Study Concerning Breakage of Concrete Block Paving Used for Paving of Roadway

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The following was the breakages characteristic to the concrete block paving: break of corners of blocks, unevenness of the pavement, local sinking of pavement, and removal of joint. These breakages not only impair the fine sight of pavement and deteriorate the durability and function of pavement, but also affect the circumference of the roadway by inducing noises at running of vehicles in some cases.

In this report, the authors investigated the causes of these breakages and suggested countermeasures to prevent them based on analysis of the results of practical survey, laboratory experiments, and model running tests using a road simulator.

1) From the statistical analysis of the results of practical survey, it was clarified that the break of corners of blocks was largely affected by the elastic deformation, which was determined by the structure of base, and width of joint.

   Based on the results, when the concrete block paving is applied on paving of roadways, it is important to use asphalt or cement treated base in order to suppress the elastic deformation to a certain degree as well as to use blocks with joint width keepers of a certain size in order to maintain a certain width of joint.

2) By analysis of the results of practical survey, it was suggested that the quality of bedding sand especially the content of fine granule fraction, affected largely on the onset of unevenness of the pavement, local sinking of pavement, and removal of joint. Bedding sand was thus subjected to tightening tests by thrusting to harden and model running tests using a road simulator in order to clarify the influence of fine granule fraction in bedding sand. Then, the authors proposed the desirable quality of bedding sand.

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1. Summary

In Japan, the concrete block paving has been applied mainly on pedestrian roads such as footway and park areas subjected to pedestrians and bicycles. Cases of its application to roadway paving are not yet so frequent as compared to various foreign countries. However, there are cases of its application to roadways of traffic level B (250-1,000 traffic volume of heavy vehicles/day.direction) mainly consisted of light traffic roadways such as shopping streets, and even to heavy load paving such as container yards. According to such extensions of application, breakages characteristic to the concrete block paving are going to occur in roadway pavements. The breakages characteristic to the concrete block paving not only impair the fine sight of pavement and deteriorate the durability and function of pavement, but also affect the circumference of the roadway by inducing noises at running of vehicles in some cases.

The authors classified the breakages characteristic to the concrete block paving based on the results of practical survey for over 10 years, and detect the factors influencing to these breakages. In this report, based on these results of practical survey, the authors clarified the quality of materials of concrete block paving when applied to roadway pavement and propose countermeasures to prevent breakages characteristic to the concrete block paving.

2. Classification of breakages characteristic to the concrete block paving

Breakages characteristic to the concrete block paving are largely divided to the following 4 categories: break of corners of blocks, unevenness of the pavement surface, local sinking of pavement, and removal of joint due to movement of blocks. Characteristics of individual breakages are as follows:



Photo. 1 Breakages Characteristic to the concrete block paving

1) Break of corners of blocks

Break of corners of blocks is a slight breakage that the corners of upper side of block is broken. It does not affect on the durability or function of pavement. However, claims occur frequently insisting that these breaks impair the fine sight of street.

2) Unevenness of the pavement

Unevenness of the pavement is the phenomenon of unevenness of individual blocks not function as a combined continuous body of small concrete blocks. This phenomenon impairs the safety and comfort of pedestrians and also induces noises due to running of vehicles. So, it considerably affects the circumference of roads. It also induces the deterioration of durability and function of concrete block paving.

3) Local sinking of pavement

According to the degree of advance of the above described floating of the pavement surface, local sinking may occur in the concrete block paving.

4) Removal of joint

According to the advance of the above described unevenness of the pavement surface, movement of concrete blocks occurs. Due to the movement, joints in the concrete block paving open to result in removal of joints between blocks.

3. Break of corners of concrete blocks

Based on the results of practical survey of concrete block paving, the authors verified the causes of break of corners of concrete blocks and countermeasures to prevent it. In order to refluct the influence of materials of base, H_A (equal value conversion coefficient of base multiplied with the thickness of base) was used.

