Proposed Structure and Construction Method for Improved Interlocking Concrete Block Pavement Used in Residential Parking Spaces

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Summary

In Japan, ready-mix concrete pavement is increasingly adopted instead of interlocking block (ILB) pavement for the parking space at newly built houses. This is mainly due to the emergence of deformation, such as settlement and surface unevenness, in previously laid interlocking blocks. In this study, the authors identified the cause of deformation, and propose a new ILB pavement structure and construction method to ensure high serviceability for residential parking spaces.

Key Words: "house", "parking space", "pavement structure", "construction method", "serviceability"

1. Introduction

In Japan, ILB pavement has been widely used for pedestrian roads, including sidewalks and park paths, since it was introduced from Germany in the 1970s. The current interest in sustainable pavement presents an opportunity to extend ILB usage to roadways. Parking spaces currently account for about 9% of all ILB projects, and the industry is hoping to extend this to parking spaces at newly built houses. However, such projects have declined since 1990 and cast-in-place concrete pavement has become the mainstream, due to the emergence of deformation such as surface settlement and unevenness in previously laid ILB pavement. Given the complaints from homeowners, designers have become reluctant to use such materials and instead specify cast-in-place concrete that has good design performance as well as resistance to settlement or unevenness.

The authors therefore investigated the cause of ILB deformation in order to resolve the problem. Here, they propose a pavement structure and construction method that provide good serviceability, which should once again make ILB a popular material for the parking space at newly built houses.

2. Facts about Japanese houses

Most houses in Japan are built on small lots compared to other countries that have larger land area and lower population density. The average land area for a Japanese house is 272 m^2 with an average total floor space of 126 m^2, according to the 2005 statistics of the Statistics Bureau of the Ministry of Internal Affairs and Communications (Figure 1). The parking space allocated for the premises is relatively large for the given land area.

3. Standards for ILB pavement in parking spaces

Table 1 shows an excerpt from the standards for pavement structure and its constituent materials used for car parking lots (up to 300 cars per day) specified by the Japan Interlocking Block Pavement Engineering Association.[1)] For parking lots used for passenger cars, the measured bearing capacity of the base course is not specified in the standards. The pavement structure design for passenger car parking lots should be based on the California Bearing Ratio (CBR) test using the T_A method (hereafter referred to as CBR-T_A method).

Table 1 Standard for pavement structure/components of passenger car parking lot

Traffic	ILB	Bedding sand	Joint sand	Necessary asphalt equivalent thickness (cm)
Less than 300 cars a day	Thickness: 80 mm Flexural strength: 5.0 MPa or more	Thickness: 20 mm Max. grain size: 4.75 mm or less Passing through a 75-µm sieve: 5% or less Fineness modulus: 1.5 to 5.5	Max. grain size: 4.75 mm or less Passing through a 75-µm sieve: 10% or less	12 cm

4. Issues related to the paving of parking spaces at Japanese houses

The issues include the following.

4.1 Problem with pavement structure design

As discussed above, the pavement structure design for passenger car parking spaces should be based on the CBR-T_A method. This requires a CBR test on the subgrade soil to determine the design CBR, but these tests are rarely performed due to limited budget for parking spaces at houses. As a result, the parking space is often constructed over a weak subgrade (design CBR of 3 or less), which is vulnerable to deformation by vehicle load.

4.2 Insufficient bearing capacity in the granular base course

(1) Compacting machine used for the base course

A granular base course is generally applied to the parking space at a house. To ensure that the base course has sufficient bearing capacity to support the load of vehicle traffic and parking, the largest available vibration roller should be used for compaction. However, because the parking space at Japanese houses is barely large enough for one or at most two cars, only a small vibration roller can be used, which often results in insufficient compaction of the base course.

(2) Buried structures

Numerous utility structures such as stormwater, sewer and water pipes are installed underground and their inspection chambers are built at the ground surface (Photo 1), and the base course above the underground structures is likely to have inadequate compaction. Also, the area surrounding the aboveground inspection chambers often lacks compaction, because a large vibration roller cannot be used in such small spaces.

