Effect of Sandwich Layer System of Pavement for Subgrades of Low Bearing Capacity by Means of Soil Cement

Effet du système à couche intercalée pour la construction des revêtements sur les sols à faible capacité portante réalisés à l'aide de sol-ciment

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SUMMARY

The author describes the sandwich layer system, which involves increasing the rigidity of a pavement on a subgrade of low bearing capacity by placing a relatively rigid layer directly on the subgrade. The author has found soil cement to be best suited for the lower rigid layer. In this paper, the author is concerned with pavement design on volcanic ash soils of low bearing capacity. The study consists of comparative elastic approximations and model experiments of both static and dynamic repeated loading on both the conventional progressive layer system and the sandwich layer system.

SOMMAIRE

L'auteur décrit le système à couche intercalée comportant l'augmentation de la rigidité d'un revêtement en plaçant une couche relativement rigide directement sur le terrain de fondation. L'auteur a trouvé que le sol-ciment est le matériel le plus propre à être utilisé pour la couche rigide inférieure. Le pointe de départ de cette étude était l'analyse du revêtement d'un sol composé de cendres volcaniques ayant une faible capacité portante. L'étude consiste en calculs théoriques et en essais de charges répétées, statiques et dynamiques, sur le système classique à couche progressive et sur le système à couche intercalée.

CONSIDERATIONS OF SANDWICH LAYER SYSTEM

PAVEMENT DESIGN at present is based on a system in which the modulus of elasticity, or the rigidity of a layer progressively increases upward. On a subgrade of low bearing capacity, an excessive total thickness is often necessary, leading not only to increased construction costs, but also to various structural defects such as a large plastic accumulative settlement due to the dynamic action of repeated wheel loads. The author has considered the possibility that a more suitable pavement can be obtained, with smaller total thickness, by placing a layer with a certain degree of rigidity directly on the subgrade, constituting a sandwich structure with the surface course or upper base course, hereafter referred to as the "sandwich layer system of pavement."

Granular materials are not well suited for use as the lower rigid layer because their compactive effect is low. Such materials as Portland cement may be used to good purpose, since they acquire rigidity with time. The use of ordinary concrete, however, leads to shrinkage cracks on hardening and the intrusion of subgrade soil through the cracks. Soil cement, therefore, is most useful because of its semi-rigid nature and low cost. The soil cement placed in the lower layer will give satisfactory results, even for poor mixtures, and also affords fair resistance against piping and other phenomena.

Where soil cement is used as sub-base, it can also be used in the upper layer. In such cases, the pavement becomes a "sandwich layer system by soil cement." Schnitter and Bollier (1961) have demonstrated that soil cement is more effective from the structural viewpoint when used in the sub-base instead of in the upper layer, a concept with which the author agrees.

EXAMPLE OF ACTUAL SITE CONDITIONS

A growing number of highways are being developed lately in the areas of typical weak volcanic ash soils in Kyushu. For instance, the Beppu-Aso highway, to be completed in 1964, runs through a zone of volcanic ash soils with a high content of humic organic matter called Kuroboku, where a value of CBR = 1.8 per cent was required as the standard bearing capacity of subgrade for pavement design. For the progressive layer system, this leads to thicknesses of more than 70 cm for medium traffic and more than 90 cm for heavy traffic. In addition to the problem of cost, there is also an extreme shortage of crushed stone and sand in the area. A volcanic ash soil called Shirasu is readily available in the district as base material of soil cement. Shirasu contains little organic matter, although some pumice is present, and shows comparatively good stabilization effects with Portland cement (Yamanouchi, 1963).

Though it is almost impossible to adjust the excessive moisture content of Kuroboku, Shirasu can be placed at optimum moisture content. A progressive system section 78 cm in total thickness has been used for the purposes of comparison (Fig. 1). In practice, for the Beppu-Aso highway, a system was used in which the crushed stone layer was reduced to 15 cm, adopting the idea of stage construction.

