DEVELOPMENT AND APPLICATION OF PERMEABLE PAVING CONCRETE BLOCK

CHICHIBU CEMENT CO., LTD. JAPAN
SHIGEO SUDA
SUSUMU YAMANAKA
OSAMU KODAMA
MINORU HATA
SANYO CONCRETE INDUSTRIES CO., LTD. JAPAN
TADAO KUNIMURA

Summary
The aim of the permeable paving concrete blocks lies in the recovery of the natural water (or hydrologic) cycle system which is considered to have been destroyed substantially due to the rapid progress of the urbanization of the land. On the other hand, the areas paved with the paving blocks are rapidly increasing in parallel with the developments of the paving blocks of refined designs, for such paving blocks are needed for the renewal or improvement of the scenes of the urbanized areas.
In developing the permeable paving concrete blocks, the emphases have been placed on realizing the permeability comparable to that of the permeable asphalt that is now used widely and the manufac-turability by the ordinary paving concrete block manufacturing lines. As a result, we have succeeded in manufacturing the permeable paving concrete blocks with desired quality. Especially, we have succeeded in obtaining a high mechanical strength for these paving blocks thanks to the fact that the viblating compaction method suits the molding of the porous concrete.
The result of the field test indicates that the newly developed permeable paving concrete blocks have the permeability that is large enough to almost prevent the rainwater from forming the puddles or running off on their surfaces as far as the intensity of the rainfall is relatively small and that the same paving blocks are capable of preventing the surface run-off of the rainwater for at least about 30 minutes even when the intensity of the rainfall is 50mm/h.

1. Introduction

In Japan, the rapid growth of Japanese economy started in 1960s has accelerated the concentration of the population in large cities and resultant expansion of the urbanized areas. Besides, the rapid progress of the motorization in Japanese society has also accelerated the destruction of its natural water system as the result of the expansion of the areas covered with the asphalt and concrete. These changes in the environmental conditions have caused various serious problems leading to the deterioration of the city lives of the people such as

(1) the adverse effect on the vegetation and the subsidence of the ground resulting from the lowering of the water table,
(2) the flooding of the rivers in the urbanized areas due to the rapid concentration of the rainwater into the sewerage systems and
(3) the resultant pollution of the rivers and seas.

In order to cope with such problems, the comprehensive rainwater utilization such as on exemplified in the following Fig. 1 has begun to be promoted recently as the means for recovering the natural water cycle system in the urbanized areas by providing the systems for letting the rainwater permeate the ground freely. For instance, the various local autonomous bodies including Tokyo are actively promoting their projects for replacing the asphalt and paving blocks of existing footways and driveways with the permeable asphalt and paving blocks.

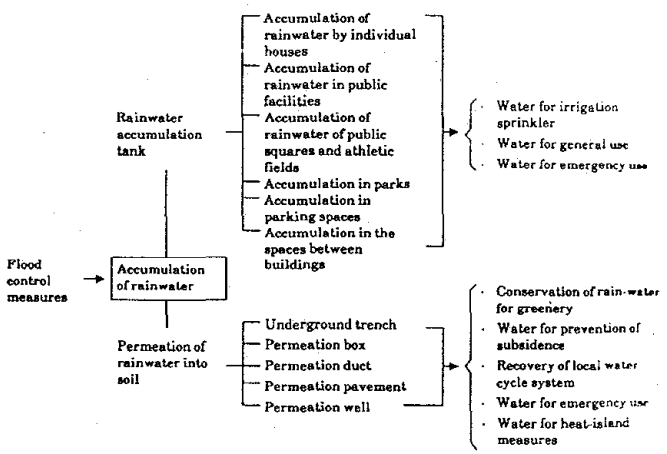


Fig. 1 Comprehensive rainwater utilization system[1)]

The permeable pavement consists of porous paving materials to permit the rainwater permeate into the soil. The asphalt, concrete and bricks are used as the materials of the permeable pavement. Of these materials, the permeable asphalt pavement is used most widely as it is not only easiest for application to the permeable pavement but also lowest in cost. On the other hand, however, the porous asphalt pavement is disadvantageous in that it is prone to clog due to its fluidization by the heat in the summertime and deteriorates faster than other materials. Besides, the asphalt pavement is less attractive in appearance than other materials in view of the recent tendency of the general public who are increasingly becoming interested in the improvement in the appearance of their living environment.
On the other hand, the demand for the paving blocks is increasing rapidly as the paving material capable of filling the need for further improvement of the urban scenes, and so if the paving blocks is given another advantage, the permeability, they will be able to contribute greately to the improvement of the urban environment by filling the aforementioned two needs, the improvement of the urban scenes and the recovery of the natural water cycle system, as the new paving materials.

