converged to a constant value. On the contrary, during repeated fixed-point loading, the vertical sleeper load gradually decreased with the number of loading cycles.

Fig 11 shows the sleeper vertical displacement amplitude. The sleeper vertical displacement slightly decreased with the number of loading cycles due to the increase of stiffness of the roadbed and subgrade, and converged to a constant value. The displacement amplitude during repeated fixed point loading also decreased, similarly to the moving-wheel loading. However, this is due to the decrease of vertical load amplitude of the sleeper No. 8 in the repeated fixed-point loading. These results show that the residual deformation characteristic under fixed point loading is essentially different from that under moving-wheel loading. This is the major problem of fixed-point loading on railway roadbed that it can not evaluate not only the residual but also the resilient deformation characteristics of the railway roadbed.

On the ground of the results of the scale model tests, the resilient strain of asphalt concrete layer in the model tests were simulated by FEM. The FEM model (Fig. 12) was three-dimensional and the physical properties of the roadbed and subgrade materials were determined from the results of unconfined compression tests and triaxial compression tests. Fig. 13 shows the maximum resilient strain of asphalt concrete layer in the case with and without ballast layer with 4-cm thick asphalt roadbed. From the result, it was confirmed that the FEM properly simulates the strain in the scale model tests. However the asphalt roadbeds are subjected by complex track structures, the FEM becomes an effective method to obtain the strain of asphalt concrete layer. Therefore, by introducing FEM, it is possible to apply fatigue criterion of asphalt concrete in the design of railway asphalt roadbed.

5 CONCLUSIONS

The deformation characteristics of asphalt roadbed were investigated by moving-wheel loading test, which was proved to be substantially different from the fixed-point loading test. An important function of asphalt concrete layer to reduce the deformation of roadbed and subgrade was clarified.

The results of the moving wheel loading tests showed that the resilient deformation kept constant condition, even the residual deformation accumulated with the number of loading cycles. The resilient strains of asphalt concrete were properly obtained by FEM. It is concluded that it is appropriate to introduce the fatigue criterion of asphalt concrete into the design of railway asphalt roadbed.

REFERENCES

Hirakawa,D., Kawasaki,H., Tatsuoka,F. and Momoya,Y. 2002. *Effects of loading conditions on the behaviour of railway track in the laboratory model* tests, Proc. 6th Int. Conf. on the Bearing Capacity of Roads, Railways and Airfields, Lisbon, Balkema, Vol. 2, pp.1295-1305

Momoya, Y., Ando, K. and Horiike, T. 2002. *Performance tests and basic design on solid bed track on asphalt pavement*, Proc. 6th Int. Conf. on the Bearing Capacity of Roads, Railways and Airfields, Lisbon, Balkema, Vol. 2, pp. 1307-1322

Sunaga, M. and Sekine, E. 1994. *A study on decrease of reinforced roadbed thickness in railway*, Journal of Construction Management and Engineering, JSCE, No. 498/VI-24, pp.57-66. (in Japanese)

Towhata, I., Kawasaki, Y., Harada, N. and Sunaga, M. (1994): "Contraction of soil subjected to traffic-type stress application," *Proc. of Inter. Sympo. on Pre-Failure Deformation Characteristics of Geomaterials*, Sapporo, Japan (Shibuya et al. eds.), pp. 305-310.

Wong, R. K. S. and Arthur, J. R. F. 1985. *Induced and inherent anisotropy in sand*, Géotechnique, Vol.35, No. 4, pp. 471-481.