ACCELERATED LOADING TESTS ON THE DURABILITY OF COOL PAVEMENT AT PWRI

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ABSTRACT

The 2001 Technical Standards for Pavement Structures introduced the concept of pavement performance, and accelerated loading tests are regarded as a very effective method for evaluating pavement durability.

The Pavement Test Field at the Public Works Research Institute (PWRI) is acknowledged as the only official test facility for evaluating pavement durability in Japan. This facility provides a circular test track with a diameter of 200 m, on which heavily loaded vehicles are driven by unmanned operation, controlled by a positioning system equipped with GPS and other sensors.

In line with global concerns over the urban heat island effect, Japan has taken various measures to decrease the road surface temperature, including the use of cool pavement that reflects solar radiation and retains water within the pavement materials. Although this pavement technique can reduce the road surface temperature in theory, its durability on actual roadways has not yet been proven. Thus, we examined its durability by conducting accelerated loading tests on test pavement applied to the test track on our Pavement Test Field.

This paper presents an outline of the Pavement Test Field and the results of testing the durability of cool pavement.

INTRODUCTION

In 2001, the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) established the “Technical Standards for Pavement Structures,”[1) and issued a notice to road administrators of national highway throughout Japan. It is mandatory to observe government notices, which are ranked after laws, cabinet orders, and official and ministerial ordinances. One of the major features of this Technical Standards is that the focus of pavement requirements was changed from specifications, such as on materials and structure, to performance. In other words, types of pavement techniques are no longer restricted provided that they comply with the required pavement performance. Accordingly, the Technological Standards provides flexibility in using novel pavement materials and structures produced by ongoing and future technological development. The required pavement performance stipulated in the Technical Standards includes durability against fatigue failure, resistance against plastic deformation, and surface evenness, as well as the volume of infiltrating water that may be added depending on the circumstances. Other factors, such as skid resistance and noise reduction effect, may also be incorporated if considered necessary by road administrators.

The indicator of pavement durability against fatigue failure designated in the Technical Standards is the “number of wheel passes causing fatigue failure,” it means that the number of wheel load of 49 kN is repeatedly applied to the paved roadway until cracking occurs on the pavement(Table 1), and fatigue failure is deemed to have occurred when the cracking ratio reaches 20%.2) The currently available methods for confirming the number of wheel passes causing fatigue failure are the accelerated loading tests on actual roadways or tests using pavement specimens. The Pavement Test Field owned by the Public Works Research Institute (PWRI) is the only facility officially authorized for conducting accelerated loading tests in Japan. Numerous tests have been conducted here for evaluating pavement durability in advance of applying newly developed pavement techniques to national highways, including those for cool pavement.

Cool pavement is a technique designed for reducing the amount of heat transferred back to the atmosphere by reducing the amount of heat stored inside the pavement materials due to infrared radiation from sunlight and the atmosphere. In comparison with general pavement techniques, cool pavement can reduce the road surface temperature by 10°C or more at maximum in midsummer. Therefore, cool pavement is expected to take effect in lowering the urban temperature in large city areas in Japan where the urban heat island effect is a matter of concern. With this background, PWRI has developed a novel cool pavement technique called “mixture-type heat-shield pavement” in pursuit of further enhancing the effect of temperature reduction in a collaborative research project with five private-sector companies,3) and conducted accelerated loading tests for validating its applicability to actual roadways.

This paper outlines the Pavement Test Field at PWRI, as well as reports on the results of accelerated loading tests conducted in line with the development of a mixture-type heat-shield pavement.

ACCELERATED LOADING TESTS CONDUCTED ON THE PAVEMENT TEST FIELD AT PWRI

The Pavement Test Field at PWRI is designed for conducting accelerated loading tests by driving heavily loaded vehicles on test pavement which was constructed to test tracks with the same structure as on actual roadways. This facility was built in 1979, where two test tracks are available (a small circular track of 628 m in total length and a large irregular elliptical track of 870 m in total length) (Fig. 1). Since the time of its completion, unmanned operation of heavily loaded vehicles has been feasible by means of magnetic cables buried on both sides of the test tracks.