We developed the permeable paving blocks, the details of which will be discussed later, in 1983 and has promoted the spread of the parmeable paving blocks since then. Fortunately, the parmeable paving blocks have been well accepted by the market, and they have already been used for the pavement of about 100,000m^2 in Japan.

2. Target of development

Conventionally, the asphalt has been used for the permeable pavement. According to the road design standard enforced by Tokyo Metropolitan Government, the construction of the footway is required to satisfy the conditions indicated in Fig. 2. Under these conditions, the coefficient of permeability should be no less than 1.0 x 10^{-2}cm/sec, and the percentage of the voids to be determined in the composition de-sign of the asphalt should be no less than 12%.

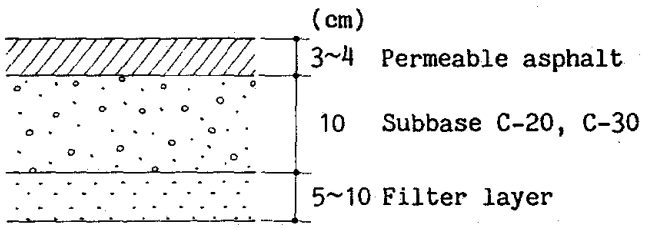


Fig. 2 Construction of permeable asphalt pavement

To provide the permeability to the subbase, the crushed stones falling under the categories of C-20 or C-30 obtained by the crusher run specified by JIS A5001 instead of the crushed stones to be used for the adjustment of the grading. The filter layer is provided to prevent the soil of the roadbed from mixing into the subbase, and the sand is used for the filter layer.
The target value of the permeability of the permeable paving blocks is set equal to or higher than that of the permeable asphalt. The structure of the pavement by such permeable paving blocks is as illustrated in Fig. 3. Under this structure, the percentage of the voids of each permeable paving block is required to be 12% as indicated in Table 1 in order to equalize the percentages of the voids of two paving materials.

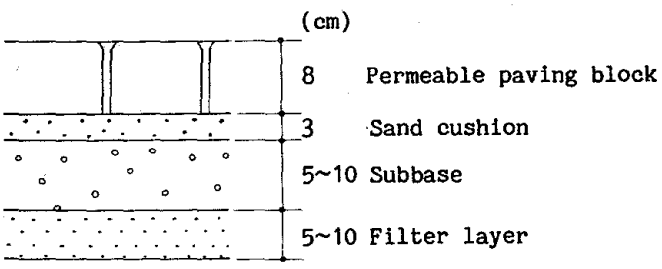


Fig. 3 Structure of the pavement using permeable paving blocks

Table 1 Percentage of voids of permeable paving blocks

Permeable paving block			Permeable asphalt		
Item	Thickness (mm)	Percentage of voids (%)	Item	Thickness (mm)	Percentage of voids (%)
Permeable paving block	80	12	Permeable asphalt	40	12
Sand cushion	30	10	Subbase	10	15
Subbase	50	15			

Percentage of voids of permeable paving block

$$= \frac{(40 \times 0.12 + 10 \times 0.15) - (30 \times 0.1 + 50 \times 0.15)}{80} = 0.12$$

If a mortar layer of 10mm thick is provided on the surface of the paving block, however, the percentage of the voids of the porous concrete is required to be at least 14%. For the mechanical strength of the permeable paving block, the bending strength is specified. Since the permeable paving blocks are used for the footways, the bending strength of at least 40kgf/cm^2 which is equal to that of the common paving blocks for the footways is adopted.
For the coefficient of the permeability, 1.0 x 10^{-2}cm/sec which is the same as that of the permeable asphalt is applied.
The quality standard of the above-mentioned permeable paving blocks is shown in Table 2.

Table 2 Quality standard of permeable paving blocks

Item	Standard value
Percentage of voids (%)	12% or more
Bending strength (kgf/cm^2)	40kgf/cm^2 or more
Coefficient of permeability (cm/sec)	1.0 x 10^{-2}cm or more

Table 3 Target values of porous concrete

Item	Target value
Percentage of voids (%)	20% or more
Bending strength (kgf/cm^2)	50kgf/cm^2 or more
Coefficient of permeability (cm/sec)	1.0 x 10^{-2}cm or more

3. Development

3.1 Composition of porous concrete

The following experiment was conducted in order to obtain the porous concrete satisfying the target values described is Section 2.

(1) Material
The qualities of the cements and aggregates used in the experiment are as shown in Tables 4 and 5.

