Transportation Association of Canada

Structural Concrete Deck Protection Systems

March 2010

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Abstract

Chloride-ion induced corrosion of reinforcing steel is the most destructive cause of the early deterioration of concrete bridge components, requiring costly maintenance and rehabilitation. A significant portion of this cost is related to the deterioration of reinforced concrete decks which are subjected to heavy loadings, harsh weather conditions, and regular winter use of anti-icing and deicing salts across most of Canada. The optimization of reinforced concrete bridge, box culvert, and parking structure deck durability performance through enhanced technical and cost-effective structural concrete deck protection systems can play a key role in reducing maintenance, repair, and rehabilitation costs. The report provides information to assist in the engineering selection, design, construction, maintenance, repair, and rehabilitation of structural concrete deck protection systems (SCDPS) to optimize deck life-cycle durability and cost for Canadian conditions.

While a full range of SCDPS are considered, the report focus is on structural waterproofing systems (SWS) that are commonly used on Canadian transportation infrastructure reinforced concrete components to provide an impermeable barrier to protect the concrete, reinforcing steel, and strand steel from corrosion damage. These SWS are mainly sealers, bonded concrete overlays, liquid-applied polymer membranes, hot-applied rubberized asphalt membranes, and torch-applied and self-adhering rubberized asphalt sheet membranes.

An illustrated overview of concrete bridge deck waterproofing systems, continuing performance problems, corrosion, and concrete deterioration, with focus on the service life of reinforced concrete decks, is provided. A list of recommended current SCDPS technical resources and a summary of North American standards for deck protection systems and their use is provided.

The technical and financial comparison and evaluation of generally available current SCDPS for a new bridge deck project involves three main components: feasibility assessment; a comparative rating of the features and performance; and a life-cycle cost analysis. An example is provided to illustrate this evaluation methodology for the main current Canadian SCDPS (SWS).

Keywords

Concrete
Steels and Metals

- Deicing
- Corrosion
- Deterioration
- Prevention
- Sealing Coat (on top of the surfacing)
- Evaluation (Assessment)
- Cost-Benefit Analysis

Supplementary Information

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Systèmes de protection pour tabliers à structure en béton

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Résumé

La corrosion de l’acier d’armature induite par les ions chlorures est la cause la plus destructrice de la détérioration prématurée des composants des ponts en béton, entraînant des travaux de réfection et d’entretien dispendieux. Une partie significative de ces coûts est liée à la détérioration des tabliers en béton armé qui sont soumis à de lourdes charges, à des conditions atmosphériques sévères et à l’utilisation régulière en hiver de sels de dégivrage et antigivrage presque partout au Canada. L’optimisation du rendement de durabilité des ponts en béton armé, des dalots et des tabliers structuraux de stationnement à l’aide de systèmes de protection améliorés et rentables pour les tabliers à structure en béton peut jouer un rôle important dans la réduction des coûts d’entretien, de réparation et de réfection. L’objectif du présent rapport est de fournir de l’information pour aider au choix de l’ingénierie, de la conception, de la construction, de l’entretien, de la réparation et de la réfection des systèmes de protection pour tablier à structure en béton (SPTSB) afin d’optimiser la durée de vie et les coûts des tabliers dans des conditions canadiennes.

Même si une gamme complète des SPTSB sont prises en compte, le présent rapport porte principalement sur des systèmes d’imperméabilisation structuraux (SIS) qui sont couramment utilisés dans les infrastructures de transport canadien à composants en béton armé, afin de fournir une cloison imperméable pour protéger le béton, l’acier d’armature et les torons (armature) des câbles d’acier contre les dommages causés par la corrosion. Les SIS sont principalement composés de produits de scellement, de resurfaçage mince adhérent, de membranes au polymère appliquées à l’état liquide, de membranes bitumineuses caoutchoutées appliquées à chaud et de membranes bitumineuses caoutchoutées en feuilles appliquées au chalumeau ou auto-adhésives.

Un aperçu illustré des systèmes d’imperméabilisation des tabliers de pont en béton, des problèmes de rendement continus, de la corrosion et de la détérioration du béton, avec l’accent mis sur la durée de vie utile des tabliers en béton armé, est fourni en tant que cadre pour établir une synthèse de la technologie actuelle des SPTSB. Une liste des ressources techniques actuelles recommandées pour les SPTSB est fournie, ainsi qu’un résumé des normes nord-américaines pour les systèmes de protection des tabliers et leur utilisation.