1) Influence of H_A of base and elastic deformation (W)

Fig. 1 shows the relationship of the onset of claims due to break of corners of concrete blocks and H_A of base or elastic deformation. The elastic deformation obtained at the spots with claims due to break of corners of concrete blocks were distinctively higher than those obtained at spots with favorable usage conditions. And at the spots with claims even when H_A values of the base were identical, there were significant variations in the elastic deformation.

Fig. 2 shows the relationship of H_A of base and flexural amount at spots with or without claims under classification of materials of the base. As shown in Fig. 2, the distributing conditions are largely different between pavements applying asphalt or cement treated base and those using macadam as the base. The latter pavements showed large elastic deformationand an increasing tendency in the variation (0.45-3.20 mm). As is seen in Fig. 1, claims were almost exclusively concentrated to pavements using macadam as the base.

Therefore, when concrete block paving is applied to pavement of roadways, the following countermeasure is considered to be effective to prevent break of corners of blocks: The base shouldbe subjected to asphalt or cement treated base in order to improvethe rigidity of the base and thus result in the reduction of elastic deformation of the surface of concrete block paving.

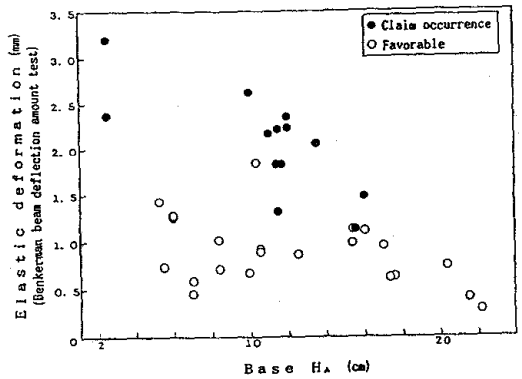


Fig-1
Relationship of base H_A with and without claims and elastic deformation

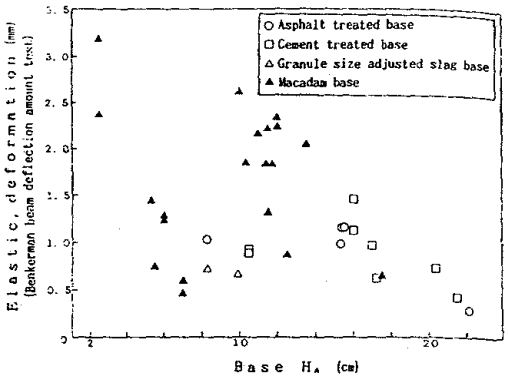


Fig-2
Relationship of base H_A classified by the base materials and elastic deformation

2) Influence of elastic deformation and width of joint

From the results of practical survey of concrete block paving, it was seen that claims occurred when the ratio of break of corners of blocks exceeded 3%. The break of corners of blocks occurs due to complex effects of increased elastic deformation, insufficient width of joint, movement of blocks on steep slopes, insufficient strength of blocks, insufficient sand for joint, etc. Among them, it is suggested from the results that the elastic deformation and width of joint are the major influencing factors. Therefore, multiple regression analysis was applied on the relationship of the ratio of break of corners of blocks (B), elastic deformation (W), and width of joint (J). The obtained regression formula is as follows:

$$B = 6.079 + 3.775W - 3.267J \quad (R = 0.779)$$

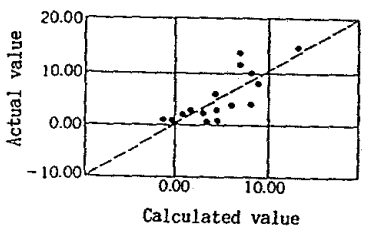


Fig-3
Relationship of actual value and calculated value

Table 1. Analysis of variance

Item	Sum of squares	Degree of freedom	Variance	Ratio of variance	Test
Regression	209.64	2	104.32	10.02	Significant at 1% level of probability
Error	135.93	13	10.45	-	-
Total	345.57	15	-	-	-

Fig. 3 shows the comparison of calculated ratio of break of corners of blocks using the above regression formula and the practical values. It is shown that the calculated values are almost similar to the practical ones. As shown in Table 1, the correlation is confirmed to be sufficiently significant by the analysis of variance.

