BRIDGE DECK PRESERVATION SYSTEMS FOR EXPRESSWAY NETWORKS

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ABSTRACT

Deicing chemicals such as sodium chloride, NaCl, are typically used in winter season to prevent the icing of pavements and bridges. However, these deicing chemicals are known to cause severe degradation and deterioration of concrete bridge decks. These chemicals penetrate into concrete and corrode the reinforcements, and thus exacerbating concrete damage. To extend the durability of concrete decks, installation of wearing surface over the concrete deck has been implemented around the world. This wearing surface, which is placed on the top of a concrete deck, is required to prevent the infiltration of water and aggressive deicing chemicals. Different types of wearing surfaces or overlays have been tried by Korea Expressway Corporation. An asphalt concrete overlay along with waterproofing membranes had typically been adopted to protect concrete deck. However, the performance of this system was not satisfactory because severe deterioration of the overlays and decks had been reported. Recently, concrete overlays are mainly used for new and existing bridges in KEC. An exposed (or monolithic) concrete deck made of high-performance concrete was also proposed for bridges where the use of deicing chemicals is limited. The leakage of deicing chemicals through expansion joints has also caused the deterioration of bridge decks.

1. INTRODUCTION

Road conditions during the winter season pose numerous problems for road agencies worldwide. Effective and efficient removal of snow and ice is essential for securing safe driving conditions. Deicing chemicals such as sodium chloride (NaCl) and calcium chloride, ($CaCl_{2)}$ are typically used in winter to prevent icing on pavements and bridges.

In the past, the Korea Expressway Corporation (KEC) used a mixture of sand/calcium chloride mixture by spreading it on icy road surfaces. The sand provided the required traction, while the calcium chloride helped to melt the frozen snow. However, it was seen that in most cases the sand scattered off the road and had to be cleaned-up. To minimize the use of calcium chloride and its harmful environmental effects, the sand/calcium chloride mixture was replaced with deicing chemicals, namely a mixture of NaCl and $CaCl_2$. Rock salt, NaCl (70%), is wetted with a 30% calcium chloride solution. The $CaCl_2$ fosters the melting of snow and ice while the NaCl helps to keep it from refreezing. These deicing chemicals are spread using spreader trucks, as shown in Figure 1. As shown in Figure 2, a number of fixed anti-icing spray systems are also installed at high-risk highway segments and bridges.

Figure 1 – Spreader trucks

Figure 2 – Fixed de-icing spray system

The use of deicing chemicals, the calcium chloride/salt mixture, has increased the effectiveness of snow and ice control and reduced the cost. However these deicing agents have detrimental effects on the transportation infrastructure and have caused widespread concrete damages and deteriorations because the chloride can easily penetrate the concrete cover and cause the corrosion of the reinforcing steel bars. The penetration of the chloride in combination with freeze/thaw cycles accelerates the deterioration of concrete structures and has caused various kinds of damage, including cracks, spalling, scaling, and expansion.

A few years after the deicing agent was changed from the mixture of sand/$CaCl_2$ to the mixture of Nacl/$CaCl_2$, a rapid increase in the damage to concrete bridge elements was seen. As shown in Figures 3 and 4, the damage has been especially severe at exposed surfaces such as bridge decks, abutments and barriers. The bridge repair costs to fix these problems have also rapidly increased and now account for almost 50% of the total bridge maintenance budget of KEC. The rapid deterioration of concrete bridge decks is becoming the most serious maintenance problem. Similar deterioration problems with chloride deicers in the USA were reported by Huang et al. [1].

This paper discusses the bridge deck damage caused by the increased deicers in KEC. To protect concrete bridge decks, different overlay systems or wearing surfaces are typically placed on the top of the concrete deck. The characteristics and performances of these overlay systems are compared in detail. Another main contributor to bridge deck deterioration is bridge expansion joint leakage. Runoff water and deicing chemicals passing through leaking longitudinal and transverse expansion joints attack the girder ends

Figure 3 – Deterioration of deck

Figure 4 – Deterioration of barrier

and bearings, as well as the bridge deck. Preventive measures are being implemented by KEC to reduce the harmful effects of deicing chemicals and increase the durability and lifetime of the bridges.