THEORETICAL APPROXIMATIONS

Fig. 1 shows a suggested pavement section, 65 cm thick, of sandwich system by soil cement that has poor soil cement in the lower layer, with the standard provided to assure cost reduction in contrast to the progressive system section. The cost of construction is estimated at 2,065 yen/sq.m. for the progressive system having 6 per cent soil cement as upper base course, and 1,747 yen/sq.m. for the sandwich system with the same upper base course and 2 per cent soil cement as lower sub-base on the subgrade. In the latter case, a cost reduction of 58 yen/sq.m. occurs because of the decrease in the amount of earth work.

Values of an appropriate modulus of elasticity and

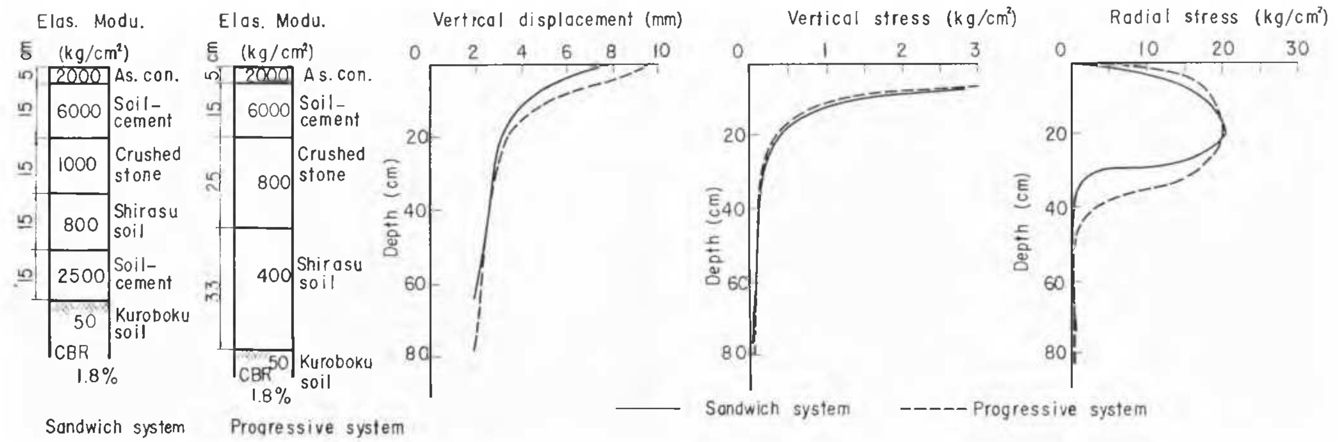

FIG. 1. Comparison between sandwich and progressive layer systems by theoretical approximation.

Poisson's ratio were assigned for each layer of both sections based on the author's investigations to date. These pavements can be solved approximately by calculating equivalent moduli of elasticity and be reducing multi-layer problems to two-layer problems. Distributions of vertical displacement and vertical stress according to Boussinesq and radial stress according to Odemark (1949) with respect to pavement section, both against surface load with 15-cm radius of contact and 6.0 kg/sq.cm. load intensity, were calculated and are shown in Fig. 1.

From this theoretical approximation it was discovered that, for the sandwich system, despite its smaller total thickness, both vertical displacement and radial stress, over the whole depth are reduced, with vertical stress remaining almost the same. However, since, in practice, a pavement behaves in a plasto-elastic manner when subjected to repeated wheel loads, such elastic calculation will be significant for the experimental studies to be described later.