4.3 Filter stability

Filter stability is an important new technique for determining the durability of ILB pavement, and has attracted considerable attention in Germany. Filter stability refers to the stability between layers with different gradation, such as between the joint sand and bedding sand, as well as between the bedding sand and the granular base course. If this stability is not ensured, unevenness or settlement may appear on the surface course of the block as a result of sand particles moving with the movement of rainwater. In Japan, recycled aggregates are increasingly used for the base course and recycled sand for the bedding sand, and thus it is not easy to obtain filter stability.

These problems related to the pavement structure design and insufficient bearing capacity in the granular base course can also trigger serviceability failures in cast-in-place concrete pavement or asphalt pavement. However, since such failures rarely appear on the surface course compared to ILB pavement, pavement designers avoid ILB pavement in favor of cast-in-place concrete that has sufficient design performance and good resistance to settlement or unevenness (Photo 2).

5. Pavement structure and construction for high serviceability

5.1 Proposed pavement structure

Figure 2 shows the proposed pavement structure for resolving the above problems and ensuring high durability. The features of the pavement structure are as follows:

- Backfilling must be at least 50 mm to prevent damage to buried pipes by the vibration roller.

- To ensure sufficient bearing capacity of the backfill above the buried pipes, geogrid (geotextile made from special polyester fiber) is laid over the backfill.
- Reinforcing nonwoven fabric (geosynthetic material made from two types of nonwoven fabrics: polyester/polyethylene composite and polyethylene yarn, laminated) is laid over the top and bottom surfaces of the granular base course to achieve filter stability between the joint sand and bedding sand, as well as between the bedding sand and the granular base course.
- Reinforcing nonwoven fabric is folded vertically and laid around the inspection chamber to compensate for insufficient compaction.
- Crusher-run material is used as the granular base course to prevent frost heave in a cold climate region. Mechanically stabilized crushed stone is not used due to the risk of frost heave.

5.2 Compactor used for construction

Three types of compactors, (1) to (3), recommended for the construction are shown below. Although compactor (4) is not used for the proposed method, it is introduced here for comparison with compactor (3) in the verification experiment.

(1) Multi-impact tool

The multi-impact tool provides a striking force of 210 kg/cm^2 as the external pipe moves up and down to create vertical vibration. To take full advantage of its strength, it should be used in a very small area such as around the inspection chamber at the ground surface. It is also used for compaction of the base course, cutting blocks, chipping or trenching, by changing to the appropriate attachment for the job.

(2) Small-size plate compactor (mass: 66 kg)

This compactor is popular with ILB pavement contractors in Japan, because the small mass (66 kg) makes it very easy to handle and control.

(3) Medium-size vibro compactor (mass: 150 kg)

This machine of 150-kg mass is categorized as a medium-size vibration roller. It is simple to handle and control because of the lever operation for traveling forward or in reverse. Few ILB contractors own this type of machine, but they rent one when needed.

(4) Large-size vibro compactor (mass: 330 kg)

This is a large vibration roller often used to compact the granular base course at larger worksites in Japan. Its compaction capability for the granular base course is fairly high. However, experience is required to handle and control the machine because of its large mass of 330 kg.

5.3 Proposed construction method

To resolve the problems mentioned above and ensure high durability, a construction method with the following features is proposed.

(1) Compaction procedures to achieve equivalent base-course bearing capacity as a large-size vibration roller

The following steps describe how to obtain the same bearing capacity with a medium-size vibration roller of 150 kg (Figure 5) as with a large-size vibration roller of 330 kg (Figure 6) often used for compacting the granular base course at a large worksite.

- Divide the crusher-run course into two layers for compaction.
- Keep the water content of the first layer at the optimal condition (Photo 3), and use the medium-size vibration roller to compact the same area eight times. The thickness after compaction shall be 80 mm (160 mm for the entire crusher-run course).
- Keep the water content of the second layer also at the optimal condition, and use the medium-size vibration roller of 150 kg to compact the same area eight times so that the base course becomes flat, with a thickness of 160 mm.

(2) Compaction procedures to achieve sufficient base-course bearing capacity in the area surrounding the inspection chamber

- Divide the crusher-run course surrounding the inspection chamber into two layers for compaction.
- Keep the water content of the first layer at the optimal condition, and use the multi-contact tool to compact the same area three times (Photo 4). The thickness after compaction shall be 100 mm (160 mm for the entire crusher-run course).
- Keep the water content of the second layer also at the optimal condition, and use the small-size vibration roller of 60 kg to compact the same area eight times so that the base course becomes flat, with a thickness of 160 mm (Photo 5).