2. DEICING/ANTI-ICING OPERATIONS BY KEC

Global warming and climate change have lead to increased snowfall in the Korean Peninsula and unpredictable weather patterns. During the winter season, heavy snowstorms and extended cold waves have become more frequent. Because of the increased snow and icing, the use of deicing/anti-icing chemical use has increased rapidly in recent years and the deterioration of bridges and pavements has worsened. Figure 5 shows the rapid increase in bridge repair costs caused by the increased use of deicing chemicals and the change in deicing materials.

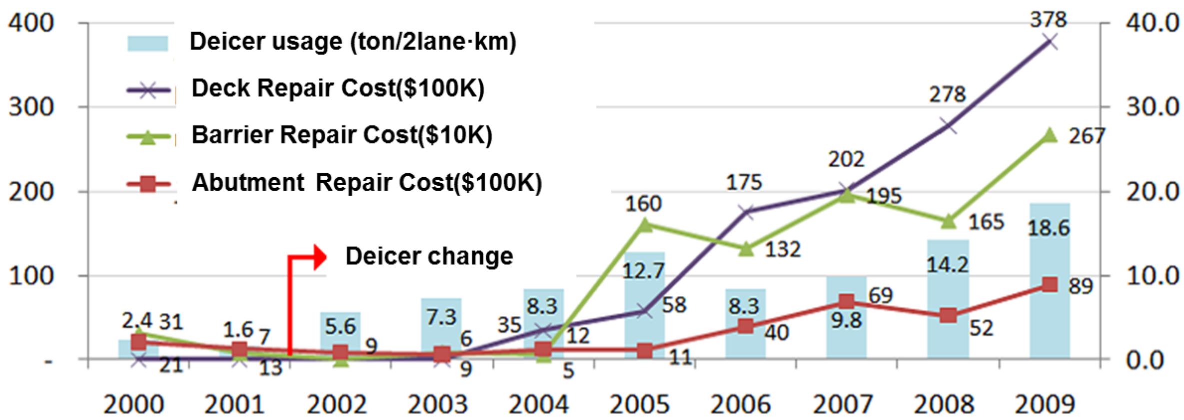


Figure 5 – Yearly deicer usage and repair cost

3. BRIDGE DECK AND OVERLAY

The concrete deck is the one of the most vulnerable structural component of a bridge and is easily deteriorated. Exposure to chloride from deicing agents, carbonation, and freeze/ thaw cycles are the major factors that reduce the durability of concrete bridge decks. An overlay is typically placed on a bridge deck to reduce the ingress of water and deicing chemicals and to improve the ride quality. Different overlay systems have been used by KEC.

3.1 Asphalt Overlay

An asphalt overlay on top of a concrete deck has conventionally been adopted. In Korea, two-course hot mix asphalt overlays, stone mastic asphalt (SMA) and polymer modified stone matrix asphalt (PSMA), have typically been applied. The PSMA wearing surface is known to have a high resistance to plastic deformation and limited permanent deformation. The typical thickness of the asphalt overlay is 80 mm: 40 mm of the base layer and 40 mm of the wearing layer. To prevent water and damaging deicing chemicals from reaching the concrete deck, a waterproofing membrane is placed between the concrete deck and the asphalt overlay.

The asphalt overlay requires a sound waterproofing membrane. Liquid membrane systems and preformed sheet membrane systems, which are made of bituminous polymeric and elastomeric materials, had typically been applied. To take advantage of the benefits of both membrane systems, combined double layer systems, which are composed of the liquid systems and preformed sheet membrane systems, have recently been favored in KEC. The typical components of these sheet and liquid membrane systems are similar to those of the membrane systems described in National Cooperative Highway Research Report (NCHRP) Synthesis 425 [2]. However, the waterproofing membrane has been found by KEC to be subject to poor performance and frequent damage because of the poor quality control during its installation and the lack of adhesion between the membrane and the asphalt overlay. Sometimes, water trapped between the membrane and the asphalt overlay leads to concrete deck deterioration.

3.2 Latex-Modified Concrete Overlay

A latex-modified concrete (LMC) overlay is produced by adding a latex admixture to Portland cement concrete. The typical thickness of the LMC wearing surface is 50 mm. It is more resistant to the intrusion of de-icing agents than an asphalt overlay and has good freeze-thaw resistance. LMC was first introduced in the early 2000s, and it has become the preferred overlay system. Though the LMC overlay has a higher initial cost than the asphalt overlay system, the overall life-cycle cost is lower because of its longer life and good long-term durability. However, it requires careful quality control, especially in an on-site production process.