STATIC LOADING EXPERIMENTS MADE ON MODEL PAVEMENTS

The two different types of model pavements made, using the actual construction materials and reduced from their actual dimensions as shown in Fig. 2, were built in concrete boxes, with inside dimensions 1.40 m by 1.40 m square by 1.00 m deep, chosen to accommodate loading tests using a circular plate 20 cm in diameter. Soil cement mixtures were mixed at optimum moisture content in a pot-type mixer. Each pavement layer was uniformly compacted using a tamping rammer with vibration. After voids in the surface of crushed stone layer were filled with crushed stone smaller than 30 mm, a prime coating of asphalt emulsion was applied to this surface as well as to that of the upper soil cement layer at the rate of 1.5 litres/sq.m. Vertical displacement meters and earth pressure meters of 7 kg/sq.cm. capacity were installed as shown on Fig. 2. A static loading test was performed using a rigid plate of 10 cm radius on each layer not only during placement but also on a portion dug out after 28 days. The purpose of these tests was to evaluate the modulus of elasticity of each layer from the relation of load intensity-deflection using the method by Palmer and Barber (1940). The results are shown on Fig. 2. The modulus of elasticity of the lower soil-cement layer in sandwich section was 23 per cent of that of the upper layer at age 28 days. The value of K_{75}, obtained by dividing K_{20} on each layer by 3.1, are also shown on Fig. 2. Both moduli are, however, rated to 1.25 mm deflection, this value being chosen to avoid excessive layer deflection.

Figs. 3 and 4 show the distribution of vertical displacement and vertical stress with depth respectively for the two sections. It will be noted from Figs. 3 and 4 that the sandwich section is statically superior to the progressive system section over the whole testing age, and therefore that it is possible to reduce the total thickness of the former,

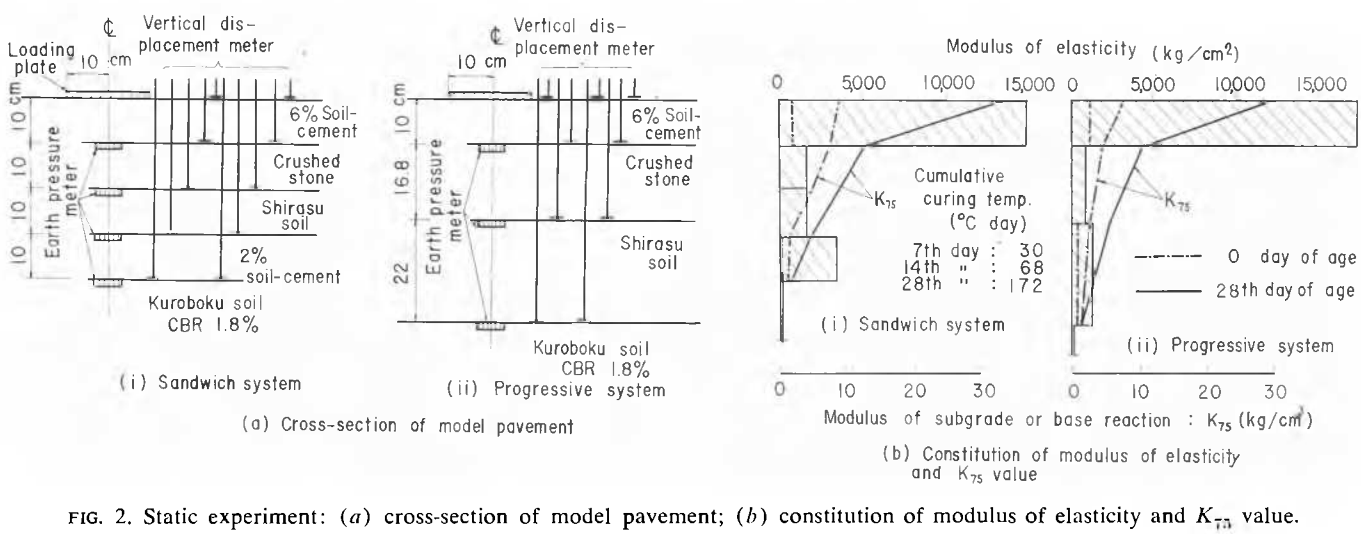

FIG. 2. Static experiment: (*a*) cross-section of model pavement; (*b*) constitution of modulus of elasticity and K_{75} value.