3) Countermeasures to prevent break of corners of concrete blocks

The elastic deformation on the pavement surface and width of joint affect largely on the onset of break of corners of concrete blocks used for pavement of roadways. Therefore, the following countermeasures are necessary to be adopted:

a) Since it is important to increase the stiffness of base, asphalt or cement treated should be used for the base especially for paving of roadways with frequent traffics of heavy vehicles.
By the treatment, as shown in Figs. 1 and 2, elastic deformation of about 1.50 mm or less is obtained.

b) Using concrete blocks with joint width keepers (Fig. 4), the standard width of joint between blocks, namely, 3 mm, should be maintained.

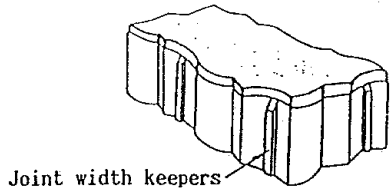


Fig-4
Concrete block with joint width keepers

c) When the value of elastic deformation obtained after the above measures a) and b) were carried out is applied to the regression formula shown beforehand, the ratio of break of corners of blocks becomes 2% or less. It means almost no breakage of blocks occur and becomes out of the range of claims (3% or more in the ratio of break of corners of blocks).

4. Unevenness and local sinking of pavement serface as well as removal of joint of concrete block.

1) Cause of uneveness of the pavement (Fig. 5), local sinking, and removal of joint

From the results of practical survey of concrete block paving, the following items were confirmed concerning the unevenness of the paving, local sinking, and removal of joint:

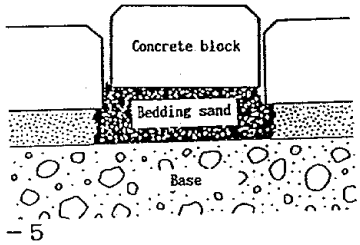


Fig-5
Unevenness of concrete block paving

a) They occurred irrespective of the traffic volume of heavy vehicles.
b) They occurred irrespective of the elastic deformation of the surface of concrete block paving or the bearing capacity of base, or CBR of subgrade.
c) They occurred irrespective of the materials of base.
d) They occurred irrespective of the shape of concrete blocks or their paving pattern.
e) They occurred from 6 months to 2 years after initiation of usage when the bedding sand layer, used as the leveling layer, becomes stable after pressed to dense condition by the traffic load.
f) Since no concrete blocks were equipped with joint width keepers in this practical survey, the width of joint in the concrete block paving tended to be relatively narrow.
g) Little sand for joint was attached to concrete blocks in which unevenness of the pavement surface, local sinking, or removal of joint occurred as well as those adjacent to these blocks.
h) The bedding sand solidified as hard as not to be loosened by the striking with a screwdriver. It was as thick as 5-6 cm and larger than the designed value of 2-3 cm.
i) The results of measurement of granule size distribution of the solidified bedding sand revealed that the granule fraction (silt fraction) of 0.075 mm or less in size occupied 6.0-15.9%. The larger the ratio became, the more the tendency of solidification of bedding sand appeared markedly. However, there were also sites with solidified bedding sand but no occurrence of unevenness of the pavementsurface, local sinking, or removal or joint.

j) Local sinking occurs due to deformation of bedding sand even when there was no deformation of base. The mechanism of occurrence is considered to be ascribed to the plastic deformation of bedding sand that may be induced by traffic loads of many heavy vehicles, thick bedding sand fine granule size of the sand used for the bedding sand, or large ratio of sand passing through the sieve of 0.075 mm.

As described above, it is considered that the quality of bedding sand, used as the leveling layer, affects largely on the onset of unevenness, local sinking, and removal of concrete block paving.

