THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2009
4(4): 168–176

A DRAINAGE SYSTEM FOR MITIGATING MOISTURE DAMAGE TO BRIDGE DECK PAVEMENTS

Jongmin Kim[1], Hyun Jong Lee[2], Yong Rak Kim[3], Hyung Bae Kim[4]

[1, 2]Dept of Civil and Environmental Engineering,
Sejong University, 98 Kunja-dong, Kwangjin-gu, Seoul 143-747, South Korea
E-mails: [1]jongmin@sejong.ac.kr; [2]hlee@sejong.ac.kr
[3]Dept of Civil Engineering, W351 Nebraska Hall,
University of Nebraska-Lincoln, Lincoln, Nebraska 68588-0531, USA
E-mail: ykim3@unl.edu
[4]Highway & Transportation Technology Institute, Korea Highway Corporation,
50-5 San-Chuck-ri, Dong-tan, Hwa-Sung-shi, Kyungki-do 445-812, South Korea
E-mail: kimhyun3@freeway.co.kr

Abstract. This study presents the development of a new drainage system that can quickly drain water that has penetrated into bridge deck pavements. The new drainage system is expected to significantly reduce potholes that typically lead to premature failure of pavements. This system can be established by applying a thin drainage layer between the waterproofing layer and top wearing course. The most important factors for this system are to meet satisfactory performance of the waterproofing layer and to develop appropriate construction technique for the thin drainage layer. The drainage layer was formulated with porous asphalt mixtures designed for the max aggregate size of 10 mm, and was validated through various physical and mechanical laboratory tests to confirm its performance characteristics. For the waterproofing layer, methyl methacrylate (MMA) – type material was introduced, and a series of mechanical tests were performed to estimate the applicability of the MMA material for waterproofing. It was observed from the tests that the MMA material satisfied all specification requirements. In addition, to evaluate the field performance of the new drainage system, a field study was conducted on a real bridge. Field performance observations on both the waterproofing and pavement materials indicated that the new drainage system performs much better than traditional methods in draining water that has penetrated into pavement layers.

Keywords: bridge deck pavement, moisture damage, waterproof, drainage layer, methyl methacrylate (MMA).

1. Introduction

Bridge deck pavements play an important role in providing comfortable and safe riding quality to the public by maintaining smoothness and surface friction of the bridge deck and protecting the structure against moisture damage through the drainage system (Kamaitis 2006). In Korea, premature failure and significant damage to the bridge deck due to infiltrated water has been considerably reduced by adopting waterproofing layers in the pavement system since the early 1980s. However, problems still remain, because water that has penetrated into the pavement does not drain out quickly, but remains in the structure for a long time because of insufficient and inefficient drainage system that has been used so far. Consequently, structural integrity of the pavement has often been degraded due to segregation and strength loss of materials, which has sequentially resulted in frequent occurrences of potholes. The potholes are significant problems, since they are typically repeated even after repairs. An experience indicated that the bridge deck's deterioration can be prevented with appropriate paving methods to protect the water related damage on the bridge deck and its service life can be raised up to more than 15 years (Knight *et al.* 2004). Therefore, there is a pressing need to develop better bridge deck paving systems that can quickly drain water and mitigate potholes, so that one can save on maintenance–repair costs, while improving the performance life of the bridge deck pavement.

Currently, bridge deck pavements in Korea employ drain channels buried under asphaltic layers to drain water infiltrated into the pavement system. The use of drain channels under the asphaltic layers was not quite satisfactory as demonstrated in Fig. 1, which presents the number of maintenances performed on each long-span bridge in Seoul during the year 2003 (Lee *et al.* 2005). Fig. 1 indi-

ISSN 1822-427X print / ISSN 1822-4288 online DOI: 10.3846/1822-427X.2009.4.168-176
http://www.bjrbe.vgtu.lt

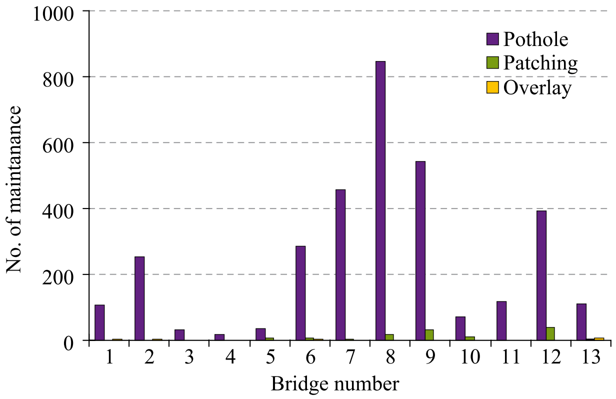

Fig. 1. Primary types of distress observed from bridge deck pavements in Seoul

cates that the potholes are the most frequent form of distress, which clearly infers that the currently used draining method for bridge deck pavements in Korea is somewhat inappropriate for mitigating moisture damage.