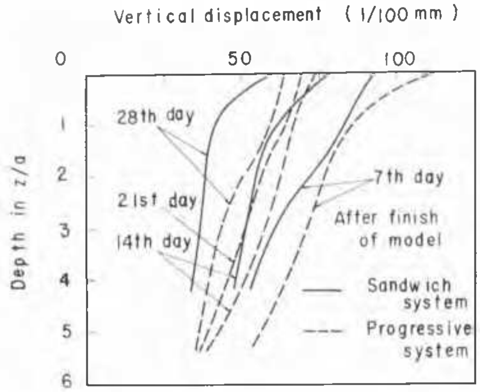

FIG. 3. Vertical displacement under the centre of load in static experiment.

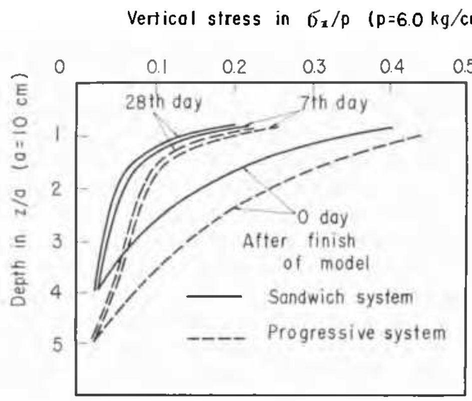

FIG. 4. Vertical stress distribution under the centre of load in static experiment.

for the same static performance. With this static loading test, however, there is no cumulative displacement contained except the residual plastic deflection for a single loading, beside elastic settlement.

DYNAMIC REPEATED LOADING EXPERIMENTS ON MODEL PAVEMENTS

In order to determine the effect of repeated loading on each of the model pavements, a test machine was set up to produce continuous repetitive loadings (Fig. 5) on sample pavements of the same dimensions as used for static loading test. This apparatus has a self-repeating piston mechanism of the oil-pressure type, giving exact trapezoidal piston pressure to a time axis. By manipulating the timer we can get the desired period, endurance time ratio of loading and unloading, and voluntary thrust pressure of piston to the loading plate according to the magnitude of oil pressure.

Imposition of repeated loading of six-second periods including a two-second application of 6.4 kg/sq.cm. was started at an age of seven days, using a loading plate, 20 cm in diameter, on the surface of pavement, a loading condition more severe than the actual one. The modulus of elasticity of the system was evaluated by the same process as in the preceding section and the result is given in Fig. 6 together with *K* value. The modulus of elasticity of the lower soil cement layer in the sandwich system was 17 per cent of that of upper one at an age of 14 days.

This test allows the determination of the difference between the two pavement types with respect to the accumulated state of plastic displacement which appears under

FIG. 5. Automatic test apparatus of repeated loading to model pavement.

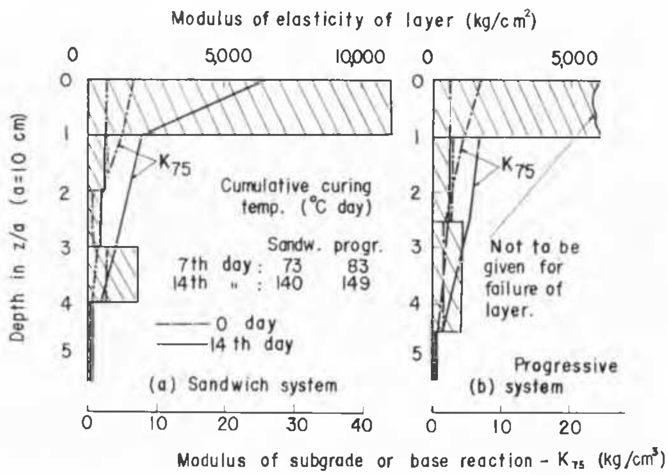

FIG. 6. Constitution of modulus of elasticity and *K* value of model pavement in the first repeated loading test.