At this Pavement Test Field, numerous pavement tests have thus far been conducted for evaluating pavement durability in advance of applying newly developed pavement techniques to national highways. Major techniques include pavement using steel slag aggregates, modified asphalt mixture, and drainage pavement. In particular, drainage pavement, which was developed in the late 1980s, attracted considerable attention for application to actual roadways because of its effect of reducing road traffic noise, in addition to improving vehicular traffic safety by promptly draining rainwater away from the road surface. Because the percentage of air voids of drainage pavement is 15 to 20%, it seems those durability is not enough for national highways with huge traffic volume. Accordingly, its durability was validated by conducting accelerated loading tests at the Pavement Test Field, and then full-scale diffusion of drainage pavement on national highways under the direct jurisdiction of MLIT began in the 1990s (Fig. 2). At present, drainage pavement is increasingly applied to urban roadways and expressways to replace conventional dense-graded pavement, and its share on all expressway routes accounts for 60%.

The original automatic driving control system at the Pavement Test Field, which was installed more than 30 years earlier, was replaced with a new system in 2004. With the recent progress in ITS technology in Japan, the new system is equipped with an RTK-GPS, as well as various other sensors and devices, such as optical fiber gyro, wireless LAN, and direction scale, which are used for controlling vehicle positioning. With these sensors, unmanned automatic operation of heavily loaded vehicles is feasible at any time of the day or night regardless of weather conditions. Furthermore, four heavily loaded vehicles can be operated at the same time at a speed of 40 km/h. To simulate the actual travel condition, the travel distribution is controlled in the normal distribution (± 25cm from the center).

The most commonly used type of truck in Japan, diesel engine with one front axle and two rear axles, was modified for use as heavily loaded vehicles (Figs. 3 and 4). The gross weight can be adjusted from 107.8 to 392 kN, as well as the axle load from 31.85 to 156.8 kN, with load plates placed on the truck bed. Theoretically, the pavement durability during a decade on roadways where the traffic volume is heavier than that on general national highways in Japan (equivalent to traffic volume category N_6 in TABLE 1) can be evaluated in approximately 200 days by operating four heavily loaded vehicles with maximized axle load for ten hours per day. However, the vehicles are actually operated for one month each season (spring, summer, autumn, and winter) with an axle load of 117.6 kN to cover 400,000 wheel passes per annum. Recently, accelerated loading tests have been conducted for evaluating cool pavement, permeable pavement, and drainage pavement using recycled aggregates.

COOL PAVEMENT

Asphalt pavement is considered to be one of the contributing factors to the urban heat island effect because its surface temperature exceeds 60°C on summer days and because the heat stored within the asphalt pavement warms the air at night. In fact, the mean average air temperature in large cities in Japan showed 2 to 3°C increase in 20th century.4) This is considered to be attributable to the urban heat island effect, in addition to the impact of global warming; thus, various measures need to be taken to mitigate these phenomena.

With this background, the development of cool pavement that can decrease the road surface temperature is being promoted in Japan to counter the temperature rise. Cool pavement is a technique to reduce the amount of heat from sunlight and solar infrared radiation absorbed to the pavement materials, thereby reducing the amount of heat reradiated back to the atmosphere. Currently available cool pavement techniques can roughly be classified into two types: water-retention pavement and heat-shield pavement (Fig. 5).

