FAA Design Competition for Universities 2007 – 2008 Academic Year

Long-Lasting Pavement Structure Rehabilitation:

Hot-Mix Asphalt Overlay with

Steel Reinforcement Netting Interlayer System

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Executive Summary

1. Title: Long-Lasting Pavement Structure Rehabilitation: Hot-Mix Asphalt Overlay with Steel Reinforcement Netting Interlayer System

2. Summary: When existing airfield pavements experience severe deterioration or need to support more and heavier aircrafts, hot-mix asphalt (HMA) overlay is a commonly used. Due to the structural features, reflective cracking as a critical distress occurs early in the service life and accelerates to damage the overlay. This project proposes a long-lasting HMA overlay which is a performance- and cost-effective method to control reflective cracking. An interlayer system made of steel reinforcement netting installed at the bottom of HMA overlays provides a strong resistance against reflective cracking. To demonstrate the performance of the steel reinforcement interlayer system in airfield pavement, numerical analysis was performed using a three-dimensional finite element method. For a minimal thickness of HMA overlay (76mm) placed on jointed plain concrete pavement, transverse and longitudinal reflective cracking was developed by a moving Boeing 747 aircraft loading. The steel reinforcement interlayer reduced the fractured area by a factor of 2.2 compared to an unreinforced overlay. In addition, a life-cycle cost analysis was conducted to investigate the cost-effectiveness of the HMA overlay. Based on relative cost benefit, the steel reinforcement interlayer achieved a positive (up to 30%) or equivalent cost-effectiveness. Therefore, the proposed steel reinforcement netting interlayer system in HMA overlay meets the design goal of Federal Aviation Administration.

3. Participants: Jongeun Baek and Hao Wang, graduate students, conducted this design project with Prof. Imad L. Al-Qadi at University of Illinois at Urbana-Champaign.

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1. Problem Statement and Background

1.1 Reflective cracking control in hot-mix asphalt (HMA) overlay

When airfield pavements reach their design service life or develop particularly severe distresses, rehabilitations are required accordingly. Several rehabilitation techniques can be utilized to restore structural and functional capacity of the pavements and/or to repair a part of or whole pavements. Hot-mix asphalt (HMA) overlay is a commonly used rehabilitation technique for deteriorated pavements. A HMA layer placed over existing HMA or PCC pavements extends the service life efficiently and also provides a good rideability. However, HMA overlays have a critical structural weakness in that transverse and longitudinal cracks occur at an early age along joints/patches/cracks in an underlying layer, called reflective cracking. Reflective cracking is inevitable especially when HMA overlays are constructed on jointed PCC pavements. Concentrated tresses, induced by environmental and traffic loading, are intensified at a vicinity of a joint, patch, and/or a crack of the PCC pavements. Moreover, further severe deteriorations may occur when water infiltrates into subsequent layers through reflective cracking. Supplementary methods are recommended in the HMA overlay design guide for airport pavements to control reflective cracking, but those solutions only diminish the occurrence of reflective cracking for a couple of years. As a result, frequent rehabilitation and/or maintenance needs to be performed in an overlay service life. Therefore, a long-lasting HMA overlay to restrict reflective cracking for longer periods needs to be developed.

According to the airport pavement management system (FAA 2006), affordable and timely actions for maintenance and rehabilitation should be provided to deteriorated airfield pavements. Previously, alternatives were selected based on two approaches: an "ad hoc" approach based on past field experiences of experts; and an "existing condition" approach based on condition indicators to predict future conditions. Neither of these approaches considered cost-effectiveness. However, the use of a cost-effective method is a key feature in the new decision making process for an airport pavement management system (APMS). For that reason, the long-lasting HMA overlay should also save total maintenance costs for the airport pavement during its service life.

1.2 Interlayer system to control reflective cracking

Interlayer systems have been successfully utilized to retard reflective cracking. An additional thin layer, called interlayer, is laid down at an interface between the overlay and an existing pavement or within the HMA overlay. Various materials are used for interlayer systems depending on their mechanisms to control reflective cracking.

According to Al-Qadi et al. (2000), interlay systems have five distinct functions as reinforcement, stress relief, separator, filter, and moisture barrier. Among these functions, reinforcement and stress relief are the main functions related to preventing reflective cracking. As for reinforcing a HMA overlay, interlayer systems consist of stiffer materials than the surrounding HMA overlay and compensate for a lack of tensile strength. Woven geosynthetics such as geogrid and metallic grid are typically used as reinforcement. On the other hand, stress relief interlayers made of soft materials are used to dissipate strain energy by deforming themselves. Stress absorbing membrane interlayer (SAMI) and interlayer stress absorption composite (ISAC) are good examples of stress relief interlayers.

Kuo et al. (1993) reported that glass fiber reinforcement placed at the bottom of asphalt overlay increased bending strength by 42% and the fatigue life of the overlay by 80% (referred by Kuo et al. 2003). Thom (2000) concluded that the inclusion of geogrid improved the service life of HMA overlay by a factor of 2.5 and 4.0. Kuo and Hsu (2003) evaluated the effectiveness of geogrid on retarding reflective cracking and concluded that when geogrid is located at one third of the overlay thickness, the performance was the best. Jun et al. (2004) found maximum shear stresses due to traffic loading at the bottom of overlay decreased as the modulus of the geogrid increased when the geogrid was strong enough to withhold the stress, not to be broken. Based on their numerical analysis, the strength of geogrid reduces the thickness of the overlay. For example, 50mm of overlay with 6000 – 8000MPa of geogrid was equivalent to 100mm of overlay with 2000 – 4000MPa of the geogrid.

Montestruque et al. (2004) pointed out that dynamic bending and shear fatigue tests were performed for asphalt beam reinforced with geogrid. They observed that reflective cracking was vertically developed but stopped at 20 – 30mm for the reinforced beam while 75mm of reflective cracking occurred at unreinforced beam. In their tests, the factor of effectiveness of geogrid ranged from 4.6 to 6.1, depending on the opening size of a pre-crack. However, some of the past applications of interlayer systems showed little or even no success on retarding reflective cracking due to the lack of understanding of the interlayer systems and inappropriate installation of interlayer (Peredoehl 1989).

1.3 Steel reinforcement netting interlayer system

A new class of steel reinforcement netting interlayer coated against rusting has been successfully reutilized to retard reflective cracking (BRRC 1998, Vanelstraete and

Francken 1993, 2000, Al-Qadi 2003). Figure 1 shows the configurations of steel netting with a double twisted and single hexagonal opening of steel wires and a reinforcing bar (Elseifi 2003).

Vanelstraete and Francken (1993) showed, from the results of two-dimensional (2D) finite element (FE) analysis, that metallic grid interlayer reduced tensile strain at the bottom of the overlay induced by thermal loading and then delayed crack initiation time. A report by the Belgian Road Research Centre (1998) concluded that steel mesh led to decrease deflection at the vicinity of a crack tip induced by shear strain performance. The relative gain factor for thermal loading was 3.2 – 5.0 for glass fiber and 6.4 – 8.8 for steel netting while, for traffic loading, the steel netting was more efficient than glass-fiber due to higher stiffness of steel.

The first successful application of steel reinforcement in HMA overlay in the U.S.A. was conducted at the Virginia Smart Road by Al-Qadi et al. (2003). He and his collogues consequently examined the benefit of the steel reinforcement by field observations and FE analyses (Al-Qadi et al. 2003, Al-Qadi and Elseifi 2004, Elseifi and Al-Qadi 2005a, 2005b). They reported that steel reinforcement netting increased the service life of overlays between 50% and 90%. Also, steel reinforcement netting reduced maximum transverse strain at the bottom of an HMA overlay of 100mm thick by 15% due to vehicular loading and by 20% due to one cycle of daily temperature variation of 22^{o}C to 51^{o}C. Baek and Al-Qadi (2006a, 2006b) evaluated the role of single steel reinforcement wire in a two-layered beam specimen on delaying crack development by numerical analysis. Crack initiation time was delayed and growth rate decreased since the steel reinforcement held and redistributed concentrated stress around a crack tip. They mentioned that the role of the steel reinforcement was affected by interface conditions, HMA material properties, and temperature. Recently, using 3D FE analysis, Baek and Al-Qadi (2008) also investigated steel reinforcement netting interlayer on retarding reflective cracking in HMA overlaid pavements on existing PCC pavements. The steel reinforcement netting interlayer significantly reduces the reflective cracking induced by traffic loading: 41% of the representative fractured area was reduced in the overall HMA overlay, and no further reflective cracking was propagated in the wearing surface.

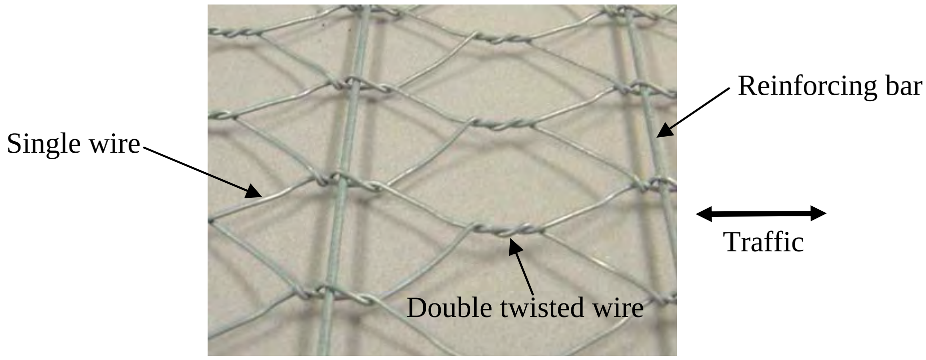


Figure 1. Configuration of steel reinforcement netting made of double twisted and single wires and a reinforcing bar (Elseifi 2003).

2. Summary of Literature Review

2.1 Reflective control in airfield HMA overlays

According to an airfield HMA overlay design procedure (FAA, 1995), two methods are recommended to retard reflective cracking: coarse aggregate binders and engineering fabrics. When larger aggregates are used in leveling binder course, it is affordable to control reflective cracking. The second method is to use nonwoven fabric interlayer systems under specific conditions. The required specific conditions includes 1) Fabric has minimum tensile strength of 41kg obtained from ASTM D 1682; density from 70 to 130g/m^2; 2) Horizontal or vertical movement of existing pavements does not exceed 1.3mm or 0.5mm, respectively; 3) HMA overlay is thicker than 75mm or thinner than 178mm; and 4) Tack coat is applied at an amount of 0.7 to 1.4 L/m^2 before fabric is installed.