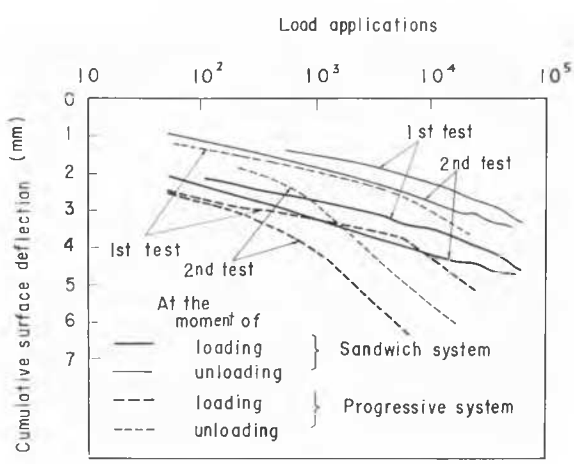

FIG. 7. Increase of surface deflection at the centre of load by repeated loading test.

repeated loading of a plasto-elastic body. Comparative tests were carried out twice under the same conditions, to obtain the relationship shown in Fig. 7. The heavy lines in the figure show total displacement, the thin lines cumulative displacement, and the difference of both the coordinates, elastic displacement.

In both tests, the progressive system section showed greater accumulation of residual plastic displacement than the sandwich system section. The progress of displacement in the sandwich system was gradual and, even after a total of nearly one hundred thousand cycles, the pavement surface appeared in good condition. In the progressive system, on the other hand, displacement rapidly increased after about six thousand cycles in the first test and after about fifteen hundred cycles in the second test, and the surface soil cement gradually broke up, so that the modulus of elasticity of the layer after the test could not be obtained.

CONCLUSIONS

By the results of studies involving theoretical approximations, and by both the static and dynamic repetition loading tests to model pavements, the author concludes that a pavement of sandwich layer system using soil cement thinner than that in the conventional progressive system serves the purpose well, using the pavement project on the volcanic ash soils of low bearing capacity typical in Kyushu as an example of the practical problems. The relative effect of sandwich layer system will be larger for lower subgrade bearing capacities. It is considered that the method is similarly applicable to the case of alluvial soft subgrade, since the principle is the same in either case, though the present study has been confined to pavement design on volcanic ash soils.

Since one of the important characteristics of soil cement with respect to its use in a sandwich layer system is that it acquires hydraulic hardness with time, unlike granular materials, it can be useful even on a subgrade that cannot support compaction with granular materials. On the weak subgrade, the requirements of construction vehicle traffic generally make it advisable in any case to perform stabilization by cement at the same time. Even if the work may be in some degree defective on the weak subgrade, construction of the sandwich layer system will compensate for this to a certain extent because of the property of hydraulic hardening. This study demonstrates that the structural effect of a soil cement layer contributes much to the slab effect due to semi-rigidity. The layer, which is monolithic and free from joints, is also very effective in preventing harmful action such as the intrusion of subgrade soil.

Though we can reduce total thickness of pavement by the sandwich-layer system, the total cost is not reduced in proportion to total thickness, since the cost of the lower soil cement layer is increased. However, the reduction in the crushed stone layer, together with the decrease in the amount of earth work required will offset this somewhat.

The author believes that this study ought to be carried further by developing a quantitative design method for pavement thickness by this system, through a parameter of the sandwich ratio of modulus of elasticity.

ACKNOWLEDGMENTS

The author is much indebted in carrying out the present study to the Fukuoka Branch of the Japanese Highway Public Corporation, the Fukuoka Branch of Nihon Hodo Co. Ltd., and also to Messrs. M. Ishido, T. Miura, and S. Tokitsu of the laboratory of Kyushu University, and wishes to express his gratitude to them all for their cooperation.

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