With water-retention pavement, water is stored inside the pavement materials and the heat of evaporation is used for mitigating the temperature rise of the road surface. As for its pavement structure, the surface course is made of a porous asphalt mixture, the voids are filled with a water-retaining material. On the other hand, with heat-shield pavement, special paint that reflects near-infrared radiation (NIR) is used to prevent the pavement from retaining heat. Its structure is same as other general pavements except that the special paint is spreaded to the pavement surface. In comparison with general pavement techniques, these cool pavement techniques can reduce the road surface temperature by 10°C or more in midsummer. Regarding the effect of the difference in road surface temperatures on air temperature, simulation results5) have shown that the air temperature with cool pavements was 0.73°C lower at a height of 1.5 m and 2.13°C lower at a height of 0.5 m from the ground level compared to that with general pavements. Thus, these cool pavement techniques are already being applied to actual roadways on a trial basis as a promising means to mitigate the urban heat island effect (Fig. 6).6), 7)

Nevertheless, there are several problems to be solved. The beneficial effect of water-retention pavement will decrease when there is no rainfall, and to install a sprinkler will raise the cost. The effect of heat-shield pavement will decrease due to vehicular traffic causing abrasion or dirt on the thermal barrier coating materials. In addition, heat-shield pavement needs to apply thermal barrier coating materials by manual labor when paving roadways.

Thus, in collaboration with five private-sector companies, PWRI developed a mixture-type heat-shield pavement technique for further improving the performance of heat-shield pavement while incorporating the functionality of drainage pavement. The pavement structure of several types of the developed mixture-type heat-shield pavement technique is shown in Figure 7. The structure is characterized by the thermal barrier mixture layer comprising aggregates with each piece coated with thermal barrier paint, although with ordinary heat-shield pavements, the heat barrier pant are applied only to the pavement surface. In addition, the thermal barrier mixture layer can be paved mechanically with an asphalt paver or other machine. Thus, the mixture-type heat-shield pavement technique can reduce abrasion of the thermal barrier coating materials and eliminate the laborious manual application work.

To confirm the effect of reducing the road surface temperature, pavement specimens each measuring 4 m in length and 4 m in width were placed outdoors and their surface temperature was measured. The measurement results showed that the surface temperature of the specimens of all types of the mixture-type heat-shield pavement was lower by 10°C or more compared to that of the drainage pavement. This is equivalent to or better than the effect of surface temperature reduction of ordinary heat-shield pavements.

Subsequently, to confirm the primary performance of the mixture-type heat-shield pavement when applied to actual roadways, accelerated loading tests were conducted to determine the state of occurrence of cracking and rutting, as well as the on-site permeability.

RESULTS OF ACCELERATED LOADING TESTS

In the accelerated loading tests, the mixture-type heat-shield pavement was constructed to the test track on the Pavement Test Field with the same pavement structure as that constructed to actual roadways (Figs. 8, 9, and 10). The heavily loaded vehicles were driven over the test pavement to cover 400,000 wheel passes with a 49 kN wheel load to measure the rut depth, cracking ratio, and on-site permeability.

Figure 11 shows the rut depth. The results were favorable, because the occurrence of rutting was low in comparison with that of drainage and dense-graded pavements, even after 400,000 wheel passes. It has already been clarified that rutting is greatly affected by the road surface temperature.8) Therefore, it is considered that the resistance against plastic deformation was high because the road surface temperature was kept lower than that of drainage and dense-graded pavements.

Figure 12 shows the cracking ratio. The results were favorable for Types B and D. For Types A and C, however, cracks increased in line with the increase in the number of wheel passes of heavily loaded vehicles, and the cracking ratio exceeded 20%. The results of investigating the cause of crack occurrence revealed that the major cause of cracking for Type A was the fact that the wheel-rolling position coincided with the position of pavement joints. For Type C, It is assumed to be caused by low compaction of binder course. Cracking of these pavement types is therefore considered to be avoidable if the work is carefully executed, taking these causes into account. In case of thin lift, careful construction might be more essential in order to get an uniform layer.

Figure 13 shows the measurement results of on-site permeability of the sections that the wheels rolled over. The results were favorable, because a permeability of 1,000 ml/15 s or higher was retained, even after 400,000 wheel passes of heavily loaded vehicles.

CONCLUSION

In this study, accelerated loading tests were conducted on the Pavement Test Field to evaluate the durability of the mixture-type heat-shield pavement, which is a novel type of cool pavement developed jointly by PWRI and five private-sector companies. In the accelerated loading tests, four heavily loaded vehicles were driven automatically to cover 400,000 wheel passes with a 49 kN wheel load.