Other significant efforts have been made to develop a technique to control reflective cracking in airfield pavements. Von Quintus et al. (2007) summarized anti-reflective cracking systems utilized in highways and airfields. Of the case studies, reflective control systems used in airfields are as follows:

Eaton and Godfrey (1980) monitored reflective cracking on a runway at Thule air base in Greenland. Due to mainly thermal contraction, 71% and 105% of reflective cracking occurred in the first and second year for thin overlay less than 2 inches; 46% and 57% of reflective cracking were shown for thick overlay greater than 3 inches. Therefore, they concluded that thicker overlay is better to retard thermal reflective cracking.

The Corp of Engineering (USACE 1992) categorized three climate zones to guide the use of fabric interlayer in conjunction with HMA overlay thickness. In the zone 1 (southern states with air freezing index < 0), fabric interlayers showed proper performance when a minimum 2in-thick or 4in-thick HMA overlay is placed on existing HMA or PCC pavements, respectively. In the zone 2 (central states with 0 < air freezing index < 500), fabric interlayer worked properly when the same or a thicker HMA overlay than those of the zone 1 is used. In the zone 3 (northern states with air freezing index > 500), fabric interlayers were not recommended to retard reflective cracking. In addition, preparation of existing pavement such as crack sealing and leveling binder is recommended.

Little (1991) performed several laboratory tests to examine the performance of polyethylene-modified rich asphalt mixture used at William Hobby Airport in Houston, Texas. He concluded that the PMA mixture was less sensitive to permanent deformation and has greater crack resistance compared to conventional asphalt mixtures.

Ellis et al. (2002) conducted an in-service performance evaluation at UK military airfields for different anti-reflective cracking methods of crack and seat, geogrid, stress absorbing membrane interlayer (SAMI), friction course, and modified asphalt. Some of the methods were not successful in retarding reflective cracking for several years while they were efficient for a couple of years. Among the methods, crack and seat showed successful performance in existing jointed plain concrete pavement (JPCP).

2.2 Finite element modeling for reflective cracking

Finite element methods have been widely used in the modeling of pavement and reflective cracking propagation by many researchers. Jenq et al. (1993) proposed a cohesive crack model using nonlinear springs and dashpots. They constructed a 2D HMA overlaid pavement model for reflective cracking due to temperature drops. Sensitivity analysis was performed for overlay thickness, service temperature, fiber reinforcement, and tensile strength of the overlay. They concluded that reflective cracking is more delayed when thicker overlay with higher tensile strength is placed at lower temperature.

Kim and Buttlar (2002) conducted 3D FE modeling for an airfield taxiway E at Great Peoria Regional Airport (GPRA) in Illinois to evaluate the influence of environmental and traffic loading on developing reflective cracking. One cycle of cooling temperature from 0^{o}C to -20^{o}C and moving aircraft loading (DC-8, Boeing 727, and BAE 146) was applied on hot-mix asphalt overlay on PCC pavement. They reported that the aircraft loading is dominant on the development of reflective cracking rather than the thermal loading. In addition, base-isolated interlayer showed a significant contribution to reducing critical responses for reflective cracking; glass-grid interlayer provided a minimal reduction.

Bozkurt and Buttlar (2002) constructed HMA overlay with interlayer stress absorbing interlayer composite (ISAC) at Rantoul regional airport. The ISAC is a strip type interlayer which is placed covered only in a small region about 3ft wide along a joint. In addition, numerical analysis was executed to examine the performance of the ISAC on retarding reflective cracking.

Elseifi and Al-Qadi (2005) analyzed a geocomposite interlayer system placed underneath HMA overlay. The path-independent J integral was computed to determine dissipated energy at a vicinity of a sharp crack presented in underlying HMA pavement.

The geocomposite interlayer absorbed more energy around the crack for modes I and II, which can be used to develop reflective cracking, and consequently reduce reflective cracking potential.

Kim and Buttlar (2007) showed fracture behavior of reflective cracking in airport pavement by using 2D FE modeling. The path-independent J integral was computed in HMA overlay placed on multiple PCC slabs. By locating aircraft gears on various places, the most critical location was determined by means of the J integral.

Dave et al. (2007) conducted 2D FE analysis accompanied with cohesive zone model. A single event of temperature drop and traffic loading was applied to induce reflective cracking. Based on opening displacement thresholds along the reflective cracking path, reflective cracking status is classified into two regions of cracking and softening. When a highly modified sand asphalt interlayer is placed between HMA overlay and existing composite pavement, no cracking region occurred.

Baek and Al-Qadi (2008) proposed representative fractured area (RFA) to quantify fractured area by reflective cracking in HMA overlay pavement through 3D FE analysis. One cycle of moving vehicular loading was applied to develop reflective cracking right over a transverse joint of existing concrete pavement. The fracture behavior of reflective cracking and performance is evaluated by means of the RFA when sand mix and steel reinforcement netting interlayer are installed. For sand mix interlayer, reflective cracking jumps to wearing surface at the beginning and expands into leveling binder layer. On the other hand, steel reinforcement netting reduces a significant amount of reflective cracking in the leveling binder as well as the wearing surface.

3. Problem Solving Approach to the Design Challenge

In order to solve the problem of reflective cracking in airfield pavements, this project proposes a steel reinforcement netting interlayer system to control reflective cracking. The overall design procedure to implement the steel reinforcement netting into HMA overlay is depicted in Figure 2. According to the Federal Aviation Administration (FAA) overlay design guide (FAA, 1995), HMA overlays are designed to carry out repetitions of aircraft loadings over a period of time. In this procedure, no special consideration is given to control reflective cracking. In this design project, an engineering-value evaluation is performed to examine the possibility of a steel reinforcement netting interlayer system by means of performance and cost.

First, a three-dimensional (3D) finite element (FE) analysis was conducted to examine fracture behavior of reflective cracking. The effectiveness of HMA overlay with steel reinforcement netting interlayer was evaluated in terms of fractured area compared to conventional HMA overlay without any interlayer system. If reflective cracking is delayed in the HMA overlay with the interlayer system, cost analysis is performed; otherwise, different interlayer systems are reconsidered.

Second, a life cycle cost analysis (LCCA) was conducted to evaluate the cost benefit of the steel reinforcement interlayer system in terms of total cost spent in a design service life. If the overlay is proven to be cost effective, then safety issues required for airport regulations are inspected. Though an additional construction procedure is needed to install the steel reinforcement netting interlayer system in the HMA overlay, it is still in accordance with the FAA safety regulations. Through this interdisciplinary process, the steel reinforcement netting interlayer systems may be selected as a part of a proper alternative HMA overlay system, which is a cost-effective and long-lasting HMA overlay system strategy.

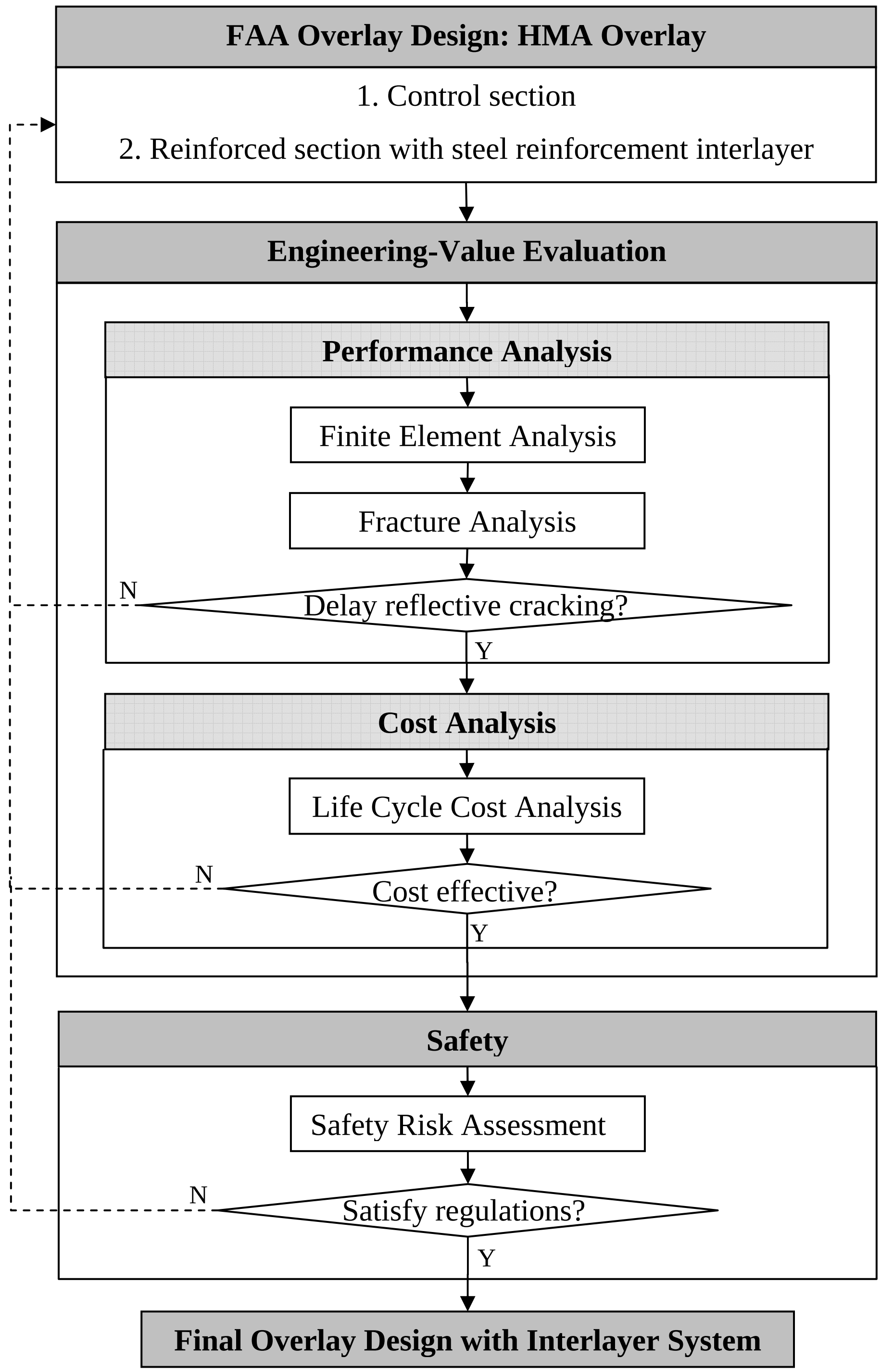


Figure 2. Design procedure of long-lasting HMA overlay with steel reinforcement netting interlayer system.