The current draining method uses a drain channel installed at the edge of the pavement, as illustrated in Fig. 2a. This might be problematic, because infiltrated water located around the center of the pavement, where it is more likely subjected to heavy traffic loads, will not be effectively transported and drained through the drain channel but will most probably stay in the pavement system, which will result in premature potholes and cracks due to significant moisture damage. To overcome the aforementioned problems observed from the current draining system, this study proposes the use of porous asphalt mixture to form a draining layer, as shown in Fig. 2b. The draining layer of porous asphalt mixture is placed between a waterproofing layer and a top wearing course so that the water that penetrates into the pavement structure can be quickly drained out without causing any significant impact on the bridge deck.

The bridge deck paving technique using the draining layer of porous mixtures was first developed in Denmark (Vibeke 2000) approx 30 years ago, and has been widely used because it is generally better-performing and more efficient than other methods. Typically, double-layer waterproofing sheets are placed on the bridge deck, and the porous mixtures with less than 8 mm max aggregate size are then compacted on top of the waterproofing sheets up to approx 2 cm thick. Finally, the upper and lower asphaltic layers (i.e. wearing course and protecting course, respectively), with 4 cm thick each, are compacted and placed on the draining layer to produce a total 10 cm thick bridge deck pavement structure.

However, the aforementioned Danish bridge deck paving technique needs to be modified to a certain extent for implementing it into bridges in Korea, since most of the bridge deck pavements in Korea have to be constructed with less than total 8 cm thickness, and the max size of aggregate for the porous asphalt mixture should be 10 mm due to limitations of aggregates available in Korea. Moreover, it may not be appropriate to use the same type of waterproofing material such as the waterproofing sheets for Korean bridge deck pavements, because bridge deck surfaces are not often smooth enough to apply the waterproofing sheets directly. The effects of interface condition between layers on the life of pavements are well known (Ziari, Khabiri 2007). Uneven bridge deck surfaces are primarily due to the significant progress of cement concrete deterioration. Although the uneven surface can be leveled with fast curing cement mortar, it takes long time until the cement mortar is completely cured. Sometimes, that is not practical where traffic volume is very heavy. It is therefore required to develop a new bridge deck pavement drainage system that is the most suitable for Korean bridges and is also sufficiently durable for long-term performance.

The most important factors for the new bridge deck pavement drainage system would be to ensure the performance of a new type of waterproofing materials applied, and to develop appropriate construction techniques for the thin drainage layer with less than 10 mm max aggregate size. Toward these objectives, this study developed a porous asphalt mixture with the max aggregate size of 10 mm, and various physical and mechanical laboratory

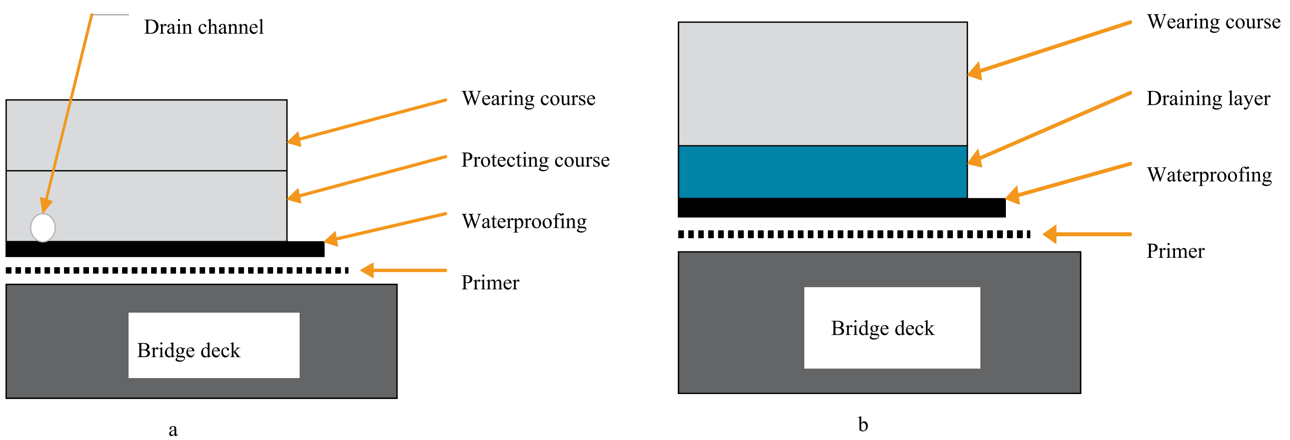

Fig. 2. Draining systems in bridge deck pavements: a – traditional system; b – new system proposed in this study

tests were performed to confirm performance characteristics of the porous asphalt mixture. For the new type of waterproofing layer, methyl methacrylate (MMA) – type material was introduced, and a series of mechanical tests were performed to judge the applicability of the MMA material for waterproofing. In addition, the MMA material was also evaluated as a potential repairing mortar that can possibly replace traditionally used fast-curing cement concrete mortar to fix old and deteriorated bridge deck surfaces. Various laboratory tests were performed, and the test data from the MMA mortar were compared to the test results from the traditional cement concrete mortar. Finally, to evaluate the field performance of the new drainage system proposed in this study, a field study has been conducted on a real bridge.