The test results are summarized below:

1) The results of measuring rutting were favorable for all types, because the occurrence of rutting was lower than that of drainage and dense-graded pavements, due to the effect of suppressing the road surface temperature.

2) Although cracking due to the passage of heavily loaded vehicles partially occurred on the specimens of Types A and C, such cracking is considered to be avoidable if the pavement work is executed carefully, taking this problem into account. In case of thin lift, careful construction might be more essential in order to get an uniform layer.

3) The On-site permeability remained favorable even after 400,000 wheel passes of the heavily loaded vehicles.

Thus, the results of accelerated loading tests proved that the mixture-type heat-shield pavement, when applied to actual roadways, has durability sustainable up to a traffic volume equivalent to categories N_4 and N_5 as defined in Table 1.

The remaining issues to be examined in future studies include elucidation of the effect of reducing the temperature of entire cities and enhancement of cost-effectiveness, which also apply to other cool pavement techniques.

ACKNOWLEDGMENT

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LIST OF FIGURES

TABLE 1 Design traffic volume and number of wheel passes causing fatigue failure

Roadway category by traffic volume	Design traffic volume for each roadway category (Vehicle passage per day and direction)$^{*1)}$	Number of wheel passes causing fatigue failure (Wheel passes per decade)$^{*2)}$
N_7	3,000 or over	35,000,000
N_6	1,000 to less than 3,000	7,000,000
N_5	250 to less than 1,000	1,000,000
N_4	100 to less than 250	150,000
N_3	40 to less than 100	30,000
N_2	15 to less than 40	7,000
N_1	Less than 15	1,500

Notes:*1) Traffic volume of ordinary large vehicles during the pavement design period

*2) Number of wheel passes with a 49 kN wheel load acting on the paved roadways during a decade