4. Description of the Technical Aspects

The engineering-value evaluation procedures (performance and cost analysis) are explained in this chapter and safety risk assessment will be explained in the next chapter.

4.1 Performance analysis

4.1.1 Finite element pavement model descriptions

A typical HMA overlaid pavement was selected to examine the performance of steel reinforcement netting interlayer. The existing pavement section is adapted from a Denver International Airport runway (Rufina et al. 2004). In addition to the existing pavement, HMA overlay was added and the following basic assumptions were specified in the overlay to develop reflective cracking:

- 76-mm-thick HMA overlay is constructed on 150-mm-thick existing jointed plain concrete pavements (JPCP) with 10mm joints.
- One gear loading of Boeing 747-400, one of the heaviest aircraft currently operating, is applied onto the HMA overlay corresponding to a concrete slab edge.
- Reflective cracking is inspected along a longitudinal joint and a transverse joint.
- Only aircraft loading is applied and no temperature and moisture variation is included.

It should be mentioned that this particular airport design may not be a good example for some airports that have different geometry, aircraft operations, climate zone, or other conditions. Also, this example design has a minimum overlay thickness regarding the given concrete pavement thickness to accelerate reflective cracking occurrence in the numerical analysis.

The geometry of the overlay pavement is shown in Figure 3. The B747-400 has one dual driving wheel, two dual tandems in wings and tow dual tandems in a body. Detailed spacing and locations are shown in Figure 3(a). One simple case is chosen for this pavement model as shown in Figure 3(b) to obtain critical pavement responses along joints out of numerous promising combinations with multiple gear locations on PCC slabs. One tire moves on HMA overlay corresponding to a concrete edge and corner along a longitudinal joint and crosses over a transverse joint (Figure 3(c)).

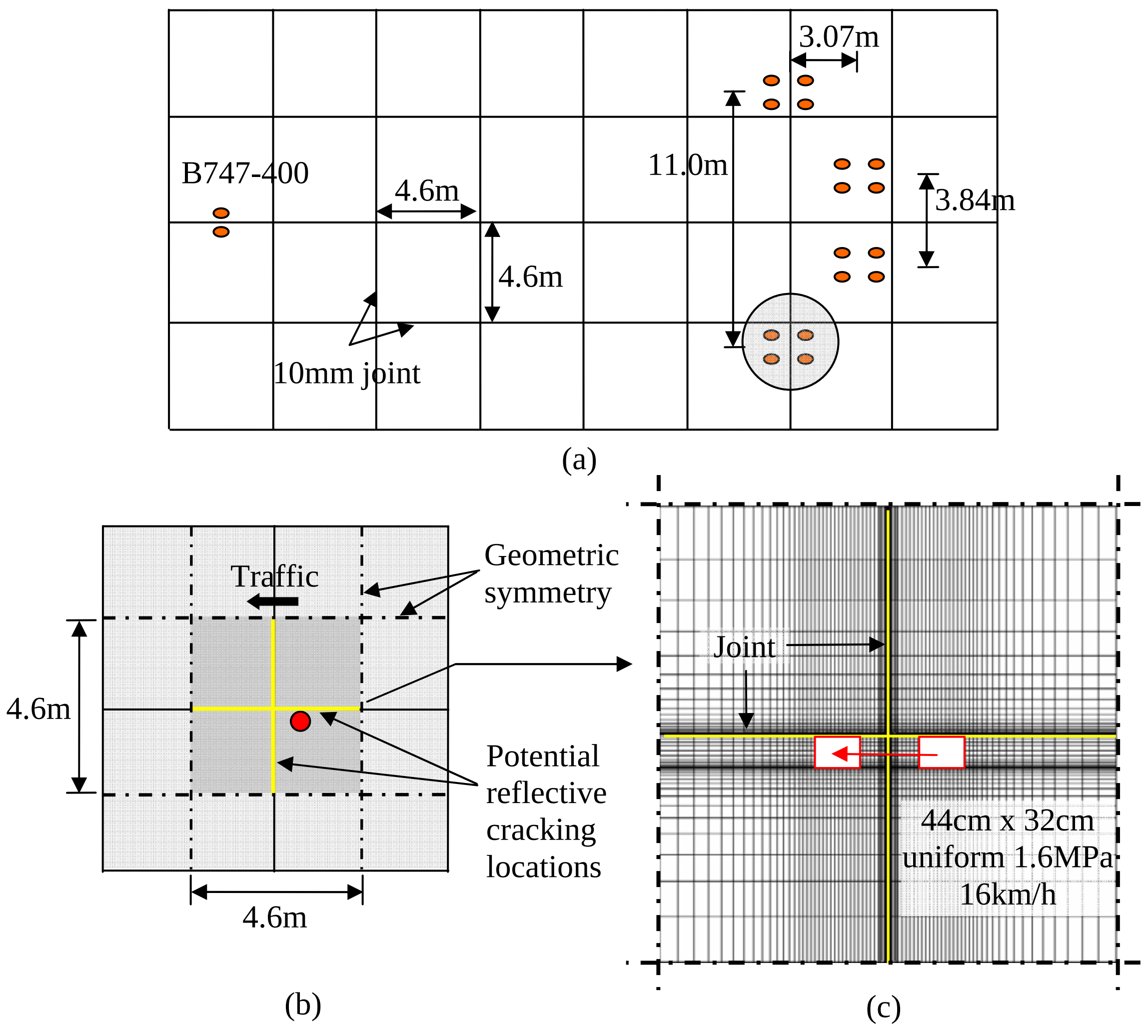


Figure 3. Schematic of HMA overlaid airport pavement model: (a) B747-400 aircraft gear configurations; (b) target domain; and (c) loading area.

The aircraft loading is simulated at moving speed of 48km/h and maximum contact pressure (p_{max}) of 1.6MPa. The contact pressure distribution in one tire imprint is shown in Figure 4. The tire imprint is subdivided into 10 elements (32mm) and 11 elements (40mm) in transverse and longitudinal direction fitting to the FE model. The pressure varies with respect to a travel distance. For example, the contact pressure jumps from zero to $0.6p/p_{max}$ during the first time step (0.003sec), keeps increasing up to the fifth and sixth time step, and then decreases at the same increase rate. To obtain time-and-mass dependent responses of the pavements by the aircraft moving loading, implicit dynamic analysis is conducted in 30 steps for a loading period of 0.09sec. Infinite elements are attached to the bottom of subgrade layer to absorb stress waves, not to be reflected.

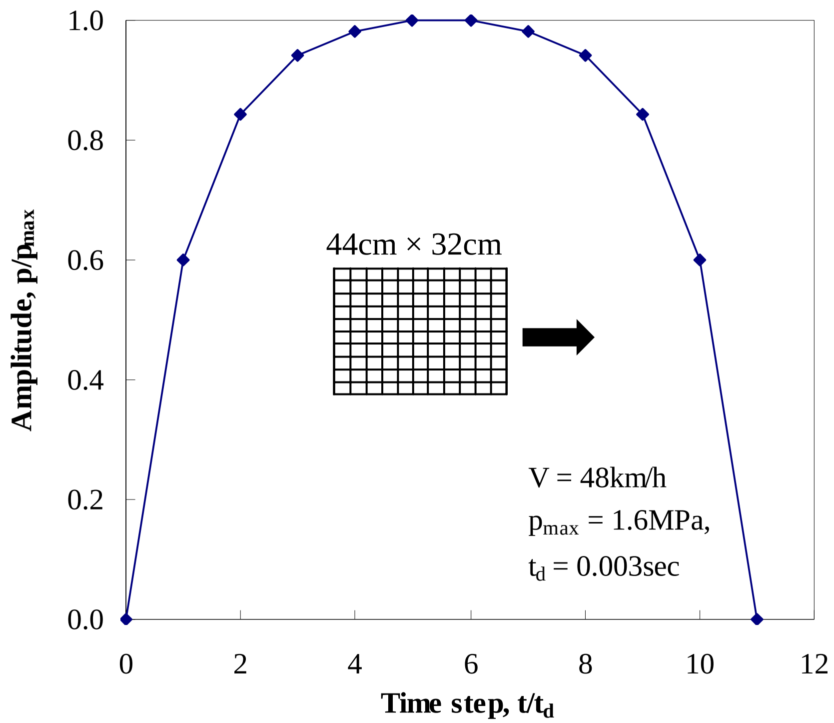


Figure 4. Amplitude variations over time for one tire imprint.

In addition to the finite element pavement model, fracture-mechanics-based cohesive elements are inserted in a potential crack surface. The most critical location at which reflective cracking would be developed is an area within HMA overlay right over joints of the JPCP. Thus, the cohesive elements are added in the overlay corresponding to the middle of joints in longitudinal and transverse directions (Figure 5). Since the cohesive element has zero thickness, it does not affect any geometric changes on the overlay. In a cohesive element, a traction force defined as a residual force to be transmitted across crack surfaces is governed by displacement jumps at the crack surfaces, so called separation. With the increase of separation, traction force increases in an elastic region; subsequently it decreases and becomes zero at a critical separation. A scalar of degradation, D, is defined to describe the status of a cohesive element: macro crack at D = 1.0, micro crack at $0.0 < D < 1.0$; and no crack at D = 0.0.

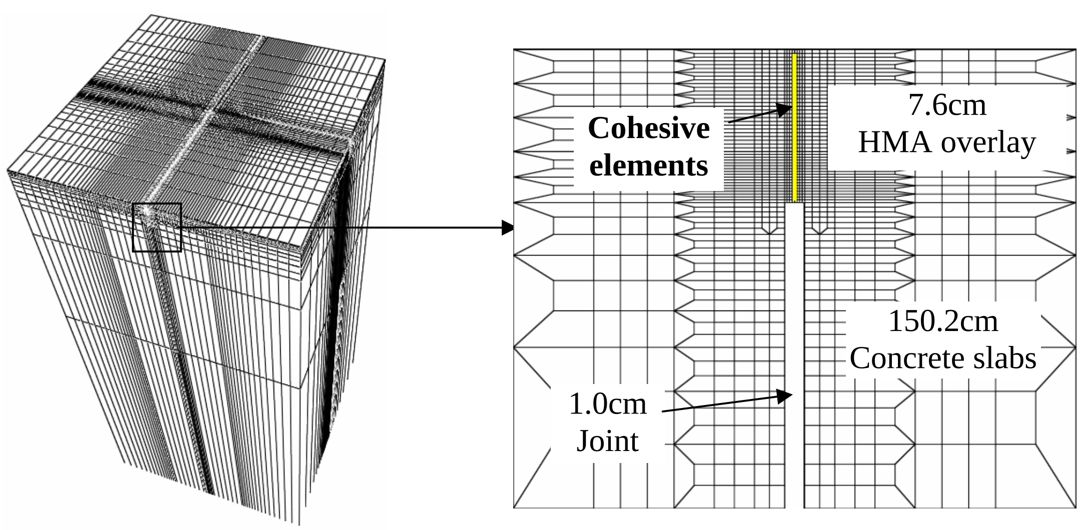


Figure 5. Cohesive element locations in a transverse joint.