La comparaison technique et financière et l’évaluation des SPTSB actuels généralement disponibles pour le projet d’un nouveau tablier de pont spécifique comprend trois composants principaux : une étude de faisabilité; une évaluation comparative des caractéristiques et du rendement; et une analyse du coût du cycle de vie. Un exemple est fourni pour démontrer la méthodologie de cette méthode d’évaluation pour les principaux SPTSB présentement utilisés au Canada (SIS).

Mots clés

Béton
Acier et métaux

- Déverglaçage
- Corrosion
- Altération (gen)
- Prévention
- Enduit de scellement
- Évaluation
- Calcul économique

Information supplémentaire

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EXECUTIVE SUMMARY

Chloride-ion induced corrosion of reinforcing steel is the most destructive cause of the early deterioration of concrete bridge components, requiring costly maintenance and rehabilitation. A significant portion of this cost is related to the deterioration of reinforced concrete decks which are subjected to heavy loadings, harsh weather conditions, and regular winter use of anti-icing and deicing salts across most of Canada. The optimization of reinforced concrete bridge, box culvert, and parking structure deck durability performance through enhanced technical and cost-effective structural concrete deck protection systems can play a key role in reducing maintenance, repair, and rehabilitation costs. The objective of this report is to provide information to assist in the engineering selection, design, construction, maintenance, repair, and rehabilitation of structural concrete deck protection systems (SCDPS) to optimize deck life-cycle durability and cost for Canadian conditions.

While a full range of SCDPS are considered, the report focus is on structural waterproofing systems (SWS) that are commonly used on Canadian transportation infrastructure reinforced concrete components to provide an impermeable barrier to protect the concrete, reinforcing steel, and strand (tendon) steel from corrosion damage. These SWS are mainly sealers, bonded concrete overlays, liquid-applied polymer membranes, hot-applied rubberized asphalt membranes, and torch-applied and self-adhering rubberized asphalt sheet membranes. The report focus on SWS must be recognized and the importance of rapid advances in new methods and materials, with enhanced durability performance and cost-effectiveness should be noted. The report is benchmarked to the Canadian Highway Bridge Design Code durability requirements, including the importance of deck drainage.

An illustrated overview of concrete bridge deck waterproofing systems, continuing performance problems, corrosion, and concrete deterioration, with focus on the service life of reinforced concrete decks, is provided as background to a synthesis of current SCDPS technology. A list of recommended current SCDPS technical resources and a summary of North American standards for deck protection systems and their use is provided. This is followed by a synthesis of Canadian, American, and international SCDPS use and experience. While SWS are commonly used across Canada, the American SCDPS focus is on multiple corrosion protection systems with little current waterproofing membranes used for new decks. The European (Eurocode) SCDPS experience is particularly relevant to Canada, with effective bridge deck and waterproofing system drainage, and detailed waterproofing, requirements.

Based on the SCDPS technical literature, a synthesis of Canadian, American, and international SCDPS technology and practical experience, the comparative features, performance advantages and disadvantages, life expectancy/ determining parameters, examples, and estimated current price ranges are outlined for: penetrating water-repellant sealers (dampproofing), rigid bonded concrete overlays, thin polymer overlays, as well as six waterproofing membrane systems: hot-applied rubberized mastic membrane; hot-applied (poured) rubberized asphalt membrane (plain and reinforced) with protection boards; liquid-applied polymer membrane; self-adhering manufactured sheet membrane with integral protection layer; torch-on manufactured sheet membrane with integral reinforcement and protection layer; and spray-applied polymer-modified asphalt membrane (proprietary system). Materials and construction methods information such as deck drainage, hot-applied rubberized asphalt membrane specifications, dense graded hot-mix asphalt (HMA) checklists, deck preparation for waterproofing, and inspection and testing requirements for waterproofing systems is also provided. Special waterproofing materials and active corrosion mitigation systems (cathodic protection) are briefly reviewed.