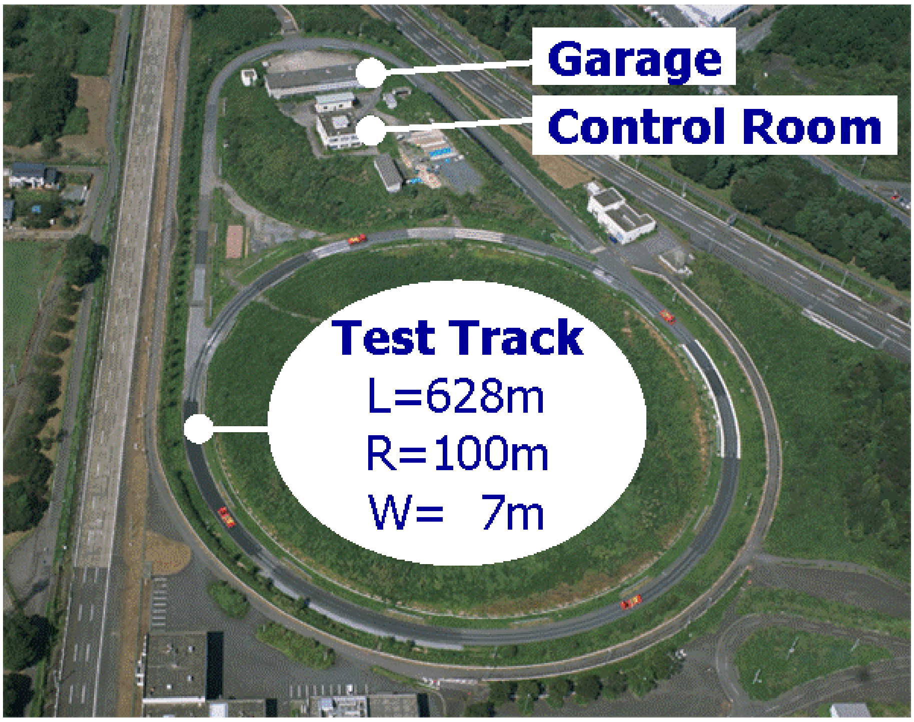


FIGURE 1 Aerial view of the Pavement Test Field at PWRI

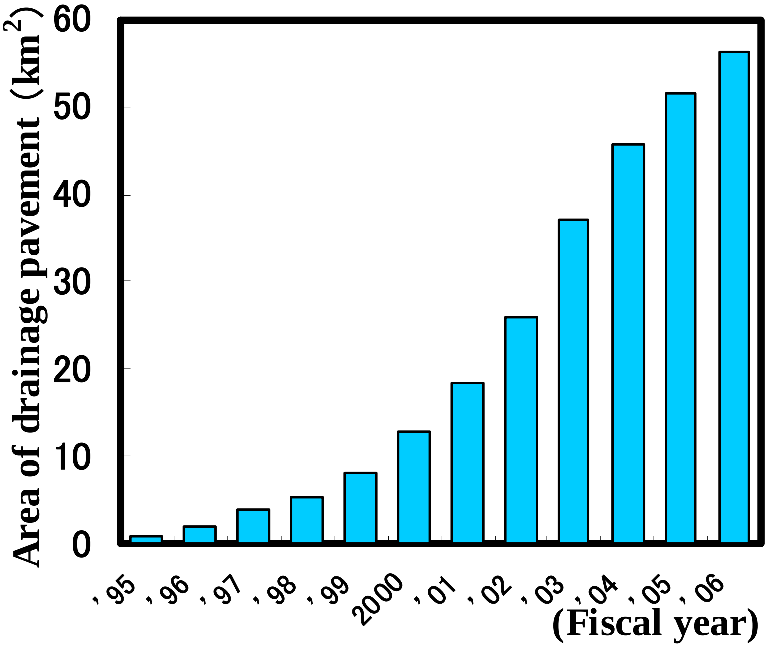


FIGURE 2 Increase of drainage pavement application to national highways under the direct jurisdiction of MLIT