The steel reinforcement netting interlayer system placed on top of existing concrete pavements is modeled with beam elements which have three sizes of circular cross sections (Figure 6). Single, double twisted wires, and reinforcing bar have 2.7mm, 5.4mm, and 4.9mm of diameters, respectively. Then, the steel mesh is embedded in a slurry seal layer which membrane elements are used to simulate. Interaction between the slurry seal layer and surrounding layers is controlled by means of friction: for strong bonding, infinite friction to the HMA overlay and for conventional bonding, μ=1.0 to the concrete pavement.

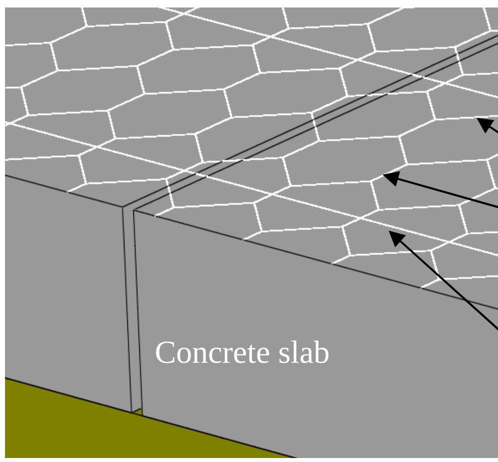


Figure 6. Steel reinforcement netting configuration and placement on the concrete slab.

Material properties for the HMA overlay, concrete, sub-layers, and steel are adapted from previous literature (Baek and Al-Qadi 2008). HMA is considered as a linear viscoelastic material at low temperature of -10^{o}C and configured with the Prony series; whereas the other materials are regarded as linear elastic materials. In addition, fracture properties of the HMA overlay are specified for the cohesive elements. Table 1 summarized the continuum and fracture material properties used in this pavement model.

Table 1. Material properties used in the HMA overlay pavement model

Material	Elastic modulus (GPa)	Poisson's ratio	Density (ton/m^3)
HMA	17.2*	0.22	2.3
PCC	27.5	0.20	2.4
Base	0.3	0.35	1.9
Subgrade	0.14	0.40	1.9
Steel	200.0	0.28	7.8
Slurry seal	1.0	0.35	2.0

* Instantaneous modulus in the Prony series

4.1.2 Reflective cracking analysis

Fractured area by reflective cracking is investigated in the cohesive elements. While one passage of traffic loading could not develop macro (or visible) reflective cracking (D=1.0), it was able to initiate micro cracks (0< D <1.0) in both directions.

Figure 7 demonstrates micro-crack zones induced by the traffic loading at the end of the analysis. In a transverse direction, reflective cracking occurs at the bottom of leveling binder; in a longitudinal direction, it happens on top of wearing surface and leveling binder. It means that transverse reflective cracking results from mainly mode I (opening) fracture and is bottom-up cracking. To the contrary, longitudinal reflective cracking happens at a location where maximum shear stress is developed, i.e., mode II (shear) fracture is dominant. In addition, a relatively large amount of fractured area occurs in the longitudinal direction compared to the fractured area in the transverse direction. This is due to the fact that aircraft loading travels along the edge of the existing concrete pavements. When the steel reinforcement netting interlayer system is utilized, fractured area at the bottom of the leveling binder decreases in the transverse direction.

On the other hand, the fractured area on top and middle of the wearing surface in the reinforced overlay is not lessened in the longitudinal direction, but reflective cracking on top of the leveling binder is alleviated. Therefore, the steel reinforcement netting interlayer system enables the mitigation of reflective cracking efficiently in the leveling binder regardless of fracture mode.

To quantify the fractured area by micro reflective cracking, normalized fractured area is computed in each column of cohesive elements by multiplying a degradation value, D, to the corresponding cross-section area, A, of cohesive elements as follows:

$$FA_i = \frac{\sum_{k=1}^{N_i} A_{i,k} D_{i,k}}{A_i} \times 100 \qquad (1)$$

where,

FA_i is normalized fractured area at the i^{th} column (%);

$A_{i,k}$ and $D_{i,k}$ are in-plane cross section area and degradation value of a cohesive element at the k^{th} row in the i^{th} column;

N_i is the number of cohesive elements in the i^{th} column; and

A_i is total in-plane cross section area of the i^{th} column.

For instance, 100% of FA_i indicates that all the cohesive elements in the ith column are fully degraded, i.e., macro reflective cracking is initiated. Based on degradation contours shown in Figure 7 and corresponding area of cohesive elements, the normalized fractured area is plotted with respect to distance from a joint. In Figure 8(a), approximately 11% of area is fractured under the aircraft loading zone; 53% more fractured area (17% of FA) is generated at a region over the longitudinal joint. The maximum FA of the reinforced overlay is 7.6%, which is 53% of that in the unreinforced overlay. The longitudinal reflective cracking has a three times larger fractured area in a wider range above the transverse joint compared to the transverse reflective cracking. As traffic loading approaches the corner of the concrete slab, more longitudinal reflective cracking is accelerated. Therefore, a corner loading is critical to develop reflective cracking.

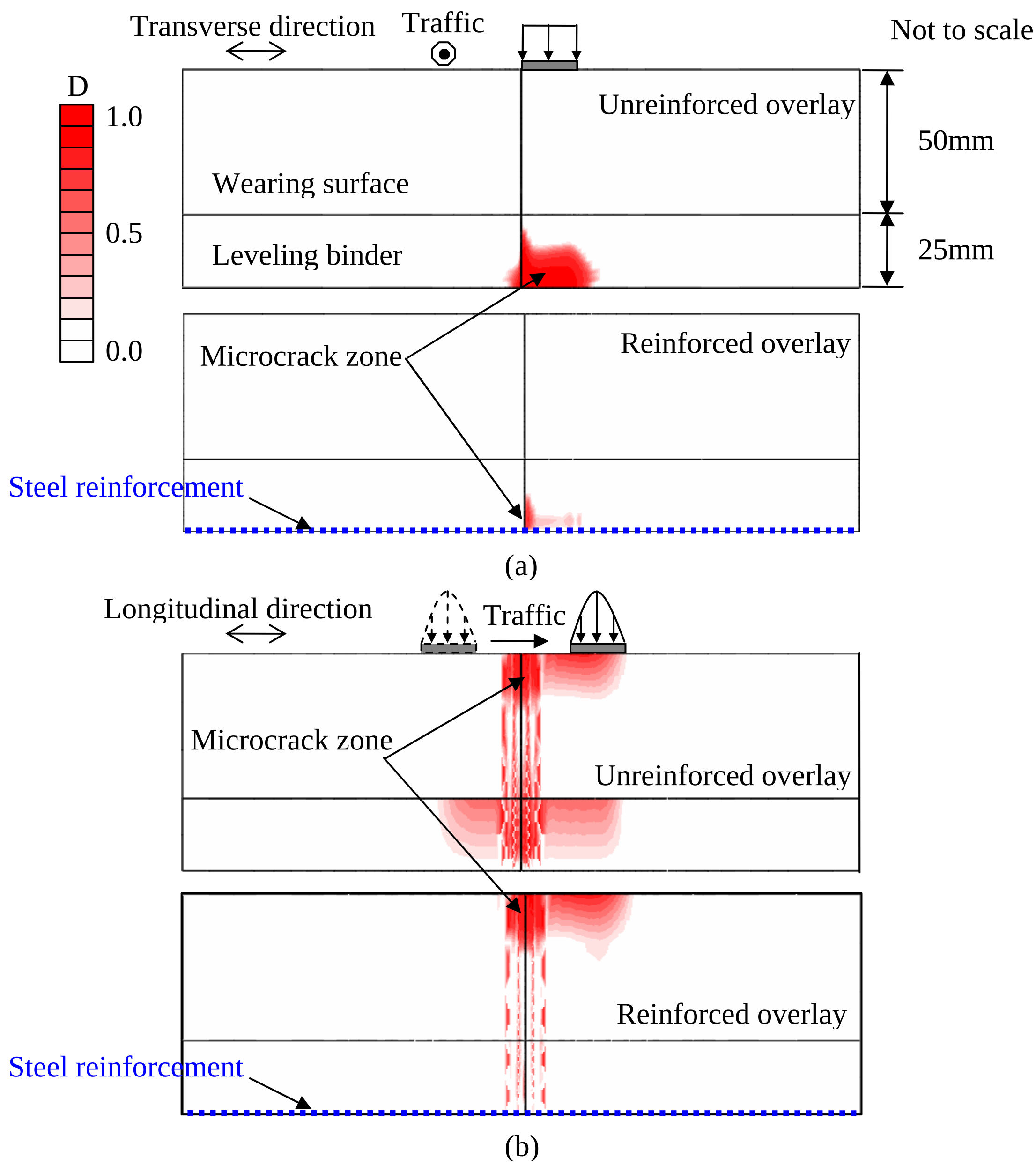
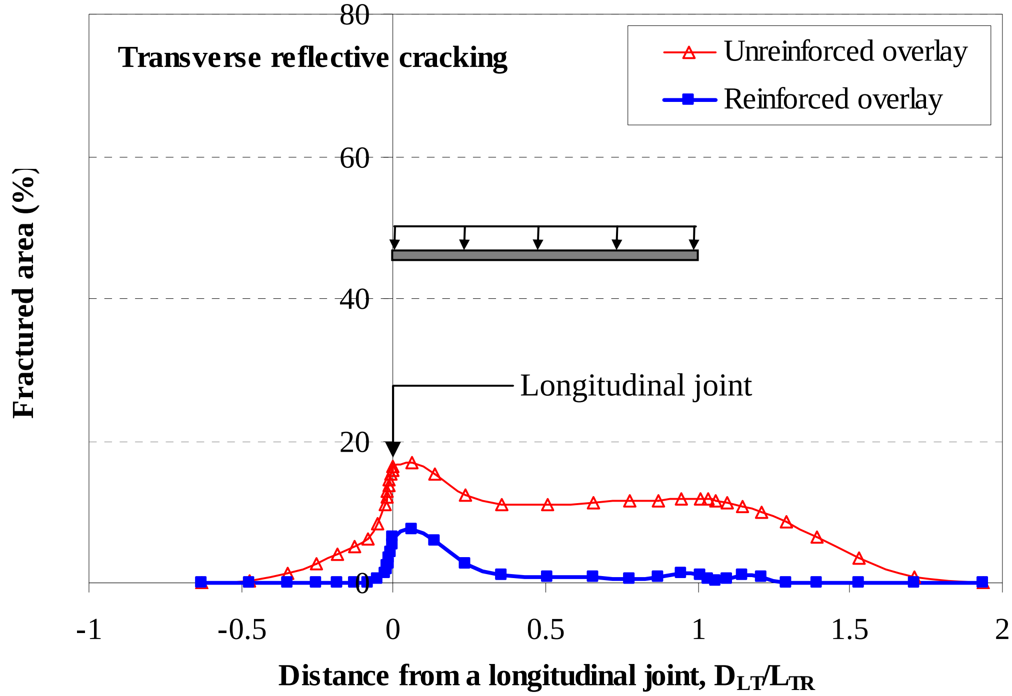
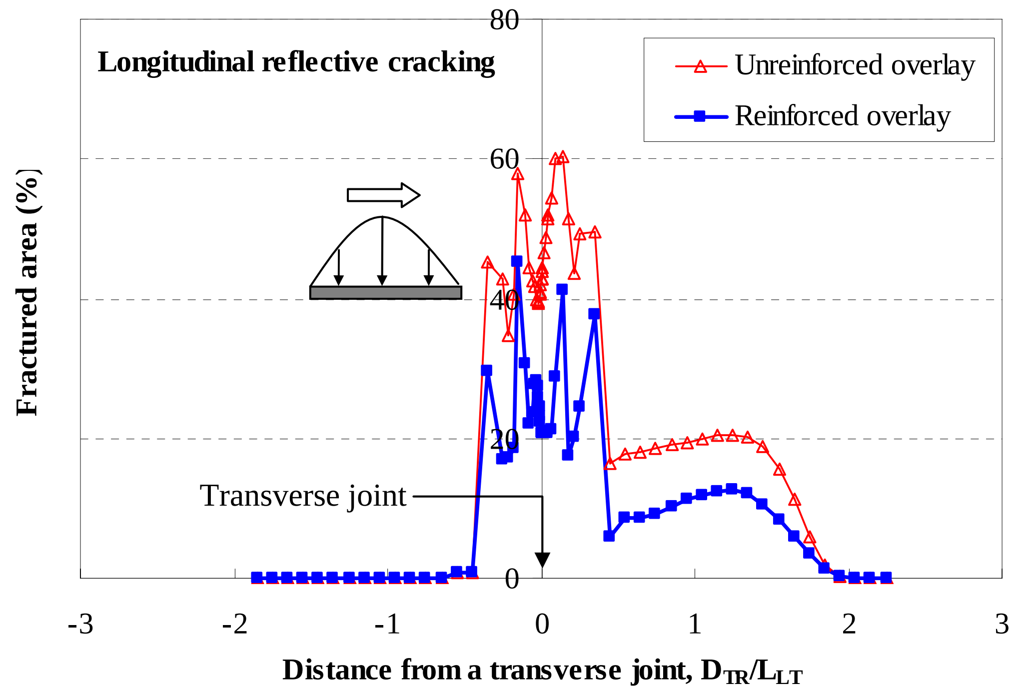