The reason for the compaction count of eight in (1) and (2) above is that the water content in the base course reaches a maximum at eight compactions, according to past research by the Public Works Research Institute, and based on the verification experiment described below.[2)]

6. Verification experiment

A verification experiment was conducted to determine whether the bearing capacity can be increased when using the proposed pavement structure and construction method.

6.1 Bearing capacity of the general portion of the base course

The base course deflection was measured using a handy falling-weight deflectometer (HFWD) on the test pavements shown in Figure 7, which were constructed by the proposed method and also by methods previously used, as listed in Table 2, for comparison (Photo 6). Figure 8 shows the measurement results. The findings are as follows:

- Increased bearing capacity was proven when the proposed construction method with the 150-kg medium-size vibration roller was used, as the deflection amount directly below the load was smaller compared to the method using a 330-kg large-size vibration roller.
- The two-layer compaction method effectively improved the bearing capacity, as the deflection amount directly below the load was smaller compared to the one-layer compaction base course.
- The proposed compaction method for the base course having optimal water content effectively increased the bearing capacity, as the deflection amount directly below the load was smaller than in the case of smaller water content.

Table 2 Construction method for the general portion of the base course

Test section		Base course layer separation	Base course water content	Construction method
1	Conventional method	One-layer compaction	Optimum water content (4.4%)	Use the 330-kg large-size vibration roller and compact the same area eight times for a total base course thickness of 160 mm.
2	Method No. 1 for comparison	One-layer compaction	Optimum water content (4.4%)	Use the 150-kg medium-size vibration roller and compact the same area eight times for a total base course thickness of 160 mm.
3	Method No. 2 for comparison	Two-layer compaction	Lower water content (1.0%)	1) Use the 150-kg medium-size vibration roller and compact the same area eight times. The thickness after compaction shall be 80 mm (160 mm for the entire crusher-run course). 2) Use the 150-kg medium-size vibration roller and compact the same area eight times for a total base course thickness of 160 mm.
4	Proposed method	Two-layer compaction	Optimum water content (4.4%)	1) Use the 150-kg medium-size vibration roller and compact the same area eight times. The thickness after compaction shall be 80 mm (160 mm for the entire crusher-run course). 2) Use the 150-kg medium-size vibration roller and compact the same area eight times for a total base course thickness of 160 mm.

6.2 Bearing capacity of the portion of base course surrounding the inspection chamber

The deflection amount on the portion of base course surrounding the inspection chamber was measured by HFWD on the test pavements shown in Figure 9, which were constructed by the proposed method and also by methods previously used, as listed in Table 3, for comparison

(Photo 6). Figure 10 shows the measurement results. The deflection amount on the area directly below the 500-kg load was 1.219 mm with the conventional method, while it was reduced to 0.851 mm with the proposed method. This proved that the proposed construction method is effective in increasing the bearing capacity of the base course.

Table 3 Construction method for the base course around the inspection chamber

Test section		Base course layer separation	Base course water content	Construction method
1	Conventional method	One-layer compaction	Optimum water content (4.4%)	Use the 60-kg small-size plate compactor and compact the same area eight times for a total base course thickness of 160 mm.
2	Recommended method	Two-layer compaction	Optimum water content (4.4%)	1) For the first layer, compact the same area three times with the multi-impact tool for a layer thickness of 100 mm. 2) For the second layer, compact the same area eight times with the 60-kg small-size plate compactor for a total base course thickness of 160 mm.

7. Conclusions

The proposed structure and construction method to ensure high serviceability in ILB pavement used for the parking spaces at houses is summarized below.

(1) The proposed pavement structure includes special materials: geogrid over the reburied utility pipes, reinforcing nonwoven fabric between the subgrade and the base course and also between the base course and the bedding sand, as well as around the inspection chamber at the ground surface.

(2) The crusher-run material in the base course of the proposed construction method should be divided into two layers, the water content of each layer should be kept at the optimal condition and the same area should be compacted eight times using a medium-size vibration roller of 150 kg in mass.