FIGURE 3 Heavily loaded vehicles

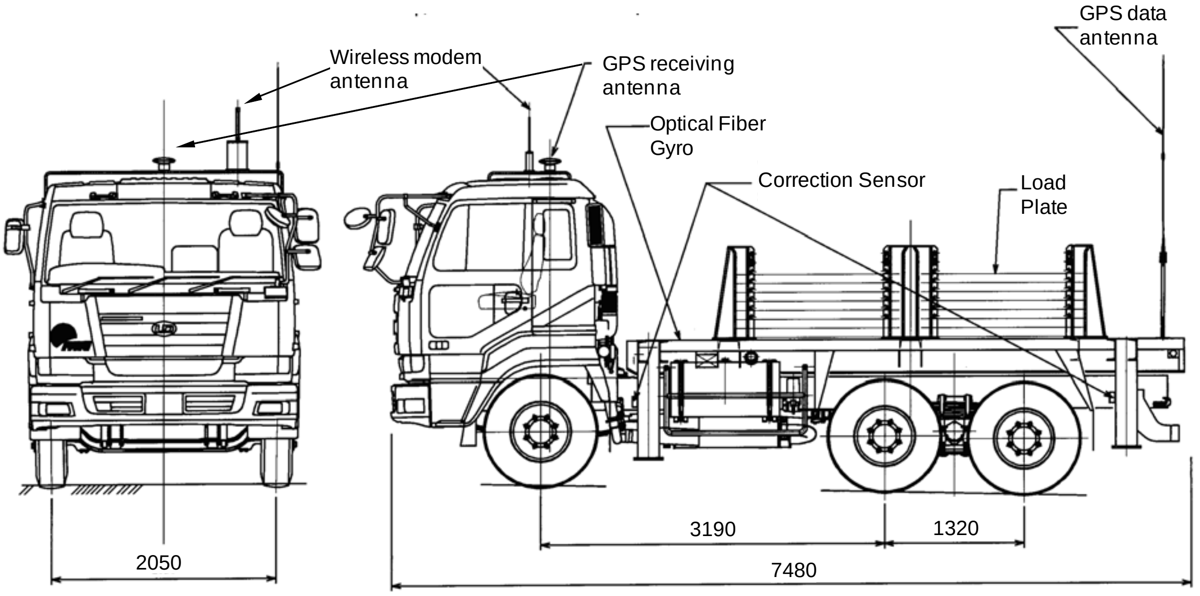


FIGURE 4 Schematic diagram of heavily loaded vehicle

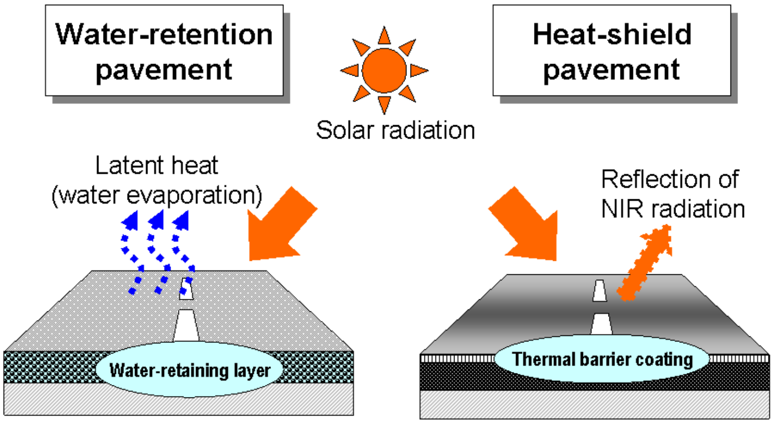


FIGURE 5 Conceptual drawing of water-retention and heat-shield pavements

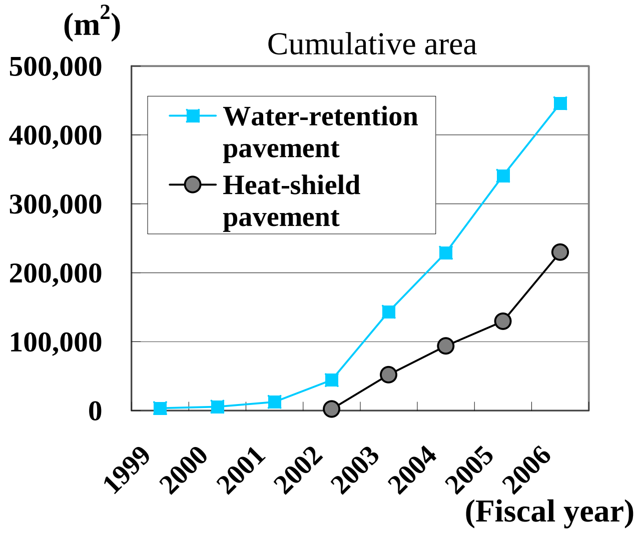
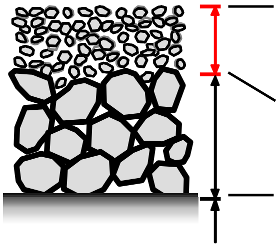


FIGURE 6 Total area of water-retention and heat-shield pavements applied to roadways[6), 7)]



Type		A	B	C	D
Thermal barrier mixture	Maximum particle size(mmtop)	2.5	5	5	13
	Layer thickness (mm)	5	20	10	50
Aspalt mixture for drainage pavement	Maximum particle size(mmtop)	13	13	13	-
	Layer thickness (mm)	50	30	40	-

