STUDY ON APPLICABILITY OF WATER-FEED-TYPE WET BLOCK PAVEMENT TO ROADWAYS

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SUMMARY

Many countries are making efforts to mitigate the heat island effect, which is a global problem. Some corporations in Japan are putting their energies into research and development of new types of pavement as measures to cope with heated environments; as a result, water-retentive asphalt pavement and interlocking block pavement are being adopted more frequently today. In hot environments, however, road surface temperatures may not be kept reduced if water supply depends only on natural rain. While asphalt pavement is prevalent in Japan, interlocking block pavement, which is mainly used for sidewalks, construction exteriors, and parks, is not yet much used for roadways and parking areas.

As a measure to cope with heated environments, the authors have been proposing a water-feed-type wet block pavement system, which ensures retention of wet condition at all times even in a hot environment by embedding a water supply system in the structure of water-retentive block pavement. This system consists of a feed pipe, water guide sheet, rainfall sensor, and control panel. In fine weather, the system feeds water according to the setting, and the water transported on the guide sheet is supplied to water-retentive blocks by capillary action through cushion sand. This allows the system to provide evaporative cooling even in fine weather and to keep pavement surface temperatures at as low as 25 degrees C in the summer. The system thus improves the amenity of pedestrians in parks, sidewalks, and other areas and contributes to the mitigation of the heat island effect. When applying the system to roadways, however, occurrence of unevenness in blocks is concerned because the water supplied to the lower block surfaces may cause outflow of

cushion sand through the block joints. The present study experimentally investigates the effects of water supply on the structural durability of the pavement system and proposes an optimal cross section of the structure.

1. INTRODUCTION

Water-retentive pavement having the capability to store water inside the pavement structure is recently gaining popularity in Japan as a means of mitigating the heat island effect. This type of pavement has been constructed in Japan at a rate of about 100,000 m^2 per year since 2003. The water stored in the pavement structure evaporates from the pavement surface, so that the surface temperature is reduced by evaporative cooling. As a type of such pavement structure, interlocking blocks with a water retention capability have recently been made by a number of manufacturers in Japan. However, the water retained in this type of pavement structure would evaporate completely in about one to three days under the hot summer sunshine, so that the evaporative cooling effect would not be maintained.

The present study adopts a water-feed-type wet block pavement system, which ensures retention of wet condition at all times even in a hot environment by embedding a water supply mechanism in the water-retentive block pavement structure. The study experimentally investigates the effects of water supply on the performance and structural durability of the system when applied to roadways and proposes an optimal cross section of the structure.

2. OUTLINE OF CONTINUOUS WATER-FEED-TYPE BLOCK PAVEMENT SYSTEM

The system has a water conveyance sheet, which is to spread the water supplied from the feed pipe efficiently. On the sheet are cushion sand and interlocking blocks having good water retention. The amount of water supplied is controlled with a timer and a rainfall sensor, so that an appropriate amount of water is automatically supplied to the water-retentive blocks. Other than service water, treated waste water and rainwater collected in a storage tank can be used for the supply of water. The system suppresses road surface temperatures at all times through evaporative cooling even in hot weather of a few consecutive days for improving amenity and reducing environmental loads.

A schematic view of the system is given in Figure 1.