2) Effect of quality of bedding sand on the performance of concrete block paving

Since the quality of bedding sand is considered to affect largely on the occurrence uneveness of the pavement surface, local sinking, and removal of joint of concrete block paving, we performed a trial examination to investigate the influence of the quality of bedding sand on the performance of concrete block paving with the road simulator.

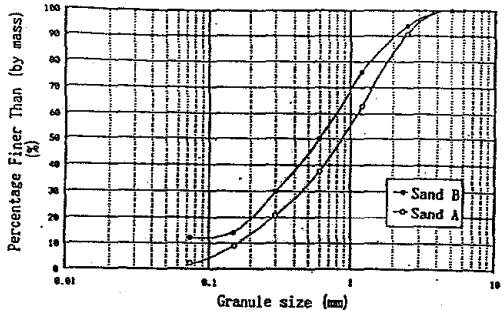
a. Quality of bedding sand used for trial examination

In the trial examination, 2 kinds of bedding sand as shown in Table 2. Granule size distribution curves of individual bedding sand are shown in Fig. 6. It is seen that the sand B contained a large ratio (11.0%) of fine granule fraction of 0.075 mm or less in size (silt fraction).

In order to clarify the material properties of the sand A and sand B, which were used as the bedding sand in the trial examination, the compacting test using a rammer and CBR test were performed and the following results were obtained:

Table 2. Quality of bedding sand used for trial examination

Item	Sand A (Crushed Sand)	Sand B (Mountain Sand)
FM (Fineness Modulus)	2.85	2.56
Ratio of sand remaining on the sieve of 5mm (%)	0	0
Ratio of sand passing through the sieve of 0.075mm (%)	3.8	11.0



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Granule size distribution of bedding sand used for trial examination

Results of compacting test using a rammer

a) Fig. 7 shows the compacting curves obtained by compacting test.

b) Sand A showed small changes in density at dryness according to the changes in ratio of water content. It was thus hardly affected by water.

c) Sand B showed large changes in density at dryness according to the changes in ratio of water content. It was thus easily affected by water. When the optimal moisture content was exceeded, the density at dryness showed a marked decreasing tendency.

Results of CBR test

a) Fig. 8 shows the CBR curves obtained by changing the ratio of water content of the sand.

b) Sand A showed small decreases in bearing capacity even when the ratio of water content exceeded 10%. It was thus hardly affected by water.

c) Sand B showed large changes in bearing capacity according to the changes in ratio of water content. It was thus easily affected by water. The peak CBR value was obtained at ratio of water content smaller than the optimal moisture one. By increasing the ratio of water content from that level, the bearing capacity showed a markedly decreasing tendency.

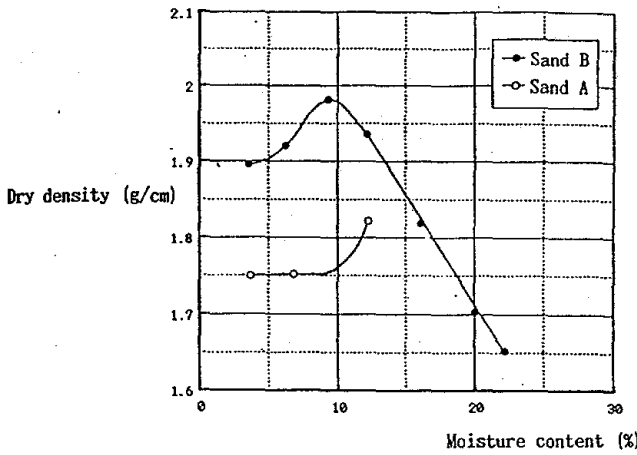


Fig-7
Tightening curve by thrusting to harden of bedding sand used for trial examination