(3) The crusher-run material around the inspection chamber should be divided into two layers, each with the optimal water content, and compacted as follows: For the first layer, the multi-impact tool should be used to compact the same area three times, while for the second layer, the small-size plate compactor should be used to compact the same area eight times.

(4) The comparison of deflection amount measured by HFWD showed that the pavement using the proposed structure/construction had less deflection than the pavement using the conventional structure/construction. This proved that a higher bearing capacity can be obtained with the proposed structure and construction method.

8. Concluding Remarks

The proposed pavement structure and construction method proved to be effective for ensuring a high standard of serviceability in ILB pavement used for the parking space at houses in Japan. The authors plan to further establish the proposed technology by testing the effects of bedding-sand water content and block compactors on the serviceability.

Acknowledgement

I would like to express my deepest gratitude to S-BIC Landscape Business Association and Mr.Souseki Adachi, the president of Association who provided carefully considered feedback and valuable comments.

REFERENCES

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2) T. Hashimoto, et al., Characteristics of Small-size Compactor Used in Small Area, 2011, Proc., Japan Society of Civil Engineers 2011 Annual Meeting, pp. 133–134

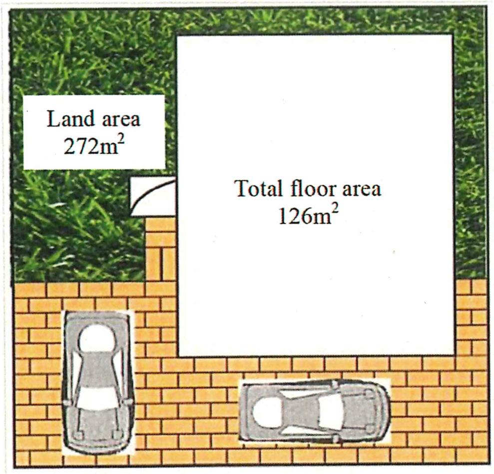

Figure 1 Typical land area of Japanese house

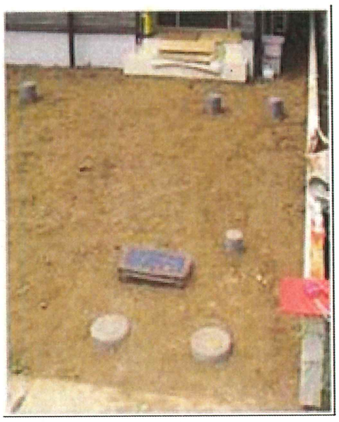
Photo 1 Buried structures in parking space


Photo 2 Cast-in-place concrete pavement

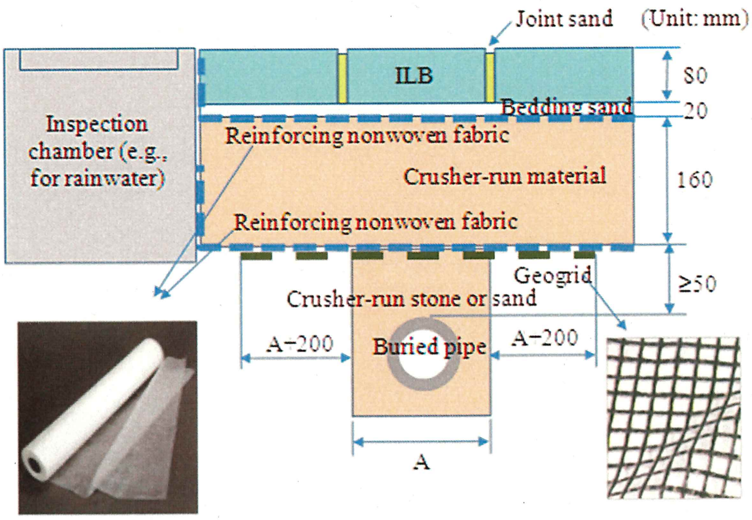

Figure 2 Proposed pavement structure

Move up

Move down

- Striking force of 210 kg/cm^2 when the external pipe is moved up/down
- Overall length: 1050 mm
- Mass: 6.4 kg
- Stroke: 915 mm

Figure 3 Multi-impact tool

- Compaction plate: 510 × 350 mm
- Vibration frequency: 5600 vpm
- Centrifugal force: 10.1 kN