Table 4 Quality of cement

Specific gravity (-)	Specific surface area (cm^2/g)	Flow (mm)	Bending strength (kgf/cm^2)			Compression strength (kgf/cm^2)		
			3 days	7 days	28 days	3 days	7 days	28 days
3.17	3160	260	33	51	78	141	264	420

Table 5 Quality of aggregate

Kind	Specific gravity	Coefficient of water absorption (%)	Washing (%)	Unit weight per litre (kg/ℓ)	Ratio of absolute volume (%)	Sieve passability (%)					FM
						15	10	5	2.5	1.2	
No.6 crushed stone	2.66	1.32	0.77	1.529	58.0	100	78	12	2	0	6.14
No.7 crushed stone	2.66	1.29	3.20	1.522	57.6		100	87	14	3	4.96

(2) Method of experiment

① The molding testing machine used for the experiment has the construction as is described in Fig. 4. The numbers of vibrations generated by the upper and lower vibrators are 4500 vpm and 5200vpm respectively.

② The form of the sample is as shown in Fig. 5.

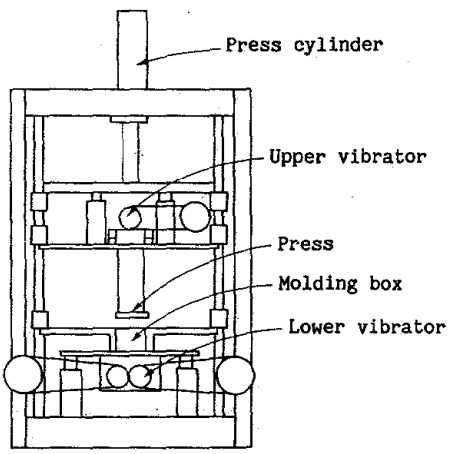


Fig. 4 Molding testing machine

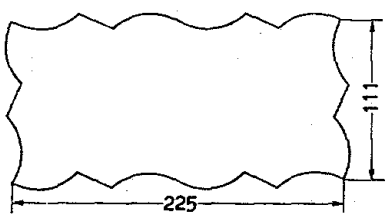


Fig. 5 Sample (Thickness: 80mm)

③ The percentage of voids is determined by the following equation (1) using the theoretical unit weight per littre, where the unit weight per littre and the percentage of the voids of the sample immediately after it is molded are assumed to be zero respectively.

$$\text{Percentage of voids (\%)} = 1 - \frac{\text{Unit weight per littre of sample}}{\text{Theoretical unit weight per littre}} \times 100 \quad \ldots\ldots (1)$$

④ The bending strength was measured using the one-week old sample and a middle-loading load testing machine with its span set to 160mm.

⑤ The coefficient of permeability was tested using the square paving blocks with the sides of 50cm long, laid adjacent to each other with their joints filled with "Toyoura" standard sand, and a water-level type permeability tester as is shown in Fig. 6.

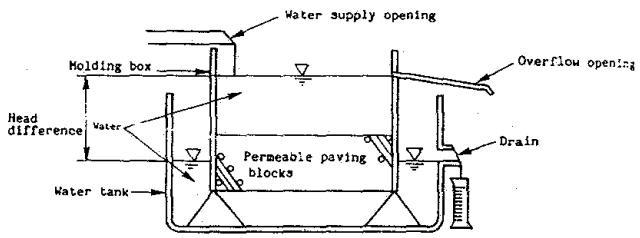


Fig. 6 Permeability tester

(3) Experiment plan

The experiment was conducted dividing it into three series of experiments devoted to the measurements of the effect of the grain size of the aggregate, the effect of the unit quantity of the cement and the effect of the admixture on the physical properties of the permeable paving blocks respectively. The details of these three series of experiments are shown in Tables 6 through 8.

Table 6 Series-1 experiment (Effect of mixing ratio of various aggregates)

Factor	Standard
Unit quantity of cement (kg/m^3)	400
Unit quantity of water (kg/m^3)	76, 84, 92, 100, 108
Mixing ratio of aggregates (%)	6:7 = 100:0 75:25 50:50 25:75 0:100

Table 7 Series-2 experiments (Effect of unit quantity of cement)

Factor	Standard
Unit quantity of cement (kg/m^3)	350, 400, 450
Unit quantity of water (kg/m^3)	76, 84, 92, 100, 108
Mixing ratio of aggregates (%)	6:7 = 25:75

Table 8 Series-3 experiments (Effect of admixture)

Factor	Standard
Kind of cement	N
Unit quantity of cement (kg/m^3)	350, 400, 450
Unit quantity of water (kg/m^3)	76, 84, 92, 100, 108
Mixing ratio of aggregates (%)	6:7 = 25:75
Kind of admixture	A: Polyacrylic sulfonate B: Naphthalene sulfonate
Addition of admixture (%)	0.5, 1.0, 1.5

(4) Result

① Effect of aggregate mixing ratio (Series-1)

The ratios of the absolute volumes of the aggregates used in the experiment are as shown in Fig. 7. The relationship between the ratio of the absolute volume of the aggregate and the percentage of the voids in the concrete is also shown in Fig. 7. From Fig. 8, we can conclude that the percentage of the voids in the porous concrete decreases as the ratio of the absolute volume of the aggregate increases, and it also decreases as the unit quantity of the water and the fluidity of the concrete increase.