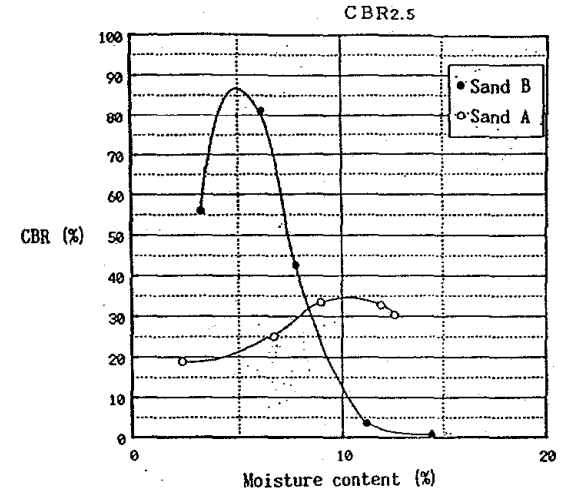


Fig-8
CBR curve according to change in ratio of water content of bedding sand used for trial examination

b. Structure of pavement and running condition of road simulator

Structure of pavement is shown in Fig. 9. As shown in this figure, asphalt concrete of 15 cm in thickness was used as the base to reduce the influence of bearing capacity of base and the subgrade. In order to stress the difference of quality of bedding sand, the thickness of bedding sand was set to be 5 cm.

Wheel load of the load simulator was set to be 4.9 KN. It was run for 15,000 times corresponding to traffic volume for about 5 years on roadway pavement for traffic level L (100 or less traffic volume of heavy vehicles/day.direction).

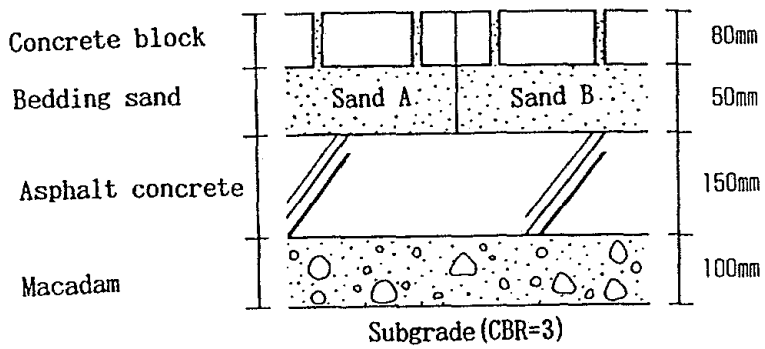


Fig-9
Structure of paving used for trial examination

c. Results of trial examination

By the trial examination using sound A and sand B as the bedding sand, the influence of quality of bedding sand to the usage property of concrete block paving was confirmed. The results almost coincided to the results obtained by the compacting test and CBR test.

a) Influence to elastic deformation

As shown in Fig. 10, the elastic deformation of concrete block paving using sand B as the bedding sand was larger than that of sand A. Keeping the ratio to the latter about 2 times, the value tended to reach a constant value according to the increase in the times of running.

b) Influence to bearing capacity

Fig. 11 shows the results of measurement of bearing capacity by the plate bearing test (K30 value) performed on the concrete block paving and on the asphalt concrete base after 15,000 times of running. While the bearing capacity on the asphalt concrete base was comparable between the 2 kinds of sand, the value on the concrete block paving via the bedding sand was smaller in the sand B by about 10 kgf/cm³ (17%) as compared to the sand A.

c) Influence to plastic deformation (rutting)

Fig. 12 is the cross sectional profiling curves after 15,000 times of running indicating the rutting of the pavement surface. The depth of rutting of the pavement surface was markedly larger in the pavement using the sand B as the bedding sand than that using the sand A. There was almost no rutting in the asphalt concrete base. A part of bedding sand using the sand B showed solidified sand or plastic deformation of sand.