When the wearing surface of in-service bridges are repaired, RSLMC (rapid set LMC), which can obtain the required strength within 3-4 hours after casting, is favored to reduce the curing and road closure time. The repair and rehabilitation of a deteriorated wearing surface can be finished in 8-10 hours, and therefore the bridge will only need to be closed overnight. However, it is expensive compared to the normal LMC overlay.

3.3 Exposed (Monolithic) Concrete Deck

A monolithic concrete deck or exposed concrete deck does not have a separate wearing surface. Instead, the concrete deck is monolithically cast with an additional 50 mm as an integral wearing surface. The additional concrete acts as the wearing surface and provides insulation against the infiltration of salt and water. The monolithic concrete deck was initially applied in the 1980s, but it was not actively employed because of its poor roughness and early cracks. However, a long-term study on bridges with monolithic decks showed that those cracks were limited to the surface and barely affected the performance and durability of the decks.

A number of studies were carried out to develop durable high-performance concrete (HPC) bridge decks without a wearing surface [3]. The HPC bridge deck thus developed satisfies the minimum compressive strength of 30 MPa, which is defined for concrete structures exposed to deicing chloride in the Concrete Structure Design Code [4]. To increase the crack resistance and durability of the deck, coal fly ash (10%) and ground granulated blast furnace slag (30%) are added to Portland cement (60%). By adding these admixtures, the resistance against freeze-thaw cycles and chloride attacks is also improved compared those of ordinary concrete. If required, diamond grinding is performed to improve the surface finish.

3.4 High-Performance Concrete Overlay

A concrete overlay made of HPC is also used to reduce the permeability and increase the durability of concrete bridge decks. To obtain durability and constructability, silica fume, fly ash, and poly vinyl alcohol (PVA) fiber, along with a high-performance air-entraining water reducer are added to the concrete mixture. Both the coal fly ash and ground granulated blast furnace slag have been found to be effective in mitigating a chemical attack caused by deicing chemicals. The thickness of the HPC overlay is 50 mm.

3.5 Selection of Overlay Systems

Asphalt overlays have mainly been used in the past. However, because an asphalt overlay has a relatively short life span of less than 10 years, its use has been limited to bridges with special needs. Recently, concrete overlays such as high-performance concrete and latex-modified concrete overlays are frequently adopted as alternatives. HPC monolithic decks are selected if the required surface roughness and constructability can be achieved. Table 1 indicates that more than half of the bridges in KEC have an asphalt overlay, while 30% have concrete overlays.

Table 1 - Use of overlay systems

Total number of bridges	Bridges with asphalt overlay	Bridges with concrete overlay			Other
		Sub total	Concrete overlay	Monolithic deck	
8,267 (100%)	4,719 (57.1%)	2,937 (35.5%)	2,504 (30.3%)	433 (5.2%)	611 (7.4%)

4. EXPANSION JOINTS

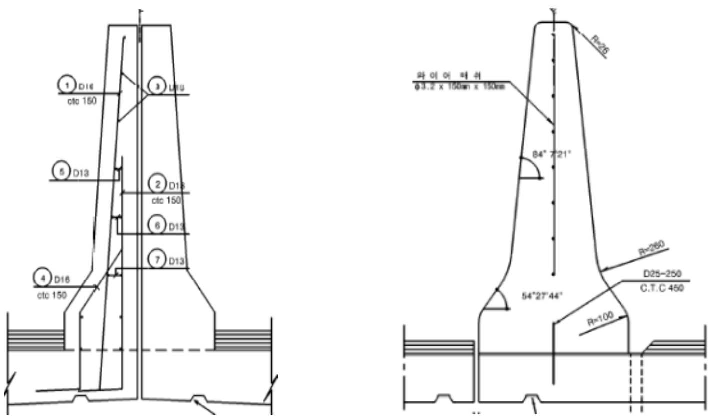
Transverse and end expansion joints are installed to accommodate movements caused by traffic, temperature variation, etc. Different types of joints are used, depending on the expansion length of the bridge. To protect the bridge elements under the expansion joints from runoff water and other contaminants, they are designed to be watertight and should be appropriately maintained. However, as shown in Figure 6, these joints are prone to damage and leakage. Deicing chemicals passing through a leaking expansion joints attack girder ends and bearings, as well as the bridge deck. A typical example of a deteriorated deck and abutment is shown in Figure 7.