The technical and financial comparison and evaluation of the generally available current SCDPS, with focus on SWS, for a specific new bridge deck project involves three main components: feasibility assessment (suitability); a comparative rating of the features and performance (technical comparison); and a life-cycle cost analysis (financial comparison). The technical comparison is based on risk, properties, constructability (reliability), and maintenance, including rehabilitation. The financial comparison is based on a net-present value life-cycle cost analysis (LCCA) and project specific unit prices. An example is provided to illustrate this evaluation methodology for the five main current Canadian SCDPS (SWS): bonded-concrete overlay; hot-applied membrane; liquid-polymer membrane; self-adhering membrane; and torch-on membrane. The illustrative comparative ratings of risk, technical, construction, and maintenance were developed with respect to hot-applied rubberized asphalt membrane systems, the most commonly used SWS across Canada.

The ACI *Guide for Maintenance of Concrete Bridge Members* is recommended to agencies as a hands-on manual for preventive and responsive maintenance procedures. The readily available NCHRP *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements* is recommended for its deck repair and rehabilitation technology in terms of detailed design, standard field evaluation, standard laboratory evaluation, and service-life model procedures. The use of this NCHRP Manual is highly recommended for construction materials and bridge engineers involved with the design, implementation, maintenance, and rehabilitation of structural concrete deck protection systems.

RÉSUMÉ

La corrosion de l'acier d'armature induite par les ions chlorures est la cause la plus destructrice de la détérioration prématurée des composants des ponts en béton, entraînant des travaux de réfection et d'entretien dispendieux. Une partie significative de ces coûts est liée à la détérioration des tabliers en béton armé qui sont soumis à de lourdes charges, à des conditions atmosphériques sévères et à l'utilisation régulière en hiver de sels de dégivrage et antigivrage presque partout au Canada. L'optimisation du rendement de durabilité des ponts en béton armé, des dalots et des tabliers structuraux de stationnement à l'aide de systèmes de protection améliorés et rentables pour les tabliers à structure en béton peut jouer un rôle important dans la réduction des coûts d'entretien, de réparation et de réfection. L'objectif du présent rapport est de fournir de l'information pour aider au choix de l'ingénierie, de la conception, de la construction, de l'entretien, de la réparation et de la réfection des systèmes de protection pour tablier à structure en béton (SPTSB) afin d'optimiser la durée de vie et les coûts des tabliers dans des conditions canadiennes.

Même si une gamme complète des SPTSB sont prises en compte, le présent rapport porte principalement sur des systèmes d'imperméabilisation structuraux (SIS) qui sont couramment utilisés dans les infrastructures de transport canadien à composants en béton armé, afin de fournir une cloison imperméable pour protéger le béton, l'acier d'armature et les torons (armature) des câbles d'acier contre les dommages causés par la corrosion. Les SIS sont principalement composés de produits de scellement, de resurfaçage mince adhérent, de membranes au polymère appliquées à l'état liquide, de membranes bitumineuses caoutchoutées appliquées à chaud et de membranes bitumineuses caoutchoutées en feuilles appliquées au chalumeau ou auto-adhésives. On doit reconnaître que le rapport est centré sur les SIS et considérer l'importance des développements rapides de nouvelles méthodes et de nouveaux matériaux, ayant un rendement de durabilité amélioré et un meilleur rapport coût-efficacité. Le rapport est basé sur les exigences de durabilité du Code canadien sur le calcul des ponts routiers, y compris l'importance du drainage des tabliers.

Un aperçu illustré des systèmes d'imperméabilisation des tabliers de pont en béton, des problèmes de rendement continus, de la corrosion et de la détérioration du béton, avec l'accent mis sur la durée de vie utile des tabliers en béton armé, est fourni en tant que cadre pour établir une synthèse de la technologie actuelle des SPTSB. Une liste des ressources techniques actuelles recommandées pour les SPTSB est fournie, ainsi qu'un résumé des normes nord-américaines pour les systèmes de protection des tabliers et leur utilisation. Par la suite, on retrouve une synthèse de l'utilisation des SPTSB canadiens, américains et internationaux et des résultats obtenus. Alors que des SIS sont couramment utilisés partout au Canada, aux É.-U. l'accent pour les SPTSB est surtout mis sur les systèmes de protection de corrosion multiple utilisant actuellement peu de membranes d'imperméabilisation dans les nouveaux tabliers.

L'expérience européenne (Eurocode) en matière de SPTSB est particulièrement pertinente pour le Canada avec un système de drainage efficace des tabliers de pont et des systèmes d'imperméabilisation et indiquant les exigences détaillées pour l'imperméabilisation.