Fig. 9 shows the relationship between the mixing ratio of aggregates and the bending strength of the paving block is shown in Fig. 9. From this figure, we can notice that the bending strength is highest where the the mixing ratio of the No. 6 crushed stones and No. 7 crushed stones is about 25:75 and the unit quantity of the water is constant.

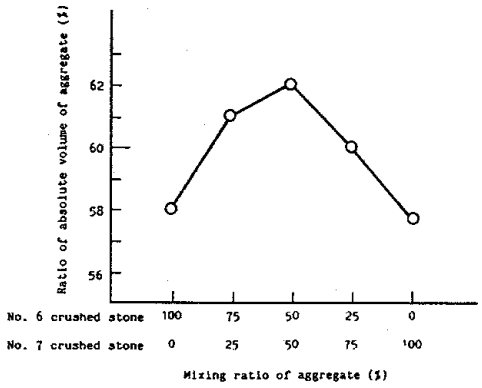


Fig. 7 Aggregates and the ratio of relationship between mixing ratio of absolute volume

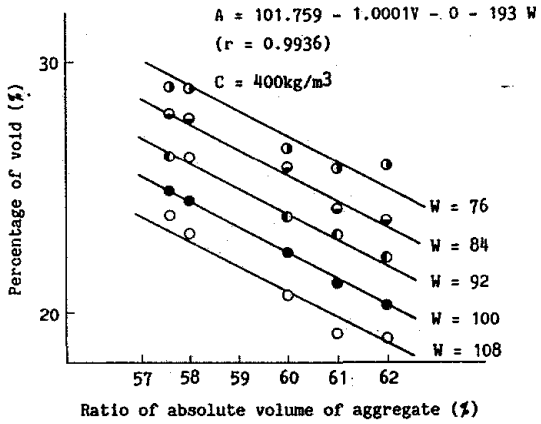


Fig. 8 Relationship between ratio of absolute volume of aggregate and percentage ofvoids in concrete

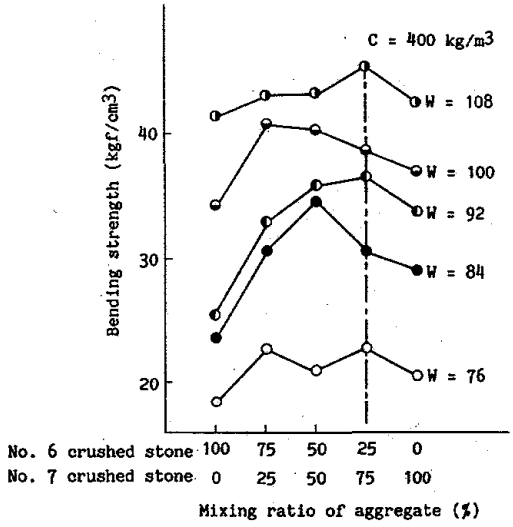


Fig. 9 Relationship between mixing ratio of aggregates and bending strength of paving block

② Effect of unit quantity of cement (Series-2)

The effect of the unit quantity of the cement on the percentage of voids in the concrete is shown in Fig. 10. On the other hand, the relationship between cement-water ratio and the bending strength is shown in Fig. 11. According to the result of this experiment, the bending strength of the porous concrete increases as the percentage of voids decreases, but it tends to decrease as the cement-water ratio increases, a result reverse to generally known fact about the concrete. This can be consid-ered to result from that, in the case of the porous concrete molded by viblating compaction, the compaction of the materials progresses by the steps illustrated in Fig. 12, and the cement paste concentrates around the joints of the aggregate due to the fulidization of the cement paste occurring at the final step of the compaction. That is, the higher the fluidity of the cement paste or the smaller the cement-water ratio, the greater the progress of the concentration of the cement paste in the joints of the aggregate, and, as a result, the bridges of large cross-sectional areas are formed to increase the bending strength.