Figure 7. Comparison of micro-crack zone of the unreinforced and reinforced HMA overlay along (a) a transverse and (b) a longitudinal joint.



(a)



(b)

Figure 8. Comparison of fractured area of the untreated and treated HMA overlay along

(a) a transverse and (b) a longitudinal joint.

A simple approach was used to evaluate the performance of the steel reinforcement netting interlayer system with respect to reflective cracking resistance. A hypothesis used in this evaluation is that the more fractured area occurs, the less reflective cracking resistance overlay has. More specifically, the fracture resistance is linearly proportional to one over the fractured area. It needs to be clarified that the relationship is assumed to be valid until macro reflective cracking occurs due to actual number of loading repetitions. Using the fractured area, a performance benefit ratio is defined as the ratio of fractured area in the reinforced overlay to the unreinforced overlay. Finally, the service life of the reinforced overlay is computed by multiplying the benefit ratio to a given original service life of the unreinforced overlay.

Figure 9 shows total fractured areas of the reinforced and unreinforced overlay and benefit ratios of the reinforced overlay regarding a reflective cracking type. The fractured area for transverse reflective cracking is significantly reduced in the reinforced overlay, producing the benefit ratio of 8.4. On the other hand, the benefit ratio for longitudinal reflective cracking is 1.8. By combining the two benefit ratios equivalently, the overall benefit ratio of the reinforced overlay becomes 2.2. Therefore, it is concluded that the steel reinforcement netting interlayer system extends the service life of the HMA overlay by a factor of 2.2.

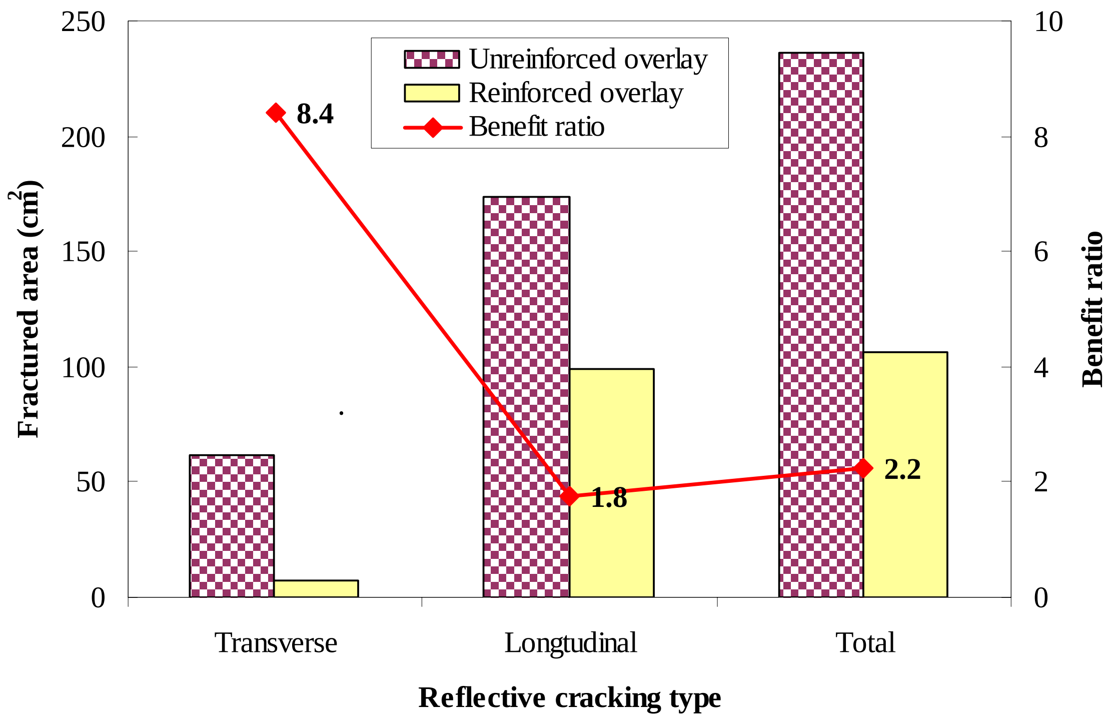


Figure 9. Comparisons of the fracture area and benefit ratio of the reinforced HMA overlay compared to the unreinforced HMA overlay.

4.2 Cost analysis

The cost benefit of the steel reinforcement netting interlayer system is evaluated through life-cycle cost analysis (LCCA). In the LCCA, total cost is comprised of agency and user cost for a design service life.

The agency cost includes all costs related to construction and management, mainly initial construction, routine maintenances, rehabilitations; the user cost is indirect costs to request facility users and is comprised of vehicle operating costs, crash costs, and user delay costs. Extra construction time is required for the installation of the steel reinforcement netting interlayer system during overlay construction. However, since it is applicable to construct HMA overlay in a short time period when no aircraft is operated, it is assumed that the construction processes do not influence airport operation. As a result, no additional cost is taken into account for the user cost in this design project, and only agency cost is included in the total cost.

The initial cost is regarded as construction cost for the HMA overlay itself and interlayer system if installed. If multiple HMA overlay are constructed for a certain design period, all costs in the future are converted to an equivalent value, net present value (NPV), regarding a current year using a discount rate (Eq. 2). Also, if the service life of the HMA overlay is extended, the residual life of HMA overlay at the end of the service life is compensated as a salvage value from the agency cost (Eq. 3) as depicted in Figure 10.

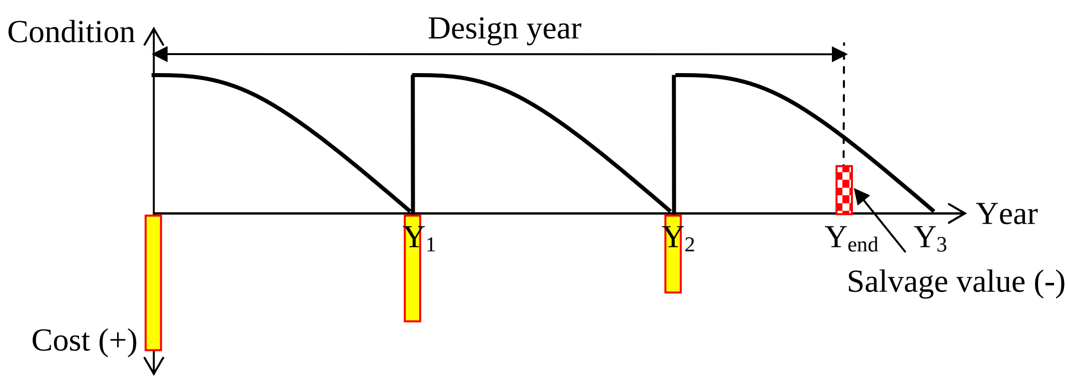


Figure 10. Schematic of net present value and expenditure diagram for multiple rehabilitations during a design year.

$$NPV = \text{Initial cost} + \sum_{i=1}^{N} \text{Future cost}\left(\frac{1}{1+r}\right)^{Y_i - Y_0} \quad (2)$$

where,

NPV is a net present value;

r is a discount rate (4% is used);

Y_0 and Y_i is current year and year at the i^{th} event; and

N is total number of events.

$$\text{Salvage value} = \text{Cost}\left|Y_2\right.\left(\frac{Y_3 - Y_{end}}{Y_3 - Y_2}\right)\left(\frac{1}{1+r}\right)^{Y_{end} - Y_0} \quad (3)$$

where,

$\text{Cost}|Y_2$ is the last rehabilitation cost at year 2; and

$(Y_3 - Y_{end}) / (Y_3 - Y_2)$ is a residual life of the last rehabilitation.