En se fondant sur la documentation technique des SPTSB, une synthèse des technologies des SPTSB canadiennes, américaines et internationales et les connaissances pratiques, les caractéristiques comparées, les avantages et les désavantages du rendement, les paramètres déterminant la durée de vie, des exemples et la gamme de prix courant estimée sont établis pour : les produits de scellement hydrofuge pénétrant (hydrofugation), le resurfaçage en béton adhérent rigide, le resurfaçage mince au polymère, ainsi que pour les six systèmes de membrane d'imperméabilisation : membrane au mastic caoutchouteux appliquée à chaud; membrane bitumineuse caoutchoutée (ordinaire et renforcée) appliquée à chaud (coulée), avec panneaux de protection; membrane au polymère appliquée à l'état liquide; membrane en feuille manufacturée auto-adhésive avec couche de protection intégrée; membrane en feuilles appliquée au chalumeau avec armature intégrée et couche de protection; et membrane bitumineuse modifiée au polymère appliquée par projection (système de marque déposée). L'information sur les matériaux et les méthodes de construction comme le drainage du tablier, les caractéristiques de la membrane bitumineuse caoutchoutée appliquée à chaud, les listes de vérification d'un enrobé dense d'asphalte mélangé à chaud, la préparation des tabliers pour l'imperméabilisation et les exigences relatives aux inspections et aux essais pour les systèmes d'imperméabilisation sont aussi fournies. On retrouve aussi un bref aperçu des matériaux d'imperméabilisation spéciaux et des systèmes d'atténuation de la corrosion active (protection cathodique).

La comparaison technique et financière et l'évaluation des SPTSB actuels généralement disponibles, avec l'accent mis sur les SIS, pour le projet d'un nouveau tablier de pont spécifique comprend trois composants principaux : une étude de faisabilité (pertinence); une évaluation comparative des caractéristiques et du rendement (comparaison technique); et une analyse du coût du cycle de vie (comparaison financière). La comparaison technique est fondée sur le risque, les caractéristiques, la constructibilité (fiabilité) et l'entretien, y compris la réfection. La comparaison financière est fondée sur une valeur nette actuelle de l'analyse du coût du cycle de vie (ACCV) et les prix unitaires pertinents au projet. Un exemple est fourni pour démontrer la méthodologie de cette méthode d'évaluation pour les cinq principaux SPTSB présentement utilisés au Canada (SIS) : resurfaçage en béton adhérent; membrane appliquée à chaud; membrane au polymère liquide; membrane auto-adhésive; et membrane appliquée au chalumeau. La description de l'évaluation comparative du risque, de la comparaison technique, de construction et d'entretien ont été établies en fonction de systèmes à membrane bitumineuse caoutchoutée appliquée à chaud; le SIS le plus couramment utilisé au Canada.

Le Guide for Maintenance of Concrete Bridge Members de l'ACI est recommandé aux organismes en tant que manuel pratique sur les procédures d'entretien préventives et adaptées. Le manuel du NCHRP Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge

Superstructure Elements, facilement disponible, est recommandé pour sa technologie en matière de réparation et de réfection des tabliers en ce qui concerne la conception détaillée, l'évaluation standard sur place, l'évaluation standard en laboratoire et les procédures pour établir un modèle de durée de vie. L'utilisation du manuel de NCHRP est fortement recommandée pour les matériaux de construction ainsi que pour les ingénieurs en ponts qui travaillent à la conception, à la mise en œuvre, à l'entretien et à la réfection des systèmes de protection pour tablier de pont à structure en béton.

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1 INTRODUCTION

1.1 Background

Chloride-ion induced corrosion of reinforcing steel is the most destructive cause of the early deterioration of concrete bridge components, requiring costly maintenance and rehabilitation (SHRP, 1993; NACE, 2001). A significant portion of this cost is related to the deterioration of reinforced concrete decks which are subjected to heavy loadings, harsh weather conditions, and regular winter use of anti-icing and deicing salts across most of Canada (Lounis, 2000). While little can be done to reduce bridge maintenance costs for existing bridges, it is imperative to reduce the maintenance, repair, and rehabilitation required, and associated costs, for new structures (TAC, 2004). It is also important to ensure the repair and rehabilitation technology adopted for existing structures provides improved life-cycle performance and cost effectiveness. To that end, the optimization of reinforced concrete bridge, box culvert, and parking structure deck durability performance through enhanced technical and cost-effective structural concrete deck protection systems (SCDPS) can play a key role in this important strategy. The objective of this report is to provide information to assist in the engineering selection, design, construction, maintenance, repair, and rehabilitation of structural concrete deck protection systems to optimize deck life-cycle durability and cost for Canadian conditions.