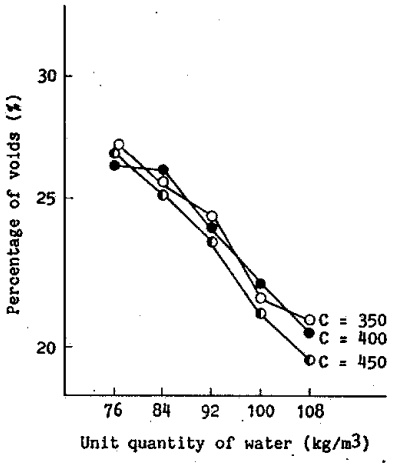


Fig. 10 Relationship between unit quantity of cement and percentage of voids

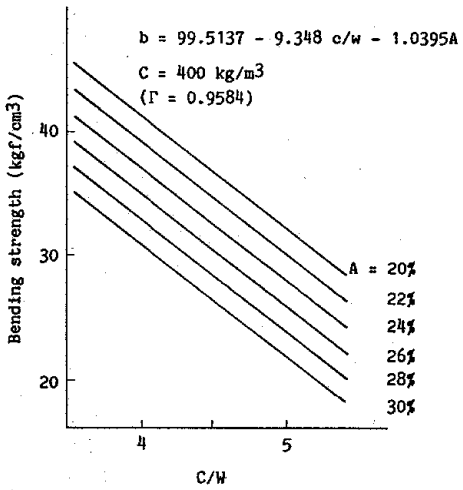


Fig. 11 Relationship between cement-water ratio, percentage of voids and bending strength

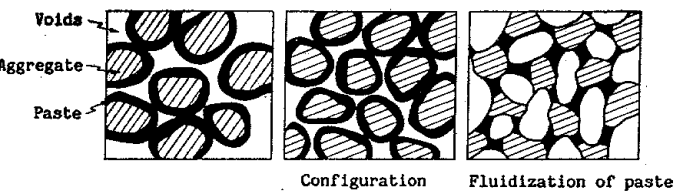


Fig. 12 Compaction steps of porous concrete by jolt molding

③ Effect of admixture (Series-3)

Fig. 13 shows the effect of the admixture on the percentage of voids. For example, in the case of the concrete including the admixture, the percentage of voids decreases as the quantity of admixture increases unlike the case of the concrete not including the admixture. When viewed by the kinds of the admixtures, we have found that the admixture B facilitates the fluidization of the paste more than the admixture A.

Fig. 14 shows the relationship between the percentage of voids and the bending strength.

According to the data shown in this figure, compared with the case of the plain concrete, the bending strength of the concrete including the admixture is larger than that of the plain concrete where the percentages of the voids are equal, and the concrete with the percentage of voids exceeding 20% and the bending strength exceeding 50 kgf/cm^2, which are larger than the target values, can be obtained when the admixture is added. When the admixture A is added, however, the plastic deformation of the concrete block becomes larger compared with that of the plain concrete. Thus, when the admixture A is used, the concrete block satisfying the specified accuracy is unable to be molded.

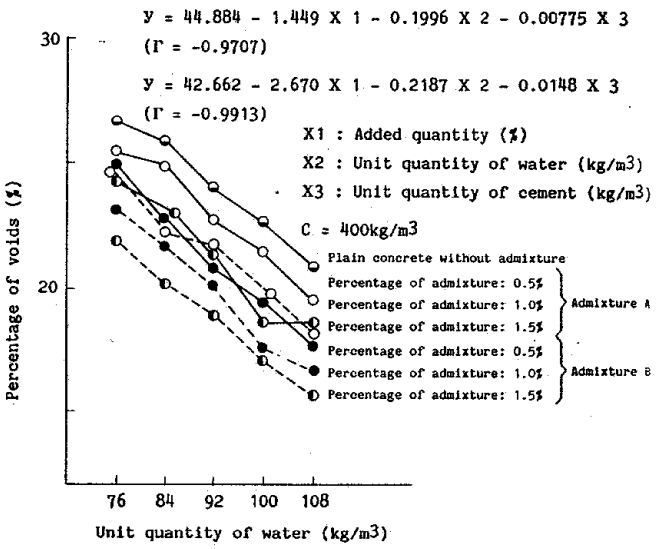


Fig. 13 Relationship between the kind of admixture, quantity of admixture and the percentage of voids

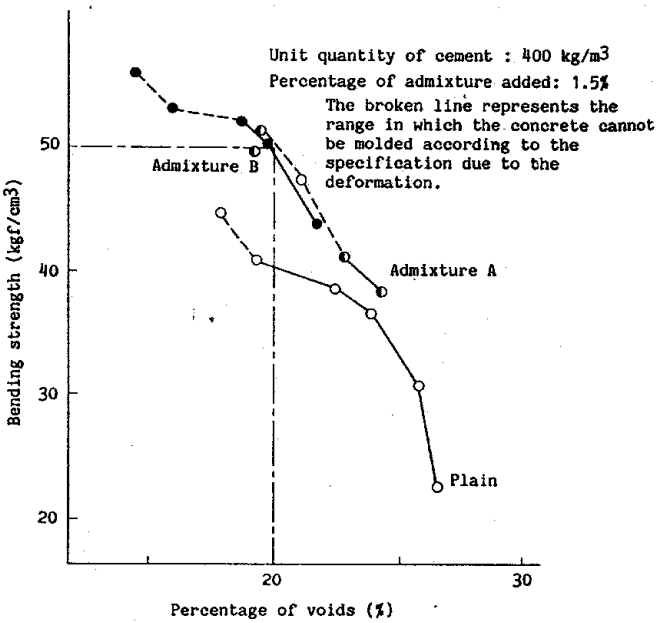


Fig. 14 Relationship between the kind of admixture and bending strength of concrete