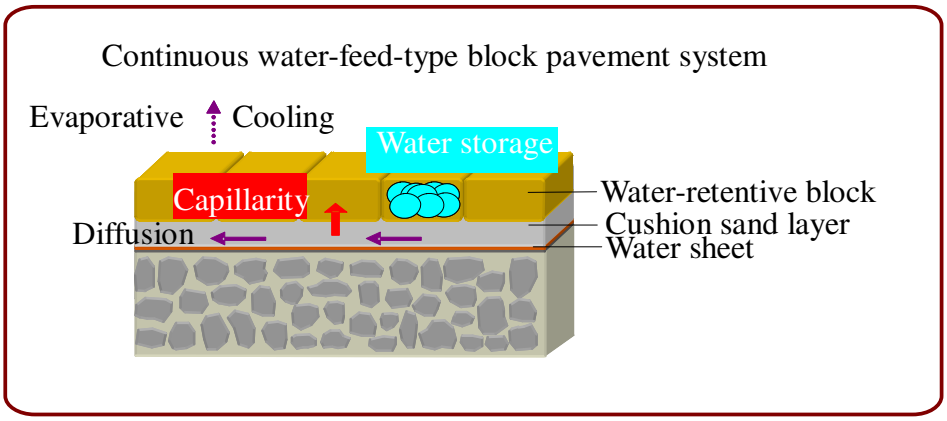


Figure 1. Schematic drawing of continuous water-feed-type block pavement system

- Water retentive blocks: Each block, with dimensions of 100 mm x 200 mm x 60 mm, has high water retention and can contain as much as 150 kg/m^3 or more (JIPEA standard) water in it.
- Cushion sand: It mainly consists of river sand and pit sand and sustains the blocks.
- Water sheet: It has high water spreading ability, so that the water supplied from the feed pipe is quickly spread throughout the sheet.
- Feed pipe: It supplies water to the water sheet evenly through discharge holes arranged at regular intervals.

3. EFFECTS OF CUSHION SAND ON PERFORMANCE AND STRUCTURAL DURABILITY OF SYSTEM

Because the properties of cushion sand may affect the performance and structural durability of the system significantly, the effects of the capillarity of cushion sand and repeated traffic loads on the flatness of the arrayed blocks were investigated in this study.

3.1 Test materials

The following five types of cushion sand were used for the experiment; their physical properties and grading are shown in Tables 1 and 2, respectively.

- Fine sand: Because river sand of good quality is hard to collect in Japan, washed pit sand, which is being used as aggregate for asphalt concrete, was adopted in this study.
- Garnet: Pale pink debris of a garnet gemstone from India. It is very hard, dense, and costly.
- Kashima silica sand: Widely used and commercially distributed in Japan as joint filler between interlocking blocks and for sandblasting.
- Crushed stone S-5(5-2.5mm): This material, made from hard stone in Japan, is commonly used as

aggregate for asphalt concrete.

- Crushed stone-sand: This material, made from hard sandstone in Japan, is commonly used as aggregate for cement concrete and asphalt concrete. It is widely available at low cost.

Table 1. Physical properties of cushion sand

Type of sand	Fine sand	Garnet	Silica sand	S-5	Stone sand
Surface-dried specific gravity	2.61	4.10	1.5*1	2.66	2.61
Water absorption (%)	3.51	-	-	0.64	0.85
Resistance to crushing (%)*2	1.3	0.0	0.2	-	0.6

*1 Bulk specific gravity

*2 Tested according to JIPEA-TM-2

Table 2. Grading of cushion sand

Type of sand	Fine sand	Garnet	Silica sand	S-5	Stone sand
Sieve			Passing (%)		
4.75mm	99.7	100	100	86.2	99.6
2.36	98.9	100	100	1.6	85.2
0.6	91.4	59.2	50.9	0.3	34.8
0.3	54.0	15.9	3.1	0.3	20.6
0.15	7.2	0.1	0.1	0.3	6.8
0.075	1.9	0	0	0.3	0.9

Because of its low price and wide availability, the stone sand was selected as a material to investigating the effect of different grading. The sand was sorted by removing the factions that passing 600 μm and retaining 75 μm.

3.2 Capillarity test of cushion sand

The pavement system has cushion sand between the water sheet and water-retentive blocks. The cushion sand is required to have the ability to lead the water spread by the sheet quickly and appropriately to the blocks through capillary action. In this test, a water sheet was attached to the bottom of an acrylic tube with a diameter of 18 mm, and the tube was placed in a vessel that was filled with water to a depth of about 1 mm. Capillary height in the tube was then measured with the scale displayed on the tube. To facilitate the measurement, the cushion sand was absolutely dried, and jigging was carried out five times after dispensing a certain amount of sand into the tube.

A view of the capillarity measurement is shown in Figure 2.