FIGURE 7 Structure of mixture-type heat-shield pavement

FIGURE 8 View of applying test pavement

FIGURE 9 View of conducting rolling compaction

FIGURE 10 View of the completed test pavement

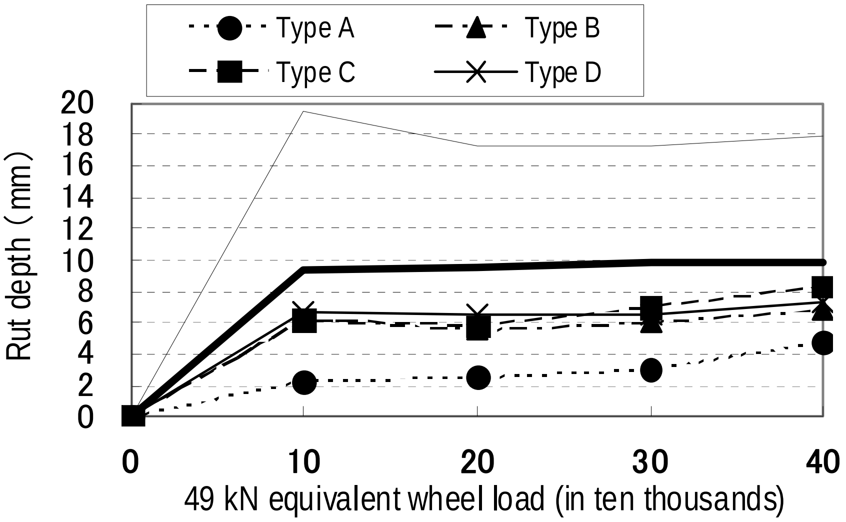


FIGURE 11 Rut depth

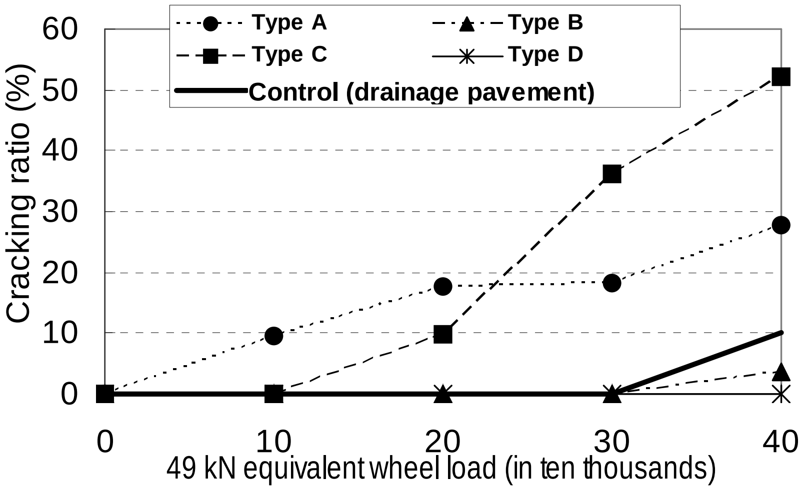


FIGURE 12 Cracking ratio

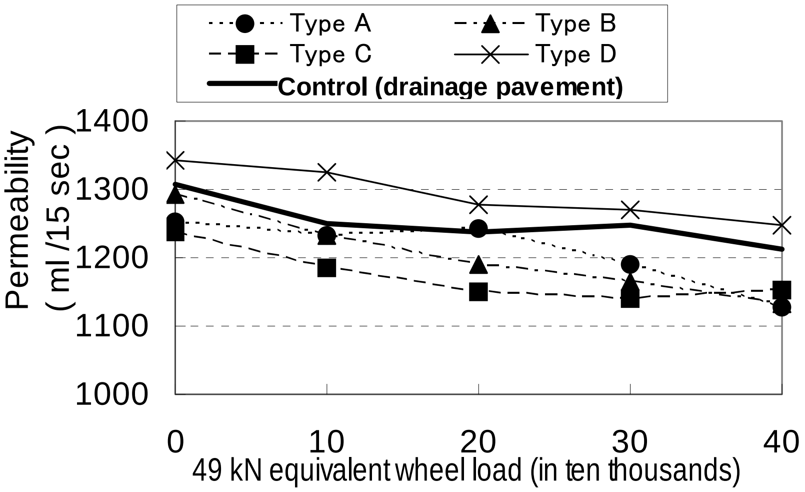


FIGURE 13 On-site permeability (OWP)