Relationship between the mixing ratio of aggregates and the coefficient of permeability

Fig. 15 shows the relationship between the mixing ratio of the aggregates and the coefficient of permeability.

As far as the result of the experiment is concerned, the coefficient of the permeability is only slightly affected by the grain size of the aggregate, and the coefficient of the permeability has exceeded (better than) the target value of 1.0×10^{-2}cm/sec.

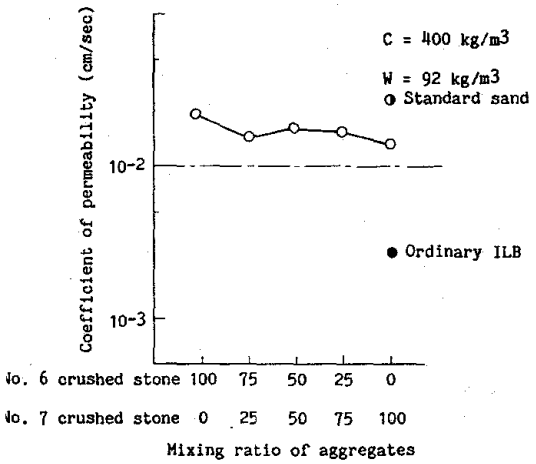


Fig. 15 Relationship between the mixing ratio of aggregates and the coefficient of permeability

From the above result of experiment, the composition of the porous concrete is decided as shown in Table 9.

Table 9 Composition of porous concrete

Mixing ratio of aggregates	No.6 crushed stone: No.7 crushed stone = 25:75, FM = 5.26
it quantity of cement	400kg/m3
it quantity of water	92kg/m3
antity of admixture added	Admixture B 1.5%

nufacture

inds of products

e kinds of the permeable paving blocks, those listed in 10 are chosen by their uses.

Table 10 Kinds of permeable paving blocks

ype	Grain size of surface mortar layer	Permeation structure
pe A	2.5mm~0mm	Joints → Base of paving block
pe B1	2.5mm~1.2mm	Surface → Base of paving block
pe B2	5mm~2.5mm	Surface → Base of paving block

ermeation structures of these paving blocks are as shown . 16. For example, in the case of Type A, the rainwater ed through the joints permeate the subbase passing the ayer of each paving block. On the other hand, in the cases of Type B_1 and Type B_2, the rainwater permeates the base layer directly through the surface layer. While the Type A paving block has the surface appearance similar to that of the ordinary paving block, Type B_1 and Type B_2 have the surfaces rougher than those of Type A paving block, and the roughness of the surface increases gradually in the order of Type B_1 and Type B_2.

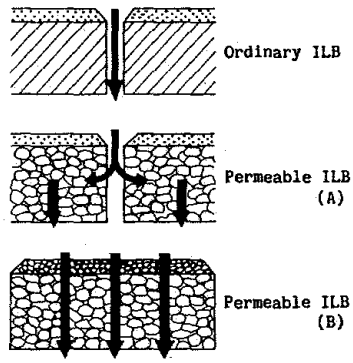


Fig. 16 Permeation structures of permeable paving blocks

4.2 Manufacturing experiment in factory

The manufacturing experiment was conducted in order to find out the problems with which we may be encountered in manufacturing the permeable paving block in the factory and devise the countermeasures against such problems. The molding machine used for the experiment was Knauer 400-3, and the compositions of the materials described in 4.1 were used. For the type of the paving blocks to be used in this experiment, the Type A having the mortar layer for the surface was chosen.

The relationship between the percentage of voids and the bending strength of the permeable paving block obtained through the experiment is shown in Fig. 17. From this figure, we can notice that the paving block meeting the requirements of the permeable paving block and also almost meeting the target value for the porous concrete can be obtained by the manufacturing method used in the experiment.

The crack of the surface and the fall-off of the block from the mold were the most common problems with which we encountered during the experimental manufacture, and so the countermeasures against such problems will be discussed in the following.