2. Development of the porous asphalt

2.1. Determination of mixture gradation

To determine allowable upper- and lower-gradation limits for the porous asphalt mixtures designed with the max aggregate size of 10 mm, several Marshall specimens designed with different trial gradations were fabricated, and air voids of each specimen were monitored. Fig. 3 presents a finally determined gradation band composed of the upper-gradation to meet 17–18% air voids and the lower-gradation targeting 20–21% void content. The lower-gradation was determined by simply shifting a gradation curve that has been typically used in Korea to produce porous asphalt mixtures with 13 mm max aggregate size.

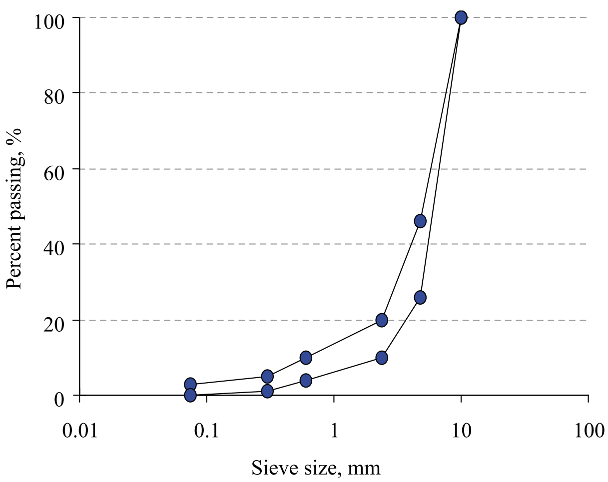

Fig. 3. Upper- and lower-gradation limits for porous asphalt mixtures with 10 mm max aggregate size pavements in Seoul

2.2. Determination of optimum level of compaction

Porous asphalt mixtures designed with the max aggregate size of 13 mm has been typically compacted by applying 50 Marshall blows, but this level of compaction may need to be modified for the mixture with 10 mm max aggregate size, since the smaller aggregates at the same level of compaction will be more likely crushed than the larger aggregates during the compaction process, and the crushed aggregates fill voids in the mixture, which is not desired. To determine the optimum level of compaction for the mixture with 10 mm aggregates, an experimental attempt was made, and test results are shown in Fig. 4.

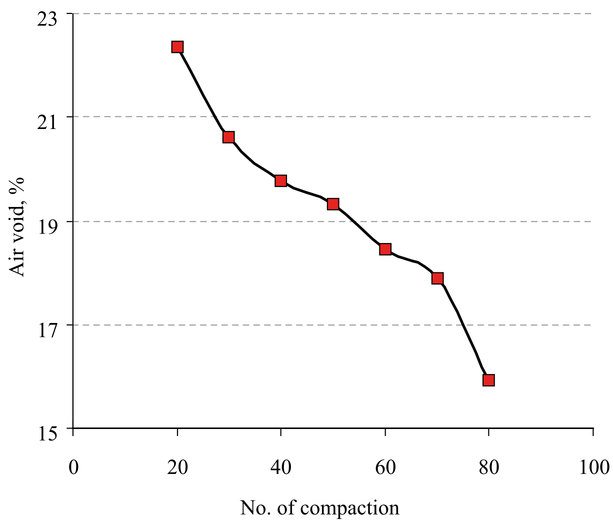

Fig. 4. Variation of air voids as the number of compaction blows increases

Fig. 4 presents a variation of air voids in Marshall specimens as the number of compaction blows increased (i.e. 20–80 blows) at the same asphalt content of 5%. Specimens demonstrated a somewhat rapid reduction of air voids at the early stage (up to 30 blows), but the rate of air voids reduction then decreased with 40–50 blows, which implies that additional compaction may not contribute to air voids reduction at a similar level as at the initial stage, once a certain level of density in the mix has been reached. It can also be noted from Fig. 4 that the second accelerated reduction in air voids after 60 blows was from the crushing of aggregates, rather than by pure densification due to aggregate reorientation. Based on test data and visual observations, 50-blow was determined as an appropriate level of compaction to accomplish the mixture design.