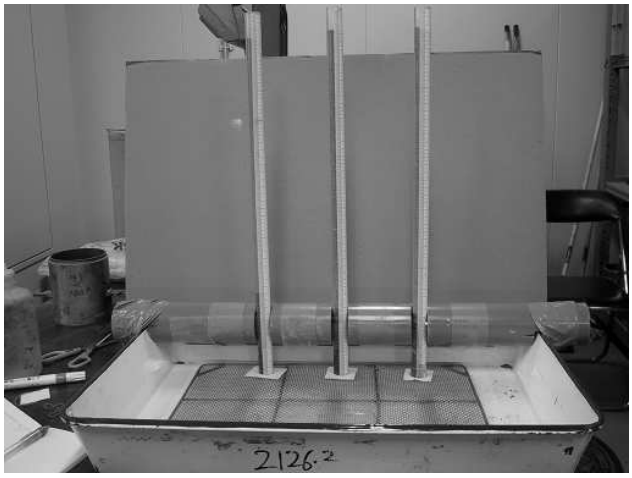


Figure 2. Measurement of Capillary height

3.3 Dynamic wheel loading test

When the pavement system is applied to roadways, the blocks may become uneven or loose and the flatness of the pavement surface may not be maintained because the repeated dynamic loading of vehicles could cause the following phenomena:

- The repetitive dynamic loading squeezes water out of the cushion sand and causes ejection of both the water and sand through the joints.
- Sand particles are further pulverized by the repetitive dynamic loading.

Dynamic wheel loading test on a specimen of the pavement was performed, and displacement of the block pavement surface with time was measured. The details of the test specimen using the aluminum form are shown in Figure 3.

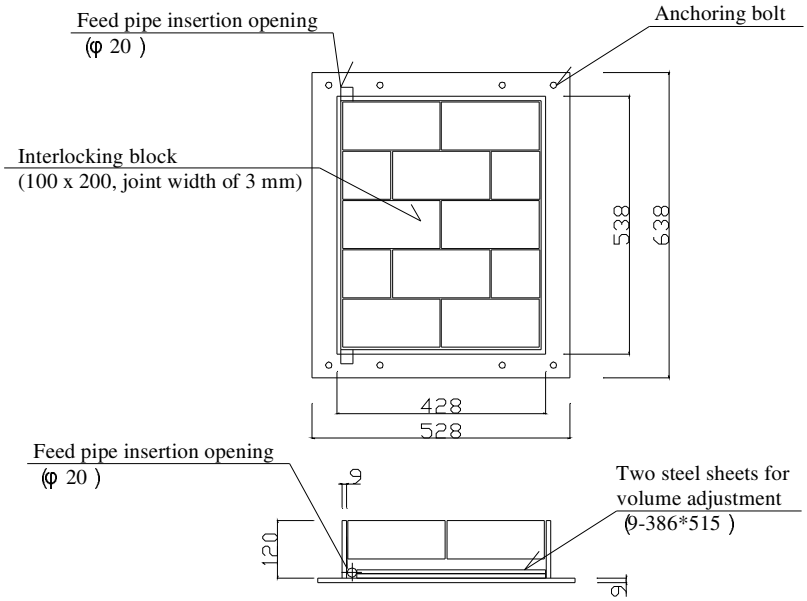


Figure 3. Detailed drawing of specimen for dynamic wheel loading test

3.3.1 Texture and block type

Straight-type blocks and a stretcher bond block pattern, the most common pattern in Japan, were used for evaluate the effect of cushion sand.

3.3.2 Thickness of cushion sand layer

In Japan, the thickness of cushion sand layer is generally in the range of 2 to 3 cm. A thickness of 2 cm was adopted in this test in view of enhancement of capillarity and application to roadways.

3.3.3 Joint filler

The joints, having a width of 3 mm, were filled with Kashima silica sand. The grading of the silica sand is shown in Table 2.

3.3.4 Amount of water supply

To evaluate the effect of water supplied to the system, the maximum amount of water was contained in the water-retentive blocks and 5 kg/m^2 of water was supplied to the feed pipe during the test. For each test specimen, 1.9 kg of water was supplied to the blocks and 1.54 kg of water was supplied to the water sheet.