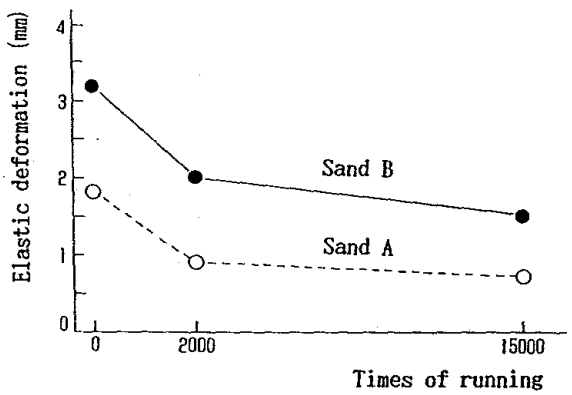


Fig-10
Results of elastic deformation measurement

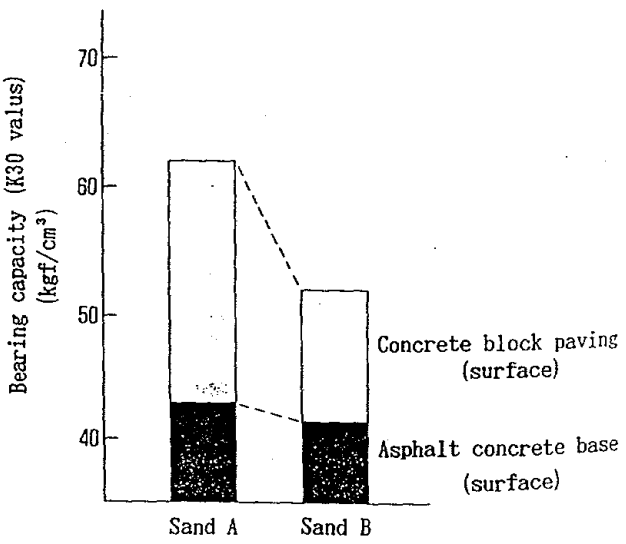
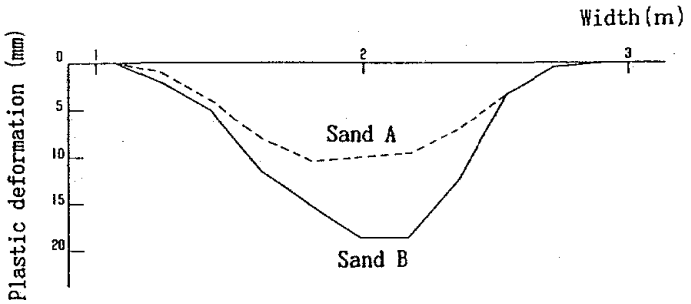


Fig-11
Results of plate loading test (after 15,000 times of running



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Results of measurement of cross sectional profiling curve (after 15,000 times of running)

3) Countermeasures to prevent unevenness of the pavement surface, local sinking, and removal of joint

It was revealed that the quality of sand used as the bedding sand affected significantly on the onset of unevenness of the pavement surface, local sinking, and removal of joint of concrete block paving. Therefore, based on the results of practical survey and trial examination using road simulator as described above, it is considered to be desirable to use sand with sufficient quality as the bedding sand for the concrete block paving. The sufficient quality for the sand is proposed as shown in Table 3 from our results bedding sand.

Table 3. Quality of bedding sand

Maximum granule size	FM	Ratio of sand passing through the sieve of 0.075mm
5mm or less	2.80 ± 0.20	5% or less

5. Conclusion

The authors described the detection of causes of breakages characteristic to concrete block paving that have occurred in Japan and the countermeasures against the breakages. When the concrete block paving is applied to pavement of roadways, it is necessary to intensify the stiffness of base, maintain appropriate width of joint using concrete blocks with joint width keepers, reduce the thickness of bedding sand as far as the pavement work permits, and use sand sufficing the quality shown in Table 3 in order to prevent the onset of breakages characteristic to the concrete block paving.

Finally, we acknowledge greatly to the guidance and cooperation of person concerned in preparation of this paper and collection of the basic data.