2.3. Determination of optimum asphalt content

Based on a well established *Open Graded Friction Course* (*OGFC*) *Mix Design Guide* (Watson *et al.* 2004), an optimum asphalt content was determined in this study by performing two tests: the Cantabro test and the draindown test (*AASHTO T305:2001. Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures*), with a variation of trial asphalt contents from 3 to 7%. As demonstrated in Fig. 5, a min of 3.6% and a max of 5.7% of asphalt can be obtained from specification requirements: max allowable Cantabro loss is 20% and draindown is 0.3%, respectively. Within the range of asphalt content allowable, 5.2% was finally determined as the optimum asphalt content because it is at 20% air voids.

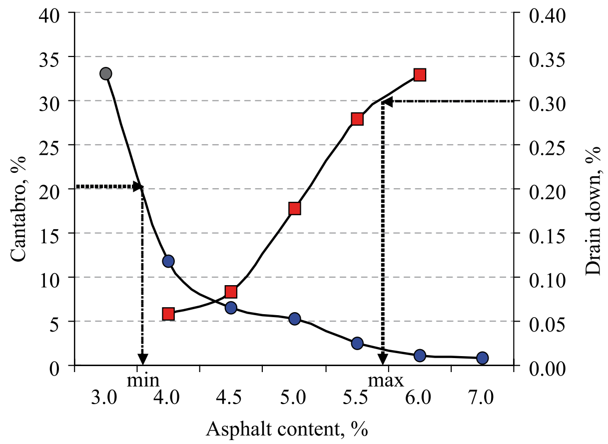

Fig. 5. Determination of max and min allowable asphalt content for the porous asphalt mixtures

2.4. Laboratory tests

In order to evaluate the physical and mechanical characteristics of the newly designed porous asphalt mixture, three laboratory tests, namely, permeability test, wheel-tracking test (*KS F2374:2000. Testing Method for Wheel Tracking of Bituminous Paving Mixtures*) and the *AASHTO T283:1999. Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage*, were carried out.

Permeability Test

To determine the hydraulic conductivity of the porous asphalt concrete, falling head tests were performed. Testing specimens were first fabricated Ø 150 mm and 100 mm in length using a superpave gyratory compactor. The specimens were then cored Ø 100 mm and used in the test. The test was conducted for 3 specimens and the results were averaged.

Wheel-Tracking Test

The wheel-tracking test measures rut depth and the number of passes of tire loads at high temperatures to evaluate the permanent deformation characteristics of mixtures. Test results are presented by a curve relating deformation with loading time (or loading cycles), and the rate of rut depth (i.e. rut depth per min) monitored during 15 min of testing (from 45 to 60 min during the test) is then recorded as an indicator to estimate dynamic stability of the mixture.

AASHTO T283 Test

Moisture-related damage is one of the most widespread and most severe forms of pavement distress along with fatigue cracking and permanent deformation. To perform the *AASHTO T283 test*, 2 subsets (3 specimens for each subset) – the 1st subset in dry condition and the 2nd subset subjected to moisture conditioning followed by one freeze-thaw cycle – were prepared and tested under indirect tension mode to obtain the tensile strength ratio (TSR), which is simply defined as a ratio of an averaged tensile strength value from the dry subset to the conditioned subset. Specification typically requires min 70% of TSR.

2.5. Laboratory tests results

Table 1 summarizes the laboratory test results. As can be seen in Table 1, all test results met specification requirements (Watson *et al.* 2004). Average dynamic stability was 3 342 cycles/mm, which was greater than the required value of 3 000 cycle/mm, and moisture damage resistance of the mixture represented by the TSR was also satisfactory. It can be inferred that the new porous asphalt mixture with the 10 mm max size of aggregates has been designed successfully.

Table 1. Laboratory test results from porous asphalt mixtures and corresponding requirements in specification

Properties	Specification	Test results
Air void, %	18 min	20
Dynamic stability, cycle/mm	3 000 min	3 442
Cantabro loss, %	20 max	3.15
Draindown, %	0.3 max	0.208
Permeability coefficient, cm/s	0.02 min	0.04
Moisture damage, TSR, %	80 min	80.3

3. MMA mortar and waterproofing

3.1. Characteristics of MMA and its composition

MMA is a reactive resin that is produced through a polymerization of acrylic and methacrylic acid ester. MMA resin is a very fast curing (typically less than one hour) material. Its fatigue performance and bonding strength to bridge deck are outperforming. Thus, it has long been used as a waterproofing material in Europe because of its excellent performance. However it has not been widely used in other regions including Korea because of its relative high cost compared to other types of waterproofing materials.

The curing time of MMA resin is controlled by curing compound. Typically 1% or 2% of benzoyl peroxide is added to control the curing time of MMA resin. For the waterproofing, a liquid type of MMA resin is applied 2 mm thick on top of the bridge deck, or MMA resin mixed with $CaCO_3$ and glass bid finer than 0.03 mm is applied 5 mm thick on the bridge deck. The latter is better if the unevenness of the bridge deck surface is severe and is the one used in this study.