Figure 4. Supplying water to blocks

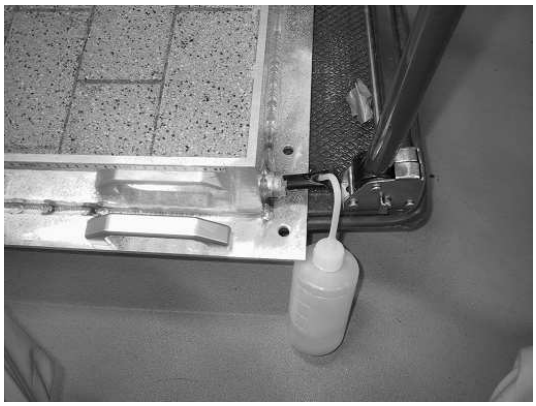


Figure 5. Supplying water to feed pipe

3.3.5 Loading conditions

Assuming that the wheel load of a typical heavy vehicle is 49 kN, the contact pressure of the tire was set to 540 kN/m^2. This is a standard load typically used in Japan for designing roads structure.

3.3.6 Number of wheels passing

In Japan, roads are classified into seven groups based on the daily traffic of large vehicles, and the number of wheels treading on the road to cause fatigue failure is referenced for a design period of 10 years. The dynamic wheel loading test assumed three levels of traffic:

- less than 15 vehicles
- at least 15 vehicles and less than 40 vehicles
- at least 40 vehicles and less than 100 vehicles

The test was conducted by assuming 1500, 7000, and 30,000 wheels treading the pavement for the

above levels, respectively. A test machine complying with ISSA TB-109 was used.

A view of the dynamic wheel loading test is shown in Figure 6. Only the central wheel in the figure was used for the test.



Figure 6. Dynamic wheel loading test

3.3.7 Displacement measurement

Settlement was measured with a digital indicator at locations shown in Figure 7 before the test and after the passage of 1500, 7000, and 30,000 wheels.

A view of displacement measurement is shown in Figure 8.