From the performance analysis, the service life of the HMA overlay with the steel reinforcement netting is 2.2 times longer than that of the untreated HMA overlay with respect to reflective cracking. For an example LCCA for this design project, the following are assumed: Conventional HMA overlay can serve for 10 years so that a total of five HMA overlays are needed for 50 years of design; HMA and steel reinforcement netting cost are \$40/ton and \$5/m^2; and no maintenance cost is included. Then, for the reinforced HMA overlay with the steel reinforcement netting interlayer system, the overlay is constructed three times during the design year. For the two cases, an expenditure diagram is shown to clarify the rehabilitation costs and salvage values in

Figure 11. Compared to the unreinforced overlay, initial and two consecutive construction costs of the reinforced overlay are expensive due to the steel reinforcement netting cost. However, longer service life of the reinforced overlay reduces the frequency of the rehabilitations, from five to two times in 50 years of the design year. Also, a negative cost of the salvage value at the end of the design year also reduces the total cost. Finally, the reinforced overlay can achieve a small amount of cost benefit (3%). The cost benefit margin of the reinforced overlay is not significant, but at least equivalent. The margin can be enlarged when less frequent routine maintenance such as crack sealing is required during the longer service life.

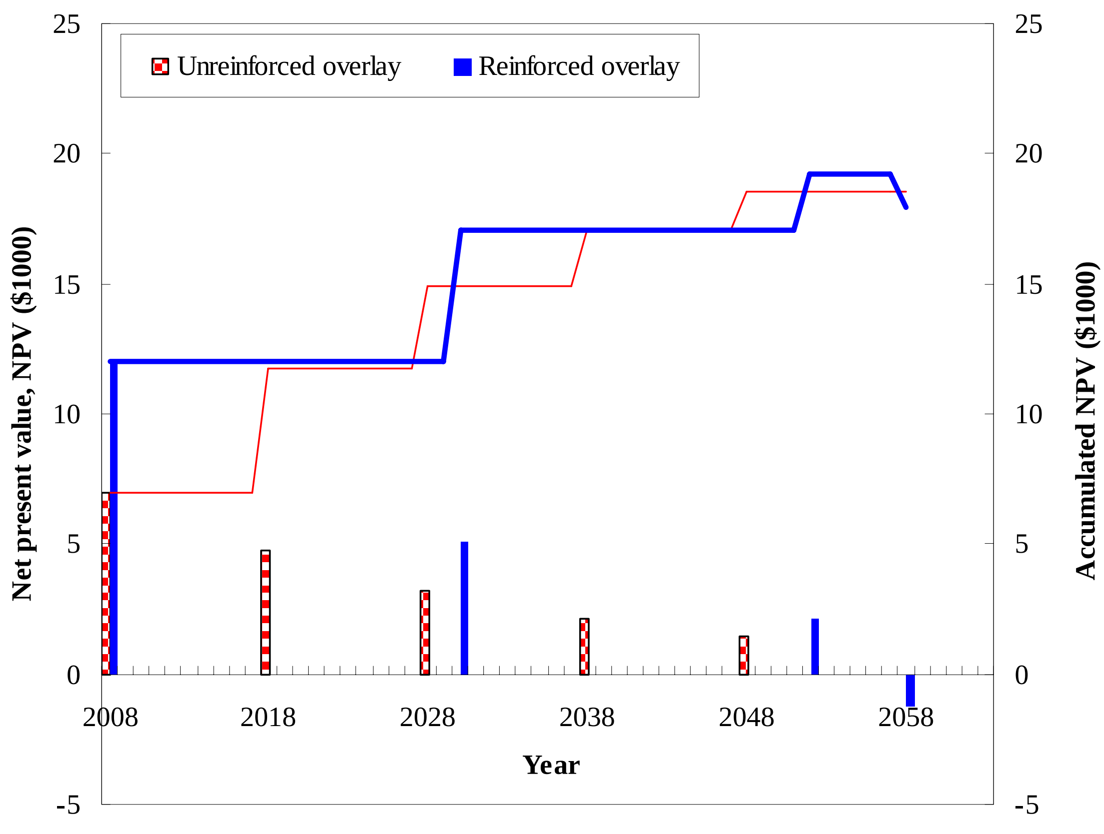


Figure 11. Net present value for overlay construction costs during a design year and salvage value.

The cost benefit is sensitive to several components used in the LCCA. First of all, material costs are one of the main variables. Actually, the market price of construction materials varies due to lots of factors related to engineering issues as well as global economics. According to Elseifi (2003), the steel reinforcement netting ranges 3.5 to $\$6/m^2$. HMA also has a wide range of costs, depending on binder grades, aggregate types, and construction conditions. So, it is required to take a wider range of material costs into the HMA overlay design procedure for the appropriate application of the steel reinforcement netting. Generally, the cost benefit increases as HMA cost increases and steel reinforcement netting cost decreases. Thus, cost ratio of the HMA to steel reinforcement netting, C_{HMA}/C_{SRN}, is adapted as one variable. The second important variable in the LCCA is HMA overlay design parameters which could be varied on purpose. Thus, HMA overlay thickness, T_{HMA}, is also regarded as one parameter.

It should be noted that since the overlay thickness can influence the overlay performance so that the thickness varies only from 60mm to 90mm (the design thickness of 76mm) and the performance benefit ratio is fixed as 2.2 regardless of the HMA overlay design. Figure 12 shows the variation of cost benefit regarding the cost ratio and HMA thickness. The cost benefit has a broad range from -30% to 30%. In other words, the reinforced HMA overlay shows cost benefit only in some cases which have higher cost ratio and thicker HMA overlay. Thus, unless superior performance is guaranteed, it is recommended that these material costs and HMA overlay design thickness are considered to use a steel reinforcement netting interlayer system as a cost-effective method to mitigate reflective cracking.

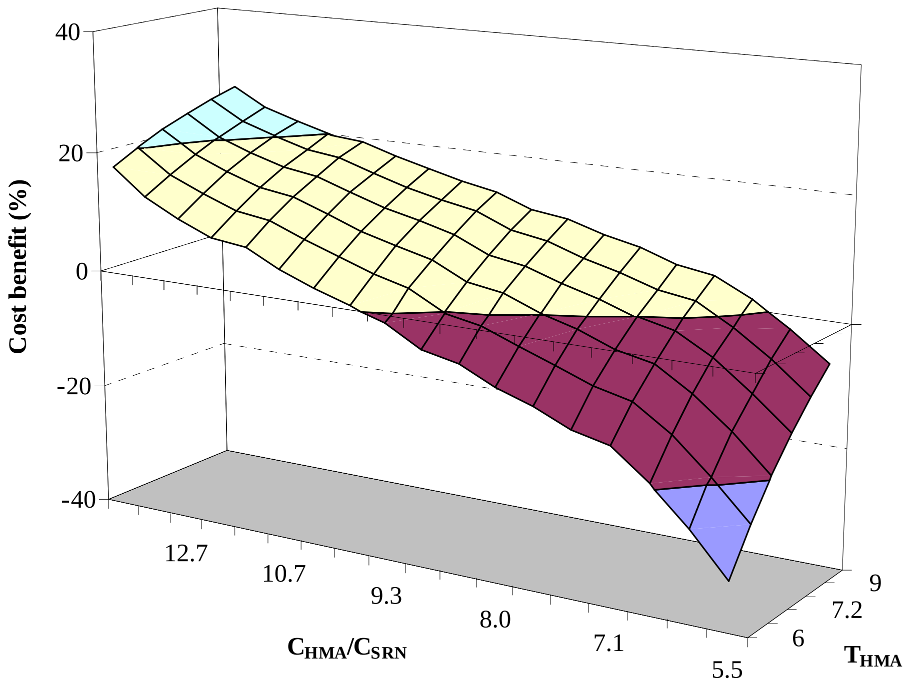


Figure 12. Cost effect variations with respect to material costs and overlay thickness.

Using a statistical approach, the cost benefit is predicted with the cost ratio, C_{HMA}/C_{SRN}, and HMA overlay thickness, T_{HMA}. Since the P-values of two the variables are significantly lower than 0.05, the influence of two of the variables is statistically significant. By using a trial-and-error method, logarithmic and linear functions are determined for the cost ratio and the overlay thickness, respectively. Finally, a linear regression equation to predict cost benefit is formulated as follow:

$$\text{Cost benefit }(\%) = 89.3\log\left(\frac{C_{HMA}}{C_{SRN}}\right) + 5.75T_{HMA} - 123.3 \tag{4}$$

where,

C_{HMA} is a HMA cost in \$/ton;

C_{SRN} is a steel reinforcement netting cost in \$/m^2; and

T_{HMA} is a HMA overlay thickness in cm.

The predicted cost benefit shows a very good agreement compared to the obtained cost benefit (Figure 13). Meanwhile, the cost benefit is overestimated in a higher cost benefit range (>20%) or underestimated in a lower cost benefit range (<10%).