MMA resin can also be used as a repairing material for the deteriorated concrete bridge deck since its mechanical characteristics are better than typical cement concretes. In Germany, MMA resin mortar has been used for repair work (Silikal 2000). Although the cost of MMA resin mortar is more expensive than conventional cement concretes, when the rehabilitation time is limited, MMA resin mortar can be a good option for the repair work due to its fast curing characteristics. In this study, 2 different types of MMA resins were used for waterproofing and for repairing, respectively as follows:

– MMA waterproofing: MMA resin (1.00 kg) + curing compound (0.02 kg) + filler (5.00 kg);
– MMA mortar: MMA resin (1.00 kg) + curing compound (0.02 kg) + filler (5.00 kg) + fine aggregate (6.00 kg).

3.2. Laboratory tests

MMA Mortar for Repairing

MMA mortar for repairing old bridge deck surfaces needs appropriate strength, durability, and bonding characteristics with existing cement concrete surfaces. In addition, the coefficient of thermal expansion of the mortar almost 7 times larger than that of cement concrete so that the mortar should be flexible enough. In an attempt to estimate these required physical-mechanical characteristics, several laboratory tests were performed: uniaxial tensile tests to estimate bonding characteristics between the MMA mortar and the existing cement concrete surface, uniaxial compressive tests to obtain elastic modulus and strength of the mortar, and tests to monitor the coefficient of thermal expansion of the MMA mortar.

For the uniaxial tensile testing, each cement concrete cylinder fabricated (100 mm tall and Ø 100 mm) was subjected to treatment with a primer after removing laitance on top of the cylinder specimen. MMA mortar was then added to the cement concrete specimen to produce a 150 mm long cylinder. A gluing jig and a uniaxial testing apparatus were developed to provide precise alignment of a cylindrical specimen with respect to the loading axis and to minimize eccentric stress concentration during tests. All tests were conducted using a servo-hydraulic closed-loop testing machine at 20 °C. Each specimen was glued to the end plates that were connected to the loading frame through a load cell. A detailed description of specimen fabrication and testing procedure can be found elsewhere (Park 2005).

Similar to the uniaxial tensile testing, uniaxial compressive tests of MMA mortar were also performed with cylinder specimens of 100 mm height and Ø 150 mm. Each specimen was cured for a day before testing. Test results are summarized in Table 2. Properties of fast-curing cement mortar are also presented in Table 2 for comparisons. The fast-curing cement mortar has been traditionally used to fix old and deteriorated bridge deck surfaces.

MMA Waterproofing Layer

As demonstrated in a later section "Field Study of the New Drainage System", MMA materials were also applied to the waterproofing layer that connects the MMA mortar placed on top of the cement concrete bridge deck surfaces and the draining layer composed of the porous asphalt mixture. To estimate the mechanical performance, in particular the bending characteristics and resistance to cracking, of the MMA waterproofing layer, 3 point bending beam tests at low temperatures (–10, 0, 10 °C) were conducted, and test data from MMA specimens were compared to the test results from Guss asphalt mixtures that have often been used for waterproofing of bridge deck pavements in Korea. Specimen dimensions were 300 mm long, 50 mm wide, and 10 mm thickness for the both mixtures. Although the 10 mm thickness is not representing the actual thickness, this test was performed for a comparison purpose.

Test results from two replicates of each case were averaged and are illustrated in Fig. 6. As shown in Fig. 6, flexural strength decreased, while failure strain increased when specimens were tested at higher temperatures. The MMA mixtures generally experienced higher values in

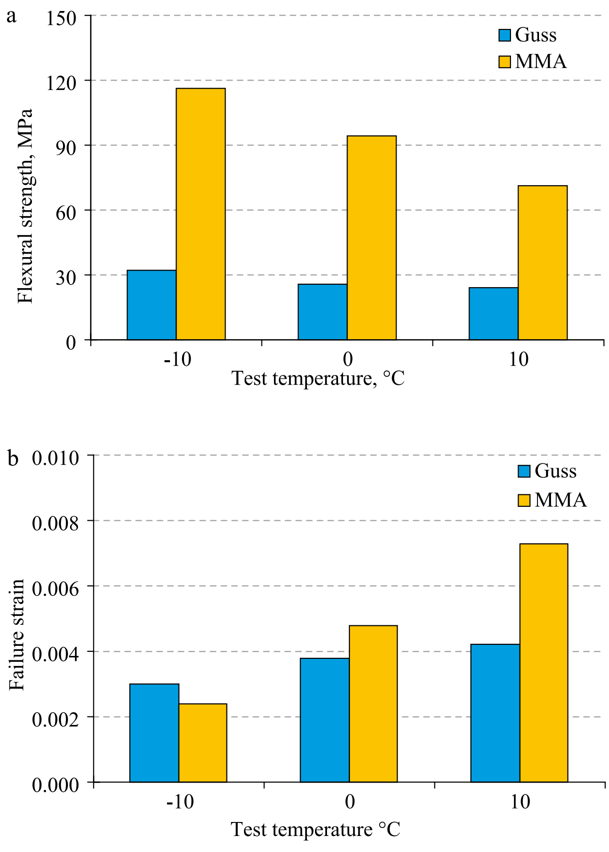

Fig. 6. Test results comparing MMA waterproofing materials with Guss asphalt mixtures: a – flexural strength at different test temperatures; b – failure strain at different test temperatures