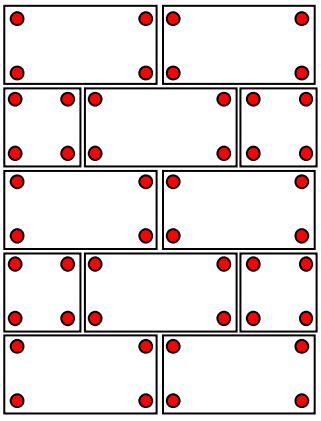


Figure 7. Locations of displacement measurement

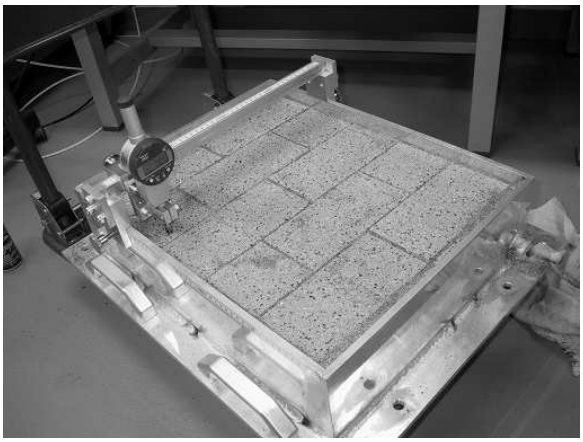


Figure 8. Displacement measurement

4. TEST RESULTS AND DISCUSSION

4.1 Capillarity of cushion sand

The results of the capillarity test of cushion sar

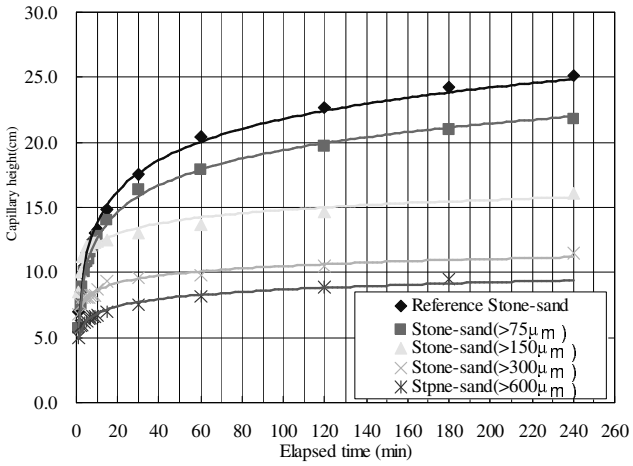


Figure 9. Results of capillarity test of Stone-sand

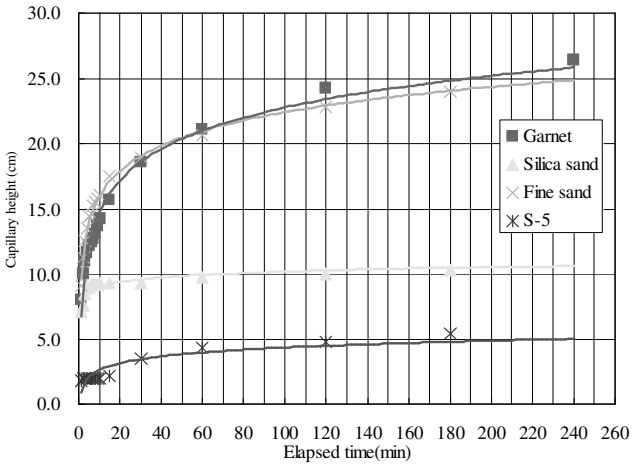


Figure 10. Results of capillarity test of crushed sand

The test results indicate that capillary height is proportional to the natural logarithm (Ln) of time. The results of calculation using a regression equation, or Equation (1), are listed in Table 3 for the different types of cushion sand.

$$y = a \ Ln(X) + b \quad \text{----------(1)}$$

where: y = capillary height (cm)
X = time (min)

Even in the case of S-5, in which capillary action was slowest, the water level rose to 3 cm, corresponding to the thickness of cushion sand layer, at an elapsed time of 20 min.

Table 3. Results of regression analysis for capillary height

Type of sand	a	b	Correlation coefficient (R^2)
S-5	0.75	0.91	0.831
Garnet	3.48	6.74	0.984
Silica sand	0.50	7.89	0.792
Fine sand	2.79	9.55	0.997
Reference Stone-sand	3.47	5.82	0.993
Stone-sand(>75μm)	2.95	5.82	0.998
Stone-sand(>150μm)	1.13	9.59	0.927
Stone-sand(>300μm)	0.80	6.79	0.966
Stone-sand(>600μm)	0.80	4.99	0.979

The test results shown in Figure 4 indicate that capillarity becomes less prominent when grading becomes narrower for the same type of stone sand. The uniformity coefficient Uc, which corresponds to the slope of the grading curve of each type of cushion sand, was then obtained from Equation (2). Because the capillarity of cushion sand may be greatly influenced by its porosity, the void ratio of each type of cushion sand was calculated from Equation (3).

The results of the calculation and the measured levels of capillary height at an elapsed time of 120 min are listed in Table 4.

$$U_c = D_{60} / D_{10} \quad \text{----------(2)}$$

where: D_{60} = particle size for 60% passing by mass

D_{10} = particle size for 10% passing by mass

$$e = (1 - Vs') / Vs \quad \text{----------(3)}$$

where: Vs' = unit weight after jigging

Vs = specific gravity (absolute dry condition)

Table 4. Calculation results

Type of sand	Uniformity coefficient, Uc	Void ratio, e	Capillary height at 120 min (cm)
S-5	1.46	0.935	4.80
Garnet	2.50	0.690	24.20
Silica sand	2.29	0.506	10.00
Fine sand	1.50	0.767	22.80
Reference Stone-sand	7.14	0.513	22.70
Stone-sand(>75μm)	6.94	0.614	19.70
Stone-sand(>150μm)	5.60	0.622	14.60
Stone-sand(>300μm)	4.57	0.730	10.50
Stone-sand(>600μm)	2.50	0.804	8.90

The calculation results indicate that there is a linear relationship between porosity and uniformity coefficient (Figure 11) and there is a high correlation between uniformity coefficient and capillary height (Figure 12).