The cracks in the surface of the block is caused by the difference between the degree of the plastic deformation of the porous concrete constituting the base layer occurring in the lateral direction and that of the mortar constituting the surface layer. Fig. 18 shows the relationship between the longitudinal deformation of the block, the number of layers of the molded block and the degree of the cracks occurred in the surface of the block. From this figure, we can learn that the lower the layer, the larger the deformation. For example, the deformation of the lowest layer measures about 5mm. Besides, the result of the experiment indicates that the upper 4 layers are free of surface cracks, but the cracks were observed in the surfaces of the layers under the upper four layers. Thus, we have decided to stack the upper 4 layers on the pallet in manufacturing the permeable paving blocks. Also, we found it useful to adjust the molding machine so as to reduce the shock to the bottom layer of the block as far as possible.

To prevent the block from falling off from the mold, it is found effective to increase the grain size of the aggregate, and so the ratio between No. 6 crushed stones and No. 7 crushed stones was changed to 50:50 from 25:75 in manufacturing.

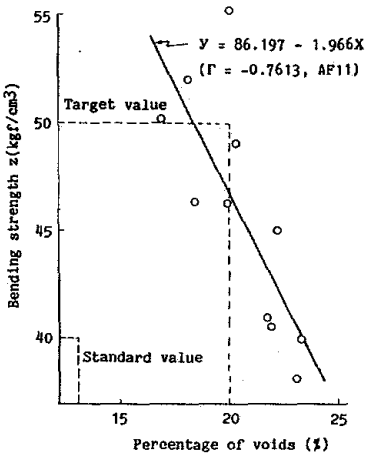


Fig. 17 Relationship between the percentage of voids and bending strength

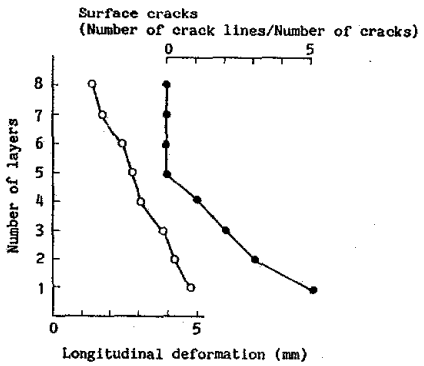


Fig. 18 Relationship between block deformation and degree of surface cracks

5. Permeation experiment by artificial rainmaking device

In order to measure the permeability of the permeable paving blocks, we have conducted the permeability test using the artificial rainmaking device. The artificial rainmaking device consists of the units as are schematically illustrated in Fig. 19. The pavement of 2m x 2m in area having the structure shown in Fig. 20 was used as the sample for the experiment. For the rainfall intensity formula, the following formula (2) used by Tokyo Metropolitan Government in designing the sewerage system was used for our experiment. In our experiment, the rainfall intensity of 50mm/hr. and rainfall duration of 1 hour are used as the standard conditions.

$$i = \frac{5000}{t + 40} \quad \text{..... (2)}$$

where i: Rainfall intensity (mm/h)
t: Rainfall duration (min.)

The result of this experiment indicates that the rainwater permeated without any surface run-off where the rainfall intensity was 50mm/h; however, the surface run-off was observed after 30 minutes. This relationship is graphically shown in Fig. 21.

More particularly, in the above case, no surface run-off was observed until all the voids in the whole pavement were filled with the rainwater and when the voids in the pavement are filled by the rainwater, the surface run-off will occur. This means that the surface run-off is the portion of the rainwater water. This means that the remainder of the rainwater wh has filled the voids in the pavement and permeated the ro runs off the surface of the pavement. In our experiment, it confirmed that no surface run-off occurred until all the voi in the pavement had been filled with the rainwater even w the rainfall intensity was 130mm/h.

As explained in the above, the permeable paving blocks use in our experiment have proved to have a high permeability and that the duration before the start of the surface run-off and the degree of the surface run-off are governed by the wa absorption capacity of the whole pavement or the thickness the subbase and the permeation rate of the rainwater into t roadbed. Fig.22 shows the relationship between the time required before the voids of the pavement are filled with the rainwater, the thickness of subbase and the permeation rat the rainwater into the roadbed where the rainfall intensity 50mm/h. This figure shows that the voids in the pavement i filled with the rainwater within half an hour where the subbase is 5cm thick, but almost the whole rainfall can be absorbed where the subbase is 25cm thick.