Table 2. Mechanical testing results of MMA mortar

Properties	PCC pavement	Fast-curing cement mortar	MMA mortar
Tensile adhesion, MPa	1.0 max	1.0 max	3.4
Compressive strength, MPa	20–30	20–30	10
Elastic modulus, GPa	22–30	25–35	6
Thermal expansion coefficient, /°C	1.2×10^{-5}	$1–3 \times 10^{-5}$	7×10^{-5}

both flexural strength and failure strain than the Guss asphalt mixtures, which implies that the MMA materials perform better than Guss asphalt mixtures because of higher toughness and better resistance to low-temperature cracking.

In addition to the bending beam tests, uniaxial tensile tests were also performed to estimate the bond strength of the MMA waterproofing layer with the porous asphalt mixture drainage layer. In the laboratory, the MMA waterproofing layer was simulated by partial curing followed by placement of the MMA materials up to 4 mm thick into a Ø 100 mm Marshall testing mold. Before the MMA layer in the mold was completely cured, chipping aggregates, approx Ø 5 mm, were evenly spread on top of the MMA layer, and a tack-coating emulsifier was then applied to the chipping aggregates. The drainage layer was then simulated with 50 mm thick porous asphalt mixtures added into the mold and compacted with the Marshall compactor.

Uniaxial tensile tests were performed with at least two replicates at 2 temperatures: –20 and 20°C. The 1st trial yielded average tensile strength values of 0.98 MPa (at –20°C) and 0.45 MPa (at 20°C), which did not satisfy the specification requirements: 1.20 MPa and 0.60 MPa at –20°C and at 20°C, respectively. This problem was overcome by replacing the general tack-coating emulsifier with a polymer-modified emulsifier to increase material bonding. The use of the polymer-modified emulsifier improved bond strengths (1.23 MPa and 0.64 MPa at –20°C and at 20°C, respectively) that satisfied specification.

4. Field study of the new drainage system

4.1. Overview of the new drainage system implemented in the field

In an attempt to implement the new drainage system proposed in this paper into field construction and to estimate its performance characteristics and economic efficiency in the field, a trial construction was conducted on a bridge (90 m long and 11.2 m wide) in October 2006. The bridge is located around Dukyoo interchange in an express highway connecting Daejeon and Jinju, as illustrated in Fig. 7. The new drainage system was applied to the bridge deck toward the Daejeon direction, while the opposite direction to Jinju was constructed by a traditional bridge deck paving method.

The specific objectives of this field study are:

– to determine optimum level of compaction of the draining layer through in-field analysis;
– to investigate efficiency of the newly designed draining layer to drain water;
– to determine locations for installation of drain channels and drip pipes;
– to estimate in-field applicability of MMA materials for repairing and waterproofing.

The bridge selected for this field study started its service in 2001, and it now requires complete repairs due to significant cracking and potholes that have occurred during the last 5 years. Prior to the trial construction, in-field cores were first taken to investigate the severity of deterioration of cement concrete decks. From the analysis of cores, it was found that severe deterioration of cement concrete decks after 5 years of service was mainly due to the use of waterproofing materials that allowed penetration of water when the bridge deck pavement was initially constructed. The field trial bridge is located in a heavy snow area. Use of calcium chloride to melt snow in the winter season may accelerate the deterioration of the bridge deck. Therefore, it was planned to use the MMA material to repair all deteriorated cement concrete decks after the deteriorated regions were completely removed. Fig. 8 illustrates a section view and a plan view of the bridge deck pavement with the new drainage system implemented. Fig. 8 also presents how the drain channel and the drip pipe were installed in the system.