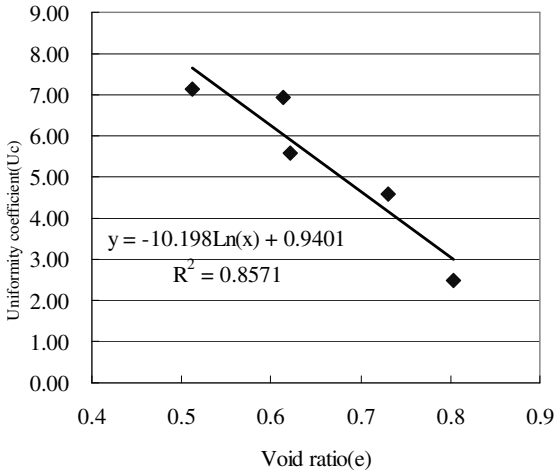


Figure 11. Relationship between void ratio and uniformity coefficient

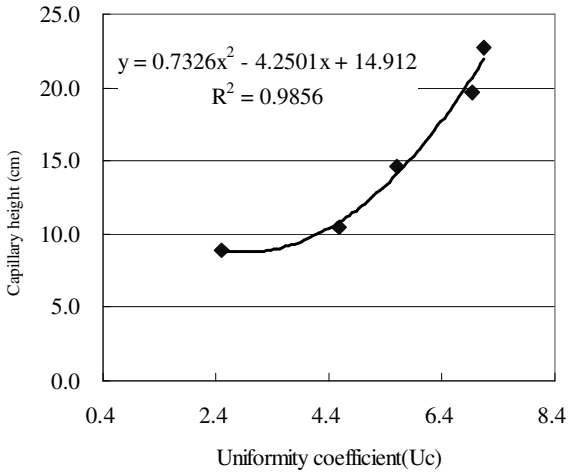


Figure 12. Relationship between uniformity coefficient and capillary height

However, these relationships do not hold true when the type of sand is changed. This implies that the speed of capillary action and the amount of capillary height vary with differences in the shape (angularity) and water absorption of sand particles even if void ratio and uniformity coefficient remain the same.

4.2 Dynamic wheel loading test

The test results for each type of cushion sand are shown in Table 5 and Figures 13 and 14.

The stone sands resulted in smaller values of maximum settlement and maximum offset than the other types of cushion sand. In the crushed sands and the fine sand, the maximum settlement values were less than 2 mm and the maximum offset values were less than 3 mm after the passage of 30,000 wheels. In the other types of cushion sand, however, the maximum offset values exceeded 5 mm, which is the reference value for maintenance set by Japanese standards (red values in Table 5).

In the fraction of stone sand grains greater than 600 μm, little increase in the values of maximum settlement and maximum offset was observed after the passage of 7000 wheels (blue values in Table 5).

Table 5. Maximum settlement and maximum offset for different numbers of wheels passing pavement

Type of sand	Number of wheels					
	1500	7000	30000	1500	7000	30000
	Maximum settlement (mm)			Maximum offset (mm)		
S-5	-1.11	-1.42	-3.74	2.40	2.91	**7.01**
Garnet	-1.43	-2.53	-3.24	1.56	3.13	**6.07**
Silica sand	-0.77	-1.22	-2.24	1.17	2.34	**5.08**
Fine sand	-1.15	-1.34	-1.75	0.96	1.57	2.86
Reference Stone-sand	-1.11	-1.54	-1.90	1.33	2.12	2.47
Stone-sand(>75μm)	-0.97	-1.11	-1.33	0.73	0.96	1.14
Stone-sand(>150μm)	-1.10	-1.22	-1.46	1.31	1.73	2.05
Stone-sand(>300μm)	-0.87	-0.96	-1.03	1.44	1.87	2.13
Stone-sand(>600μm)	-0.62	**-0.80**	**-0.80**	0.80	**1.24**	**1.37**