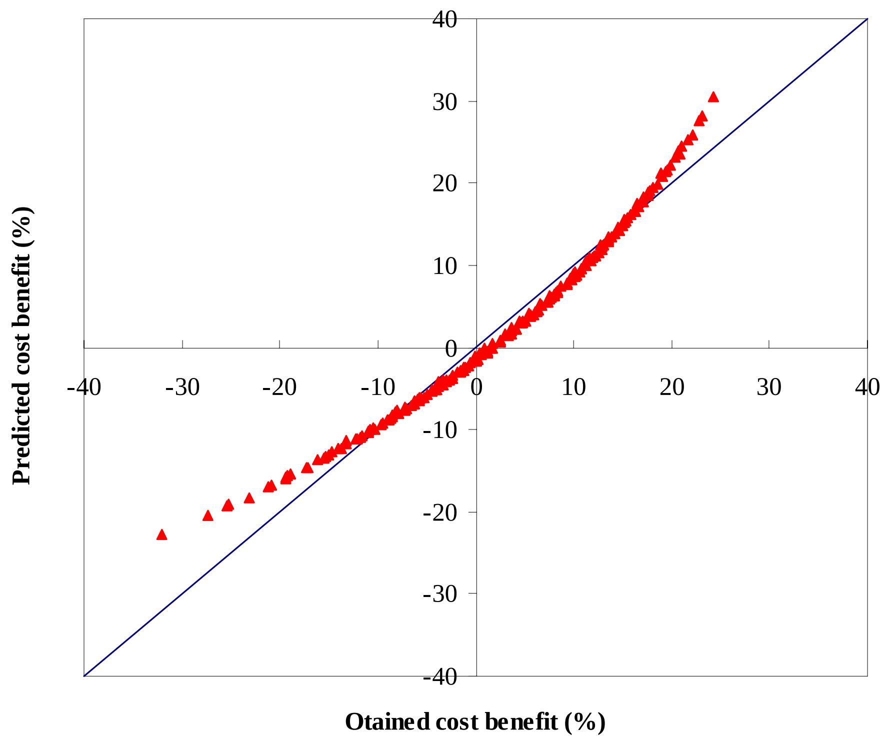


Figure 13. Comparison of obtained and predicted cost benefit.

5. Safety Risk Assessment

As requested by the FAA for safety issues during airport operations, the existing FAA safety management system guidance was examined regarding to the proposed pavement overlay design solution. According to Introduction to Safety Management Systems for Airport Operators (FAA 2007) and FAA Safety Management System Manual (FAA 2004), no inherent risks were found to ensure safe operations. It results from the aforementioned design demand that in order to guarantee the safety as well as not to hinder airport operations, the HMA overlay should be constructed during a period when no operation is requested.

6. Description of Interactions with Airport Operators and Industry Experts

The interaction with airport operators and industry experts was achieved through a technical survey that was sent to several experts in airport pavement design, maintenance, and management. Five responses to the questionnaire were received, and the experts' information is listed in Table 2.

Table 2. List of Expert Advisors for Questionnaire

Name	Title	Company/Organization	Phone	Email
Frank Farmer	Aeronautics Manager	Alabama Department of Transportation Aeronautics Bureau	(334) 242-6820	farmerf@dot.state.al.us
David Peshkin	Vice President	Applied Pavement Technology	(630) 434-9210	dpeshkin@pavementsolutions.com
Matthew Wenham	Managing Engineer	C&S Engineers	(216) 619-5449	mwenham@cscos.com
Monty Wade	Program Director	Applied Pavement Technology, Inc.	(217) 398-3977	mwade@pavementsolutions.com
Steve Lawrence	Senior Project Mgr	Union Station	(317) 786-0461	slawrence@rwa.com

The summary of the received feedbacks are listed as following:

1) *Airport pavement type*

Generally, both HMA and PCC pavements were widely used for airport runways and PCC pavements were more often used for parking areas. One pavement consultant who has worked on over 10 airport projects pointed out that general aviation (GA) airports without much jet traffic use primarily HMA pavements in all areas and at large hub airports, like Cleveland and Detroit Metro, PCC pavements are primarily used in most areas.

2) *The most three distresses exist in airport pavement*

A crack was considered as the most common distress in the airport pavement, including thermal cracking, fatigue cracking, and joint-associated reflective cracking. Thermal cracking was often found at small airports, while rutting and depression were only found at large airports with large aircraft operations. It was noted that cracks should be correctly sealed after the cracks occurred; otherwise, water can go through the cracks and erode subbase over time and finally produce secondary cracking and some load failures. Reflective cracking is almost always an issue when there is HMA overlay on existing concrete or asphalt pavements. Only one answer out of the five questionnaires pointed out that raveling was also one of the three most common distresses in airport pavements.

3) *The reflective cracking treatment technology*

With the increased demand for using HMA pavements in airport runways due to its smoothness and low maintenance cost, HMA overlay was often encountered in airport runway pavement rehabilitation. Reflective cracking becomes an issue when the HMA overlay is placed on existing jointed concrete pavements or deteriorated asphalt pavements. Many different treatment technologies have been used to prevent and retard the reflective cracking based on the questionnaire feedbacks.

As shown in Table 3, the geosynthetic interlayer systems have been widely used in the HMA overlay on existing PCC pavements, comparable to other reflective cracking treatment technologies. Rubblization and milling were also considered as possible cost effective approaches to prevent reflective cracking. None of the answers indicated awareness of a steel reinforcement netting interlayer system, which is proposed in this project.

Table 3 Reflective Cracking Treatment Technologies from Questionnaires

Questionnaire answers	Available reflective cracking treatment technology	Expected most cost effective approach
1	Fiberglass grid geotextile fabric between 50-mm HMA overlay lifts	Rubblization
2	Repairing distresses in the existing pavement section prior to overlay; membranes such as GlasGrid.	Milling out full depth; Membranes with multiple lift; white-topping might be effective
3	Fabrics; thick overlays	No
4	Milling; Crushed aggregate treatment	Milling
5	Milling/paving; patching; fabric	Varies on the application, construction performance, weather

7. Description of the Projected Impacts of the Team's Design and Findings

Using a steel reinforcement netting interlayer system, an innovative HMA overlay system, was proposed in this design project. Primarily, the proposed anti-reflective cracking HMA overlay system was shown to satisfy a performance criterion to resist reflective cracking. Through 3D FE modeling, the steel reinforcement netting interlayer reduces reflective cracking induced by an aircraft loading and consequently, extends the service life of the HMA overlay by a factor of 2.2 compared to a control HMA overlay section. Moreover, the reinforced HMA overlay could meet a cost-effective criterion, which is a main goal in the new decision making procedure for airport pavement management. Depending on material costs for HMA and steel reinforcement netting as well as HMA overlay thickness, the cost benefit ranges from -30% to 30%. However, the negative cost-effective range can be disregarded if the overlay thickness is greater than 76mm and unless a significantly lower cost ratio is considered such as too expensive steel reinforcement netting and/or too cheap HMA. The FAA recommends using a thicker HMA overlay than 76mm when it is constructed on rigid pavements. Also, according to recent news (MSNBC 2008), oil prices keep increasing and are expected to hit the highest price ever for a barrel. It is expected that asphalt binder and HMA prices will consequently increase in the near future. So, the cost ratio of HMA to steel reinforcement netting will increase and the cost benefit of the reinforced HMA overlay can be held in a positive range. Therefore, the HMA overlay with a steel reinforcement netting interlayer system can be an affordable alternative to meet the FAA's HMA overlay design goal. Furthermore, this design team achieved particular findings through performance and cost analysis for the HMA overlay with steel reinforcement netting interlayer system as follows:

- When an aircraft loading moves along the edge of underlying jointed plain concrete pavement (JPCP), longitudinal reflective cracking is more likely to develop than transverse reflective cracking.
- The steel reinforcement netting interlayer system installed at the bottom of the HMA overlay on PCC pavements reduces fractured area by transverse and longitudinal reflective cracking by a factor of 8.4 and 1.8, respectively, compared to unreinforced HMA overlay; and for both reflective cracking, total fractured area, is reduced by a factor of 2.2.
- Based on life-cycle cost analysis (LCCA), a cost benefit is dependent on the thickness of HMA and the cost ratio of HMA to steel reinforcement netting. As the cost ratio increases and/or the thickness of HMA overlay increases, higher cost benefit can be guaranteed. A regression equation was proposed to predict the cost benefit.

Supplementary, some future projects are recommended to accomplish the proposed method in nationwide airports as following:

- Field and/or full-scaled pavement tests are required to validate the overlaid pavement model.
- Environmental problems such as temperature and moisture variations need to be included in the analysis to consider an airport located at a different climate zone.

- Various design parameters for HMA overlay and existing pavements may need to be utilized to evaluate the effectiveness of the steel reinforcement netting such as thickness, slab size, modulus, and strength.
- The performance and cost benefit are compared with a variety of interlayer systems currently used.

List of Appendix

A. List of complete contact information

B. Description of the university

C. Description of non-university partners

D. Sign-off from for faculty advisor and department chair

E. Evaluation of the educational experience provided by the project

F. Reference list with full citations

G. Other support materials - Questionnaires

Appendix A. List of Complete Contact Information

1. Advisor

- Name: Imad L. Al-Qadi

- Affiliates: Founder Professor of Engineering, Illinois Center for Transportation Director

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- Phone: (217) 265-0427, Fax: (217) 333-1924

- Email: alqadi@uiuc.edu

2. Student #1

- Name: Jongeun Baek

- Affiliates: Graduate Research Assistant

- Email: baek2@uiuc.edu

3. Student #2

- Name: Hao Wang

- Affiliates: Graduate Research Assistant

- Email: haowang4@uiuc.edu

Appendix B. Description of the University

The University of Illinois at Urbana-Champaign is one of the top engineering schools in North America. In its 2008 rankings, *U.S. News & World Report's America's Best Colleges* rated Illinois as the number 8 public university and the number 38 national university. The university has 16 Colleges & instructional units and 37 campus libraries; with the largest U.S. engineering library. The College of Engineering is ranked 5th (tie) in undergraduate and 5th in graduate programs nationally in 2008. The university has a comprehensive educational program designed to serve the widely varied needs of undergraduate and graduate students and conduct innovative research for excellence worldwide in many key areas.

The University is located in the twin cities of Champaign and Urbana (total population 180,000) in east-central Illinois. It is situated about 140 miles south of Chicago, 125 miles west of Indianapolis, and 180 miles northeast of St. Louis. Around 30,895 undergraduate and 11,431 graduate students study at the University of Illinois.

Mission

The University of Illinois will transform lives and serve society by educating, creating knowledge and putting knowledge to work on a large scale and with excellence.

Vision

To create a brilliant future for the University of Illinois in which the students, faculty and staff thrive and the citizens of Illinois, the nation and the world benefit, a future in which the University of Illinois is the recognized leader among public research universities in:

- Teaching, scholarship and service

- Engagement and public service
- Economic development
- Arts and culture
- Global reach
- Athletics

History

The University of Illinois at Urbana-Champaign was founded in 1867. Chartered as the Illinois Industrial University, the University opened for business in 1868. Renamed the University of Illinois in 1885, it is one of the original 37 public land-grant institutions created after President Abraham Lincoln signed the Morrill Act in 1862.