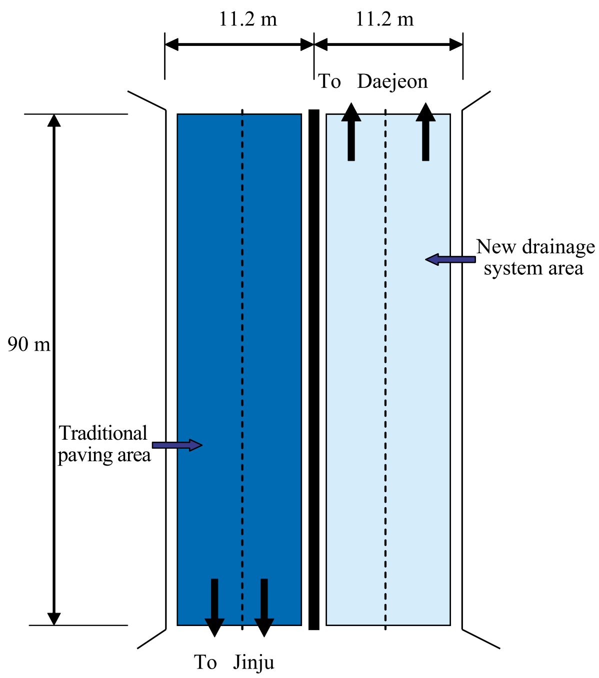

Fig. 7. Layouts of the in-field trial construction

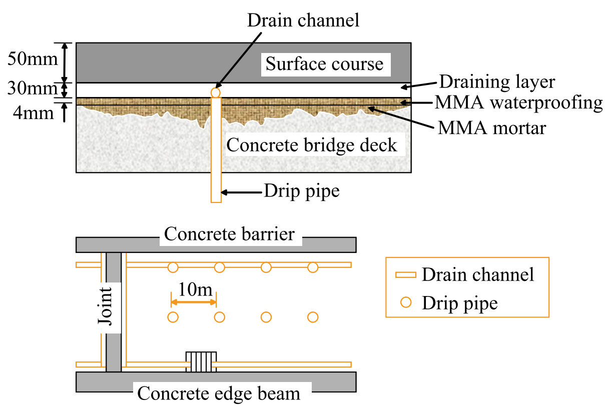

Fig. 8. Section view and plan view of bridge deck pavements with the new drainage system installed

As shown in Fig. 8, MMA mortar repairs deteriorated cement concrete decks, and 4 mm thick MMA waterproofing materials were placed on top of the MMA mortar. Top surfaces of the MMA waterproofing layer were then treated with chipping aggregates followed by polymer-modified emulsifiers for tack-coating. Then, 30 mm thick porous asphalt mixtures were placed to act as the draining layer. Finally, dense-graded asphalt mixtures were compacted to produce the 50 mm thick wearing (surface) course. In order to accelerate draining of water that had penetrated into pavement layers, plastic drain channels of Ø 15 mm and drip pipes of Ø 10 mm were also installed within the draining layer.

Fig. 8 also demonstrates that the drain channel with the of Ø 15 mm was installed along the boundary between the concrete structure and the pavement. As noted, this study used the plastic drain channel to drain water instead of using a 25 mm thick, 150 mm wide waterproofing epoxy concrete drain which has been typically used for bridge deck drainage systems in Denmark (Vibeke 2000). The plastic drain channel was not installed at joints intentionally, even if the joints were susceptible to water infiltration and corresponding moisture damage. This is because the joints are likely weak zones against traffic loads, and the severity of joint damage will be greater due to incomplete bonding of the plastic drain channel buried under joints with surrounding pavement materials.

In addition to the use of drain channel, drip pipes Ø 10 mm were also installed at every 10 m interval to improve draining efficiency, which simply followed the methodology presented in Denmark guidelines (Vibeke 2000). Epoxy glue was used to fill gaps between drip pipes and draining holes.

4.2. Performance evaluation of the new drainage system implemented in the field

Performance evaluation of the new drainage system was conducted in two stages: during and after construction. 1st, as shown in Fig. 9a, in-field permeability of the new drainage system was investigated by directly pouring water on the draining layer when the surface temperature of the porous asphalt mixtures was 60 °C after lay down and compaction of the mixture. Fig. 9b demonstrates that water infiltrated into the pavement is drained through the drain channel installed at the edge of the bridge deck.

2nd, on-site performance investigation was conducted twice: after 3 months (i.e. January 2007) and 20 months (i.e. June 2008) of public service. Fig. 10a shows pictures taken after 3 days of snowfall in January 2007. As shown in Fig. 10a, pavement surfaces were completely dry, while water in the pavement was still drained through the drain channel. Fig. 10b shows field conditions after 4 days of rainfall in June 2008. An intensive investigation of all draining pipes in the bridge was performed, and it was observed that infiltrated water was primarily drained to pipes located at the lowest level. Based on these observations, it can be inferred that the new drainage system developed in this study works quite well to drain water that has penetrated into the bridge deck pavement layers.