Figure 4 Small-size plate compactor

- Machine mass: 150 kg
- Compaction plate: 700 × 430 mm
- Vibration frequency: 5400 vpm
- Centrifugal force: 27 kN

Figure 5 Medium-size vibro compactor

- Machine mass: 330 kg
- Compaction plate: 860 × 600 mm
- Vibration frequency: 4400 vpm
- Centrifugal force: 45 kN

Figure 6 Large-size vibro compactor

Photo 3 Crusher-run material with optimal water content

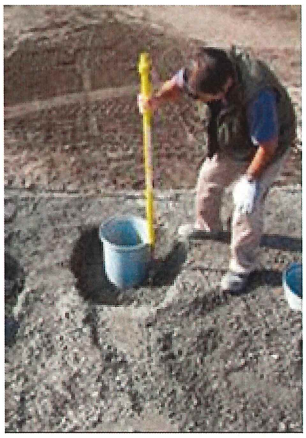

Photo 4 Compaction using multi-impact tool

Photo 5 Compaction using small-size plate compactor

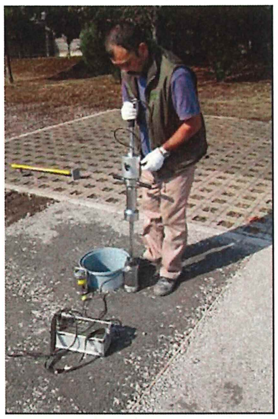

Photo 6 Measurement by HFWD

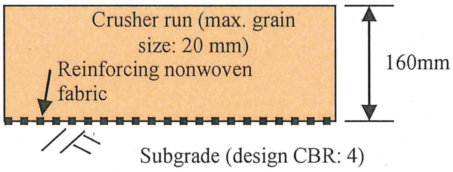

Figure 7 Pavement structure No. 1 used for verification experiment

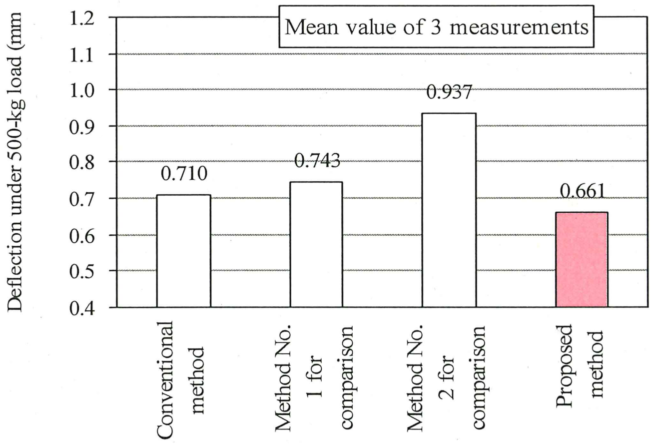

Figure 8 HFWD measurement results No. 1

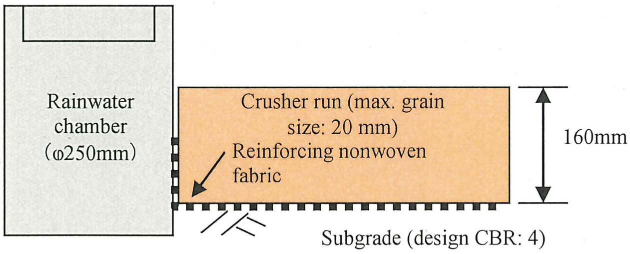

Figure 9 Pavement structure No. 2 used for verification experiment

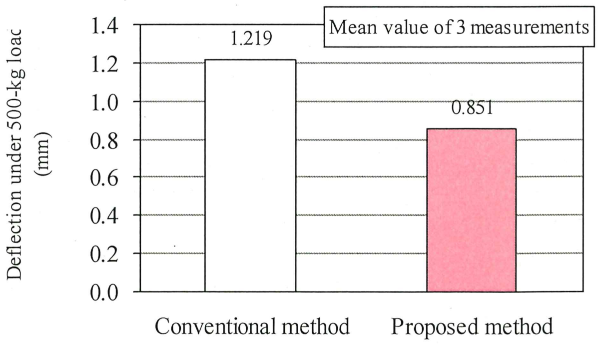

Figure 10 HFWD measurement results No. 2