Requirements for the durability of reinforced concrete components and protective measures to ensure that the design life of new bridges is achieved are specified in the Canadian Highway Bridge Design Code (CHBDC; CSA, 2006a; CSA, 2006b), including deck waterproofing. CHBDC 8.11.2.7 Waterproofing states "Unless otherwise Approved, concrete decks that are expected to be salted for winter maintenance or are exposed to a marine environment shall be waterproofed with an Approved waterproofing system." The CHBDC also emphasizes the importance of deck drainage. CHBDC 1.8.2 Bridge deck drainage (1.8.2.1 General) states "Bridge deck drainage shall be designed to remove water from the deck as completely and quickly as possible and to discharge the runoff harmlessly." This report is benchmarked to the CHBDC throughout, as the CHBDC gives comprehensive SCDPS Code requirements and Commentaries.

While a full range of SCDPS is considered in this report, the focus is on structural waterproofing systems (SWS) that are used extensively on Canadian transportation infrastructure reinforced concrete and prestressed (pre- or post-tensioned) reinforced concrete components such as bridge, box culvert, and parking structure decks. The purpose of these waterproofing systems (mainly sealers, bonded concrete overlays, liquid-applied polymer membranes, hot-applied rubberized asphalt membranes, and torch-applied and self-adhering rubberized asphalt sheet membranes) is to provide an impermeable barrier to protect concrete, reinforcing steel, and strand (tendon) steel from damage, mainly due to chloride ion penetration. The SWS are generally applied directly to a properly prepared concrete surface, and the membranes are usually then protected from traffic action by placing a hot-mix asphalt (HMA) surfacing.

The SWS used, and their costs, requirements, and specifications vary across Canada, with performance advantages and disadvantages for each system in terms of risk, technology, construction, and maintenance. Unfortunately, there are some continuing, significant performance problems with SWS related to materials quality, surface preparation, construction problems, rutting and shear resistance, and asphalt concrete surface durability, that can be mitigated by close attention to overall system materials, construction, and maintenance quality (MTO, 1997). Basal shear failures associated with hot-applied (poured) rubberized asphalt membrane systems (most common Canadian waterproofing system), resulting in severe rutting, shoving, and cracking (failure) of the asphalt concrete surface, can be mitigated through enhanced membrane performance requirements and rutting resistant/thicker HMA, for example. Inadequate performance of a bridge deck waterproofing system will result in: significant impacts on the long-term integrity of the deck; damage to other bridge components subjected to leakage such as bearings and joints; costly repair, or rehabilitation, and work zone safety requirements; and reduced levels of service with user delays. It is very important when selecting a SWS to consider not only the potential performance and initial cost, but also the comparative life-cycle durability and cost.

1.2 Scope and Objective

In developing this report, the scope of work included:

- reviewing and synthesizing the current Canadian and relevant 'snowy' climate American and international SCDPS technology (including an overview of corrosion and concrete deck deterioration) with focus on Canadian harsh concrete deck exposure conditions (snow, ice, and salt);
- documenting the different SCDPS currently in use, with focus on SWS, in terms of:
  - comparative advantages and disadvantages;
  - design, construction, maintenance and rehabilitation standards, specifications, and procedures;
  - type, extent, and reasons for performance problems and their resolution; and
  - relative costs;
- developing guidelines for the technical comparison and evaluation of SCDPS and applying to representative SWS;
- developing guidelines for the financial comparison (service-life models and life-cycle cost analysis) of SCDPS and applying to representative SWS;
- identifying non-destructive methods to evaluate the effectiveness and condition of SCDPS;
- identifying maintenance, repair, and rehabilitation methods for poor performance SCDPS; and
- providing best practices recommendations for the engineering (technical and financial) selection, design, construction, maintenance, repair, and rehabilitation of SCDPS, with focus on structural waterproofing systems (SWS) in Canada.