As mentioned earlier, the traditional bridge deck paving method was also applied to the same bridge for comparisons with the new drainage system. For the traditional method, fast-curing cement mortar was used to repair deteriorated cement concrete decks, and waterproofing was accomplished by using asphaltic waterproofing materials (i.e. Guss asphalt mixtures). On top of the waterproofing layer, dense-graded asphaltic mixtures were then compacted with 2 layers of 4 cm thickness each. As presented in Fig. 10c, various types of damage were observed from areas constructed by the traditional method after 6 months of public service. The most frequently observed forms of damage were localized failure in circular- or oval-shaped upheaval, efflorescence, and cracks. Even if it is not conclusive, one can expect that the premature degradation and failure resulting from the traditional method might be due to some swelling of pavement layers where rapid generation of hydration heat and vapor occurred, because the hot mix asphalt waterproofing materials were usually placed before the cement mortar was completely cured. Furthermore, it can be inferred that infiltrated water in the pavement system accelerated the damage process. A more accurate investigation to explain damage mechanisms of the traditional bridge deck paving method is necessary and currently under study by the authors.

a

b

Fig. 9. Investigation of in-field permeability of the porous asphalt mixtures:
a – spraying water on the draining layer; b – drainage of infiltrated water through the drain channel

Fig. 10. Investigation of in-field water draining:
a – after 3 months (January 2007) with the new drainage system;
b – after 20 months (June 2008) with the new drainage system;
c – after 20 months (June 2008) with the traditional bridge deck paving system

The field study clearly demonstrated that the bridge deck pavement system constructed by the traditional method was subjected to significant distresses, while the new drainage system performed very well without causing any significant moisture-related damage. Therefore, one can expect better-performing and longer-lasting pavements with the new drainage system based on its superior characteristics in repairing old bridge deck surfaces and draining water that penetrates into the pavement layers.

5. Conclusions

A new drainage system to quickly drain water that penetrates into pavement layers and consequently mitigate potholes, which is one of the primary distresses in bridge deck pavements, was developed in this study. Some of the important findings from this study can be summarized as follows.

The porous asphalt mixture design with the maximum aggregate size of 10 mm was developed, and various physical and mechanical laboratory tests confirmed that the porous asphalt mixture satisfied all the specification requirements to form a thin drainage layer within the bridge deck pavement structure.

In order to overcome limitations observed from traditional waterproofing materials such as waterproofing sheets, MMA type waterproofing materials were employed in this study, and it was found that the MMA could be a good option for the repairing and waterproofing of deteriorated bridge decks. Furthermore, a series of laboratory tests including low-temperature bending and bond strength tests demonstrated that the MMA material satisfies the required mechanical properties.

A field study has been conducted to evaluate field performance of the new drainage system. The new drainage system was implemented to a real bridge. It has been found that the drainage system works quite well to drain the water that penetrates into pavement layers.

Based on field performance evaluation for 20 months after construction, it can be concluded that the traditional bridge deck paving method generally caused significant distresses, while the new drainage system performed very well due to better draining. One can expect more durable, long-lasting bridge deck pavements with the new drainage system than with the traditional paving method.

Since the 20 months of performance period is too short to completely evaluate the new bridge deck pavement system suggested in this paper, a continuous monitoring of the field test site is needed and additional field studies should be performed.

Acknowledgments

The study was conducted under the support of the research program for "Long-lasting and Environmental Friendly Pavement Technologies" funded by Korea Institute of Construction and Transportation Technology Evaluation and Planning.

References

Kamaitis, Z. 2006. Deterioration of Bridge Deck Roadway Members. Part I: Site Investigations, T*he Baltic Journal of Road and Bridge Engineering* 1(4): 177–184.

Kandhal, P. S.; Mallick, R. B. 1999. *Design of New Generation Open-Graded Friction Courses*. Research Report No. 99-3. National Center for Asphalt Technology (NCAT). Auburn. Alabama. 64 p.

Knight, M. L.; Wilson, G. S.; Seger, W. J.; Mahadevan, S. 2004. Overlay Types Used as Preventive Maintenance on Tennessee Bridge Decks, *Transportation Research Record* 1866: 79–84. DOI: 10.3141/1866-10

Lee, S. K.; Lee, H. J.; Park, S. W.; Seo, Y. C. 2005. *Strategic Research to Improve Road Pavement Quality in Seoul Metropolitan*. Research Report. Seoul Metropolitan Government. Korea.

Park, H. Y. 2005. *Development of A Drainage Method to Prevent Bridge Deck Pavement From Moisture Damage*. Master's Thesis. Sejong University. Seoul. Korea.

Silikal. 2000. *Reactive Resin and Polymer Concrete for Industrial Flooring and Civil Engineering*. Technical Documentation. Silikal. Germany. 112 p.

Vibeke, W. 2000. *Surfacing of Concrete Bridge*. Research Report No. 106. Danish Road Institute. Denmark.

Watson, D. E.; Cooley, Jr, L. A.; Moore, K. A.; Williams, K. 2004. Laboratory Performance Testing of Open-Graded Friction Course Mixtures, *Transportation Research Record* 1891: 40–47. DOI: 10.3141/1891-06

Zairi, H.; Khabiri, M. M. 2007. Interface Condition Influence on Prediction of Flexible Pavement Life, *Journal of Civil Engineering and Management* 13(1): 71–76.

Received 9 October 2008; accepted 11 November 2009