Appendix C. Description of Non-University Partners

No non-university partners participated in the design competition.

Appendix E. Evaluation of the Educational Experience Provided by the Project

E.1. Faculty advisor: Imad L. Al-Qadi

For faculty members:

l. Describe the value of the educational experience for your student(s) participating in this Competition submission.

- *This project helps Jongeun and Hao tremendously. It allows them to work together as a true team, combine their expertise to provide a complete work, review the FAA regulations, work on the development of an advanced model and yet present the outcome in a very simple way that can be used by design engineers, understand that a good engineering work requires, modeling, cost-benefit ratio, and safety dimension. In addition, combining their efforts allow them to look at the problem from different point of view and shows the importance of shear in HMA in developing reflective cracking. On other important thing is expanding their knowledge in airfield pavements as booth do their research on highway pavements.*

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

- *Yes. The students, who took a course in airport earlier, did this project in their own time.*

3. What challenges did the students face and overcome?

- *The simulation of interface layer in there dimension and creating a damage parameter were very challenging and they were able overcome that through hard work and then* *added to that the innovative work of a moving load to show the reflective crack behavior under continuously moving load.*

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

- *Yes. For the reasons mentioned in #1.*

5. Are there changes to the Competition that you would suggest for future years?

- *No, it was very appropriate. However, it was time consuming.*

E.2 Student #1: Jongeun Baek

For the students, the evaluation should minimally address the following questions:

1. Did the FAA Airport Design Competition provide a meaningful learning experience for you? Why or why not?

- *Yes, it was very useful to look over the whole design procedure for HMA overlays in airfield pavements. Especially, I extended my knowledge of overlay used in roads to airfield. Beyond the technical aspects, I could get positive and educational experiences on how to "cooperate" as a leader as well as a member.*

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

- *It was not easy to work together in a short time and we had different ideas, approaches, and many other considerations to be solved. Lots of discussions and debates on my own side and other parts enabled us to discuss the issues and figure them out.*

3. Describe the process you or your team used for developing your hypothesis.

- *We tried to understand the different characteristics of airfield pavement design with the aid of literature, resources in the FAA website as well as an advisor. After running lots of numerical analysis, the best representative model was adapted for this project*

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

- *Yes, it was a positive cooperation. Based on the feedback we received from experts, I realized that reflective cracking is a practically important problem to be resolved and still no ideal solution is developed. Also, we were able to introduce our proposed method to them.*

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

- *Comparing and contrasting the overlay features in different pavement structures in roads and airfields gave me an idea of which design parameters should be considered to design characteristics better. Also, the project encouraged me to think of the importance of a cost-effective method.*

E.3 Student #2: Hao Wang

For the students, the evaluation should minimally address the following questions:

1. Did the FAA Airport Design Competition provide a meaningful learning experience for you? Why or why not?

- *It was a great experience to work on the design competition. The competition helped me better understand the airport pavement design methods and various asphalt overlay treatment technologies. Another important thing that I learned is how to effectively and actively work with other people toward group goals.*

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

- *There was a challenge of short time period for preparing the competition because we have other class assignments and research projects during the work for the competition. To overcome this problem, we divided the total work into several tasks and each one of us took charge of the parts based on his expertise and experience.*

3. Describe the process you or your team used for developing your hypothesis.

- *The resources in FAA websites helped us a lot to outline the design objective. After we decide the design topic thought literature review and consulting with our faculty advisor, we assigned different tasks to each group member to fulfill the requirements which covered everything that need to be addressed.*

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

- *The participation of industry is achieved by sending the questionnaire to several experienced experts in airport pavement design, maintenance and management. The feedback from these expert advisors is really valuable and useful.*

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

- *I will definitely put this competition experience into my resume. It broadened my knowledge in airport pavement design and maintenance. Also, it helped me better understand how to work as a team member and made my own contribution.*

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Appendix G. Other Support Materials

G.1 Questionnaire to airport experts

We greatly appreciate your kind participation in this survey. This survey will be used only for the "FAA Design Competition for Universities 2007-2008 Academic Year". The objective of our design team is to develop a long-last rehabilitation strategy for airport pavements using hot-mix asphalt overlay systems. In order to accomplish the goal, current problems in airport pavement rehabilitation procedures need to be collected. Please answer the following questions:

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency.
2. What kinds of pavements are used in your airport and on which part?
3. What are the most three distresses exist in your airport pavement?
4. Is reflective cracking a concern for your pavement team?
5. Which techniques have been utilized to control reflective cracking?
6. In your opinion, what is the most cost effective approach to control reflective cracking?
7. Are you interested in a new technique to control reflective cracking if proven cost effective?

If you have any questions, please feel free to contact Hao Wang at haowang4@uiuc.edu, 217-979-1580

G.2 Survey response #1

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency.

- *Burlington International Airport, Burlington, Vermont*

- *See traffic mix in table below.*

Aircraft Type	***MTOW, Lbs***	***Gear Type***	***MTOW Wheel Load, lbs***	***Avg. Ann. Deps.***
Airbus A-319	*166,500*	*DW*	*39,544*	*173*
Airbus A-320	*170,000*	*DW*	*40,375*	*1,859*
Boeing B737-300	*115,500*	*DW*	*27,431*	*719*
Boeing B727-200	*190,000*	*DW*	*45,125*	*124*
Beechcraft 1900	*16,600*	*DW*	*3,943*	*519*
DeHavilland Dash 8 Series 400	*41,100*	*DW*	*9,761*	*1,112*
DO-328	*30,843*	*DW*	*7,325*	*692*
McDonnell Douglas MD-80	*140,000*	*DW*	*33,250*	*124*
Canadair CRJ	*95,000*	*DW*	*22,563*	*11,055*
Embraer 145	*48,500*	*DW*	*11,519*	*5,330*
F-16	*37,500*	*DW*	*8,906*	*2,379*

2. What kinds of pavements are used in your airport and on which part?

- *New PCC, New HMA, and HMA overlays*

3. What are the most three distresses exist in your airport pavement?

- *Thermal cracks, joint reflective cracks, and alligator (fatigue) cracking*

4. Is reflective cracking a concern for your pavement team?

- *Yes.*

5. Which techniques have been utilized to control reflective cracking?

- *Fiberglass grid geotextile fabric between 2-inch HMA overlay lifts.*

6. In your opinion, what is the most cost effective approach to control reflective cracking?

- *Rubblization*

7. Are you interested in a new technique to control reflective cracking if proven cost effective?

- *Absolutely*

G.3 Survey response #2

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency

- *As a consultant, I work for a variety of airports. Currently, I have 10 airport clients ranging from small, general aviation airports to large hub airports.*

2. What kinds of pavements are used in your airport and on which part?

- *General aviation (GA) airports without much jet traffic use primarily asphalt in all areas. Some GA have corporate jet traffic in which PCC is used on ramps for aircraft parking.*

- *Small commercial service airports such as Syracuse and Akron-Canton have a mix of asphalt and PCC. More so than not, PCC is used for parking areas and asphalt in all others.*

- *At large hub airports, like Cleveland and Detroit Metro, primarily PCC is used in most areas. In some areas where there is asphalt, asphalt is used for rehabilitation as well.*

3. What are the most three distresses exist in your airport pavement?

- *Asphalt: at small airports loads are not common, so typical distresses are environmentally related from temperatures changes such as L&T cracking. If cracks are not sealed, what gets in and can erode the subbase over time and produce secondary cracking and some load failure. At large airports, rutting and depression are also common with L&T cracks.*

4. Is reflective cracking a concern for your pavement team?

- *Very much so*

5. Which techniques have been utilized to control reflective cracking?

- *Repairing distresses in the existing pavement section prior to overlay*

- *Membranes such as GlasGrid.*

6. In your opinion, what is the most cost effective approach to control reflective cracking?

- *Ideally, milling out full depth*

- *Membranes help delay if affordable and if you can use multiple lifts. I have not tried, but I could see how white-topping might be effective.*

7. Are you interested in a new technique to control reflective cracking if proven cost effective?

- *Yes*

G.4 Survey response #3

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency.

- *Burlington, Vermont*

- *Approximately 40 commercial departures daily, ranging from commuter prop planes up to A320; cargo aircraft; general aviation operations; Air and Army National Guard (F16s and some transport aircraft).*

2. What kinds of pavements are used in your airport and on which part?

- *HMA pavements on runways and taxiways; PCC on apron*

3. What are the most three distresses exist in your airport pavement?

- *Thermal cracking, fatigue cracking, block cracking*

4. Is reflective cracking a concern for your pavement team?

- *Yes*

5. Which techniques have been utilized to control reflective cracking?

- *Fabrics, Thick overlays*

6. In your opinion, what is the most cost effective approach to control reflective cracking?

- *There is no cost-effective solution that we're aware of, whether it's for reflective cracking of HMA over HMA or HMA over PCC.*

7. Are you interested in a new technique to control reflective cracking if proven cost effective?

- *Probably*

G.5 Survey response #4

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency.

- *The information provided is considered representative of general aviation airports in Alabama*

2. What kinds of pavements are used in your airport and on which part?

- *Asphalt*

3. What are the most three distresses exist in your airport pavement?

- *Longitudinal cracking, Reflective cracking, Raveling*

4. Is reflective cracking a concern for your pavement team?

- *Yes*

5. Which techniques have been utilized to control reflective cracking?

- *Milling, crushed aggregate treatment*

6. In your opinion, what is the most cost effective approach to control reflective cracking?

- *Milling*

7. Are you interested in a new technique to control reflective cracking if proven cost effective?

- *Probably*

G.5 Survey response #5

1. Please provide brief information on your airport: name, location, and traffic volume including type of airplanes and frequency.

- *N/A as I am an airport design consultant.*

2. What kinds of pavements are used in your airport and on which part?

- *In my experience, concrete and asphalt pavements are in all facets of airport pavement. Concrete is typically the material of choice for a complete rehab of a runway. Asphalt is typically the choice for a milling/paving maintenance or partial rehabilitations.*

3. What are the most three distresses exist in your airport pavement?

- *N/A*

4. Is reflective cracking a concern for your pavement team?

- *Reflective cracking is almost always an issue, especially with deteriorating overlays on both concrete and asphalt.*

5. Which techniques have been utilized to control reflective cracking?

- *Milling/paving, patching, fabric*

6. In your opinion, what is the most cost effective approach to control reflective cracking?

- *Varies on the application, construction performance, weather*

7. Are you interested in a new technique to control reflective cracking if proven cost effective?

- *Definitely*