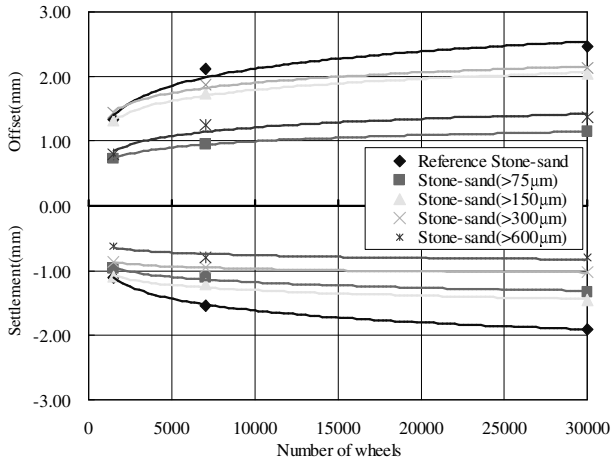


Figure 13. Settlement and offset values for crushed sands

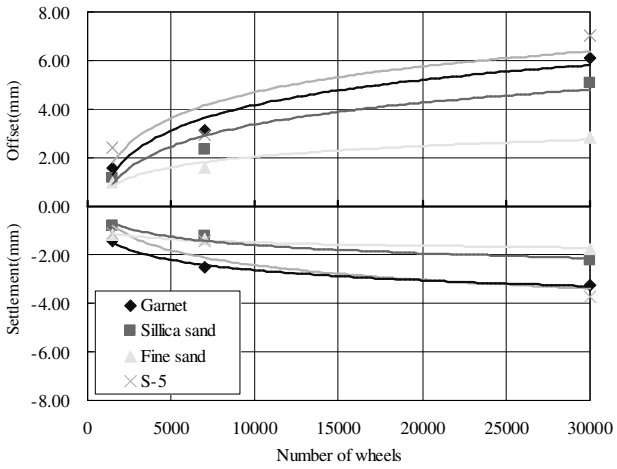


Figure 14. Settlement and offset values for garnet and other types of sand

It was considered that further crushing of cushion sand into finer grains might influence settlement. On the contrary, the garnet sand showed greater settlement than the other types of cushion sand, which should be less resistant to further crushing. It is thus considered that the supply of water made the size and shape (angularity) of grains are more influential than further crushing.

5. CONCLUSIONS

The structural durability of the water-feed-type wet block pavement system was evaluated by capillarity

and dynamic wheel loading tests using different types of cushion sand, and the following findings were obtained:

- When the thickness of cushion sand layer is in the range of 2 to 3 cm, water is supplied to the blocks by capillary action within 20 min for all the grading studied.

- For the same type of cushion sand, water is more quickly supplied to the blocks by capillary action when void ratio is smaller and uniformity coefficient is larger.

- The structural durability of the system is improved by using stone sand for cushion sand.

- The durability of the system varies with different types of cushion sand because of differences in grain shape and other factors, even when void ratio and uniformity coefficient remain the same.

- By removing the fraction of sand grains smaller than 600 μm, settlement can be reduced to 1 mm or less, and settlement and offset after the passage of 7000 wheels can be suppressed completely.

- By removing the fraction of sand grains smaller than 600 μm, offset can be reduced but capillary action is suppressed compared with the other types of sand.

6. FUTURE CHALLENGES

The structural durability of the pavement system was evaluated and discussed in this study by using a small-scale laboratory test setting. The actual use of the system on a road is expected to be influenced by rainfall, vehicle speed, vehicle direction, and other factors. Outdoor trial construction should be done in the future for further evaluation and verification. When using treated cushion sand, precision and easiness of construction should also be evaluated in detail.

7. REFERENCES

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8. STANDARDS AND TEST METHODS

- JIPEA-TM-2: Japan Interlocking Block Pavement Engineering Association, Resistance of Cushion sand to Crushed Damage
- ISSA TB-109: International Slurry Surfacing Association, Multilayer Loaded Wheel Test Vertical and Lateral Displacement at Ambient