To keep the joints in place and waterproof, preventive maintenance programs involving activities such as cleaning the joints and removing debris have been implemented. The expansion joints of bridges located in heavy deicer-use regions are retrofitted with a drainage trough to collect deck run-off water and deicers. Where possible, KEC also tries to minimize and eliminate the expansion joints on new bridges.

Figure 6 **–** Leaking expansion joint

Figure 7 **–** Deterioration of decks

In addition to the expansion joints in the bridge's transverse direction, a large number of KEC bridges have been constructed side-by-side to accommodate two-way traffic. Each bridge carries traffic in one direction. Each bridge has at least two lanes and a shoulder. When two bridges are constructed side-by-side, a concrete median can be constructed on one of the bridges, as shown in Figure 8(a), or on both bridges such that it is divided in half, as shown in Figure 8(b). When the median is installed on only one bridge, the other bridge is separated by approximately 20 mm, and the longitudinal joints between the two bridges are typically filled with filler such as Styrofoam. The median haven been usually installed on one bridge to increase the constructability and save construction costs. However, an internal study of in-service bridges with longitudinal joints showed that the joints have a negative impact on the durability of the bridge deck (Figure 9). Deicing chemicals were found to leak through the longitudinal joints and deteriorate the edge of the deck. Over 150 bridges had been affected by leaked deicing chemicals, and the decks of those bridges were substantially damaged.



(a) (b)

Figure 8 – Longitudinal joint details

Figure 9 – Deterioration of deck under longitudinal joints

To prevent further deck damage due to leakage at longitudinal joints, new joint systems such as a closed cell elastomer joint seal and an asphalt plug joint are being tried for in-service bridges. Water drainage systems to carry away runoff water and deicing chloride are also being installed. After the study, it was also recommended that new bridges be designed with a divided concrete median, as shown in Figure 8(b), with the exception of wider bridges with at least four lanes in one direction or bridges with different span lengths.

5. PREVENTIVE MEASURES

The increased use of deicing chemicals is becoming a major source of bridge deck damage and deterioration. Numerous preventive measures are being taken to control the harmful effects of deicing chemicals and increase the durability of the bridges in KEC.

5.1 Bridge cleaning

During the winter and early spring, water tanker trucks and high-pressure hoses, as shown in Figures 10 and 11, are used to remove the de-icing agent residue from bridges. It is carried out to prevent the chloride residue from attacking the concrete surface. Abutments, piers, barriers, medians, bearings, and expansion joints are cleaned using high-pressure water. Laboratory tests and a field study showed that the chloride content can be reduced by as much as 30% by cleaning. In regions of heavy snowfall, this cleaning must be carried out twice a month or after a couple of deicing operations.

Figure 10 – High-pressure water cleaning

Figure 11 – Water tanker truck

5.2 Deck Inspection Using Ground-Penetrating Radar

The condition of a concrete bridge deck covered with an asphalt overlay can be investigated by either removing the overlay or using non-destructive investigation methods. Though conventional non-destructive investigation methods such as chain dragging have been used earlier, ground-penetrating radar (GPR) has proven to be the most effective deck condition assessment method. GPR uses high-frequency radio waves to detect potential problems under the overlay. The vehicle-mounted GPR system shown in Figure 12 has been used for the condition evaluation of the decks in KEC because it can scan bridge decks rapidly and continuously. The system, which has four ground-penetrating radars, can be driven at speeds between 60 and 80 km/h. Each year about 100 bridge decks are investigated using the GPR system.

Figure 12 **–** A vehicle mounted GPR system

6. CONCLUSION

A bridge deck is directly exposed to not only vehicular live load but also various environmental attacks such as those from moisture, deicing agents and freeze/thaw cycles. The performance and durability of the overall bridge system is strongly affected by the durability of the bridge deck. The overlay installed to protect the bridge deck plays a critical role in bridge durability. The asphalt overlay system was predominantly employed earlier, but nowadays, concrete overlay systems are preferred if their implementation is possible. The leakage of deicing chemicals through the transverse and longitudinal expansion joints of a bridge has also contributed to the deterioration of the deck as well as the bearings and girders. To extend the service lives of decks and bridges, preventive maintenance and inspection programs have been devised and actively implemented.

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