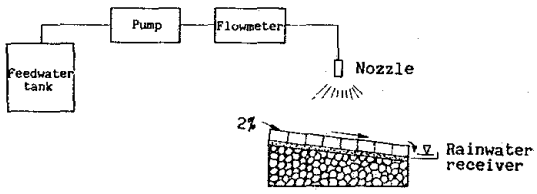


Fig. 19 Artificial rainmaking device

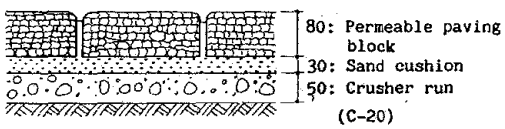


Fig. 20 Structure of pavement

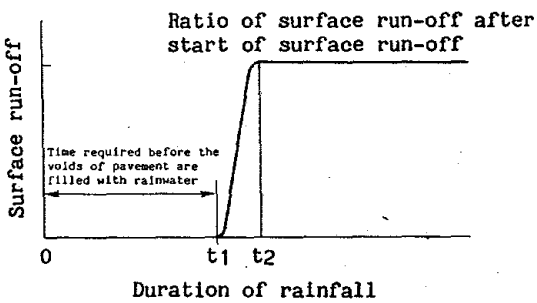


Fig. 21 Change in surface run-off with time

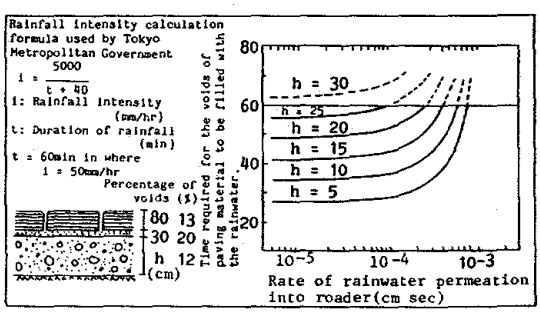


Fig. 22 Water absorption capacity of pavement consisting of permeable paving blocks

6. Examples of application

6.1 Footway and parking zone

Photo-1 shows example of the footway paved with the permeable paving blocks. As is clear from this photo, the puddles of rainwater are seen on the surface of the driveway paved with the asphalt, while the rainwater on the footway has permeated completely thereby proving the effect of the permeable paving blocks. Photo-2 shows an example of the parking zone paved with the permeable paving blocks. From this photo, we can notice that the pavement is strong enough to withstand the traffic of the vehicles.

Fig. 23 shows the change in the coefficient of permeability of the permeable paving blocks used for actual pavement. This chart indicates that the coefficient of permeability has dropped by one order in its value due to the clogging of the voids with the litters and dust. Nevertheless, there is no sign of further progress of the clogging, and so the practical function of the permeable paving blocks is still maintained.

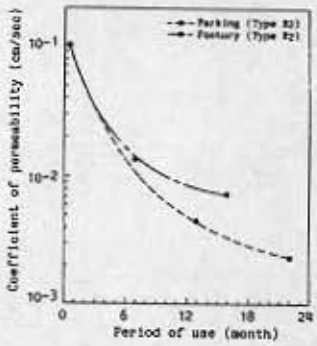


Fig. 23 Change in the coefficient of permeability with time



Photo-1 An example of application of permeable paving blocks to the pavement of footway



Photo-2 An example of application of permeable paving blocks to the pavement of parking zone

6.2 Special applications

Here, let's take a look at an example of the application of the permeable paving blocks to the doline and its surrounding area in Akiyoshidai National Park. Akiyoshidai National Park is known for its largest expansion of the karstic tableland in Japan. In this national park, there are number of doline created by the limestones errored by the rainwater to create the landscape peculiar to the karstic tableland. Akiyoshidai Town situated near this national park has constructed a recreational plaza in one of the doline. The permeable paving blocks are used for the pavement of this recreational plaza due to the reasons that the asphalt pavement is detrimental to the ecosystem around the doline and that permeable paving blocks are superior both in designability and permeability.



Photo-3 An example of application of permeable paving blocks to the pavement of recreational plaza in doline of Akiyoshidai National Park

7. Conclusion

(1) The permeable paving blocks are advantages in that they enable the recovery of the natural water cycle system in urbanized areas by permitting the rainwater to permeate into the soil and contributes to the improvement in the appearance of the cities.

(2) The permeable paving blocks are manufactured by the viblating compaction method using the zero-slump no-sand concrete. The paving block manufactured in this process has the bending strength of 40kgf/cm^2 or more spite of each paving block has the voids of more than 12%. Such excellent physical properties owe much to the fluidization of the cement paste resulting from the vibration at the time of the manufacture by the viblating compaction method.

(3) In manufacturing the permeable paving blocks, it is important to prevent the cracks in the surface of block due to the plastic deformation of the porous concrete constituting the base layer and the falling off of the of the block from the mold.

(4) The permeable paving block are capable of preventing the surface run-off of the rainwater for about half an hou at the rainfall intensity of 50mm/h.

Reference

1) Permeable Pavement Handbook, Japan Road Contractors Association, 1979.

2) Isao Oshida, Solar System Researchers Group, Water Environment in Urbanized Areas, 1982.