It should be noted that while a full range of SCDPS are overviewed, the scope of the report is limited to products applied to reinforced concrete deck surfaces (essentially structural waterproofing systems); epoxy-coated reinforcement, concrete additives, and high performance concrete were not considered. This report focus on SWS must be recognized and the importance of rapid advances in new methods and materials, enhanced performance, as well as cost-effective SCDPS should be noted. For example, there is an American focus on multiple corrosion protection systems for bridge reinforced concrete components - silica fume high performance concrete with both layers of reinforcing steel epoxy-coated and a sealed exposed textured surface, for example (FHWA, 2000; FHWA, 2007). However, it will be fairly easy to extend this report beyond the SCDPS in current common Canadian use to a fuller SCDPS scope, once more Canadian experience with multiple corrosion protection systems develops such as some current British Columbia, Ontario, and Québec projects.

1.3 Overview of Concrete Bridge Deck Waterproofing Systems and Performance Problems

The photographs presented within this report, particularly in Appendix B, provide an overview of: reinforced concrete component deterioration and corrosion damage associated with poor drainage and chloride ion penetration; hot-applied (poured) rubberized asphalt membrane waterproofing system installation; some other SCDPS; typical waterproofing system asphalt concrete surface distresses; and testing hot-applied rubberized asphalt waterproofing system components. The following general background comments on SWS, based on a review of technical literature and practical experience with typical performance problems, provide an overview to the report:

- the function of the waterproofing (sealant, overlay, membrane, and sheet membrane) is to protect the new concrete deck from water and salt (chloride ion) ingress;
- the waterproofing (membrane) application will not stop corrosion in an existing deck with chloride ion ingress (may reduce rate), but may be a cost-effective approach to extending the concrete deck serviceability, depending on the overall rehabilitation work required;
- the asphalt concrete surface (overlay) protects the waterproofing (membrane) from traffic action and provides the wearing surface for traffic;
- the waterproofing (membrane) protection board/sheet (if any) and asphalt concrete surface (overlay) must be designed, specified, and constructed as an integral system (waterproofing system);
- the long-term integrity of the waterproofing (membrane) is a function of how well it is bonded to the properly prepared concrete deck surface and how much it is damaged during installation and by traffic action (however, even a damaged membrane will slow and limit water/salt ingress if it is well bonded);
- the bond of the membrane to the deck, protection board (if any) to membrane, and asphalt concrete overlay to protection board (all system components to be well bonded) is critical to

the satisfactory performance of the asphalt concrete overlay such as resistance to blistering, rutting, slippage, and cracking, particularly for heavy truck and bus traffic;

- the rutting resistance (shear and permanent deformation resistance) and thickness of the asphalt concrete surface are also critical to its satisfactory performance and must be dealt with through appropriate asphalt technology;
- the asphalt concrete surface is not impermeable and deck drains ('bleeder' or 'weep' tubes) are critical to prevent water/salt ponding at the membrane - asphalt concrete interface that will contribute to potential ingress, and particularly water damage ('pumping') of the asphalt concrete surface (emphasized in CHBDC);
- the overall waterproofing system (membrane and surface) involves a number of components, such as primer, membrane, vertical and horizontal details, protection layer (typically protection board), tack coats, drains, and HMA, and installation/construction details, procedures, and quality, that interact in developing the desired waterproofing system long-term performance;
- the development of depression and shearing (slippage) deformations and cracking in areas subjected to heavy wheel loadings is not uncommon for asphalt concrete placed over waterproofing (membrane) where the in-place overall shearing deformation resistance ('stability') is not sufficient (distresses typically start at weakened areas and may 'stabilize' with time);
- several interacting factors can contribute to a lack of sufficient shearing deformation resistance, including: fairly low basal shear resistance of some waterproofing (poor membrane adhesion and/or too thick for instance); exposed deck situation, with hot weather, that significantly reduces the stability of asphalt concrete; early heavy traffic wheel action before asphalt concrete has cooled adequately; generally thin nature of asphalt concrete surface over waterproofing; difficulty in achieving specified compaction; poor asphalt concrete quality; and potential trapped water action if appropriate drainage is not provided;
- the potential impact of asphalt concrete surface top-down cracking distress on bridge decks that has been recently identified must be dealt with through appropriate asphalt technology;
- the asphalt technology aspects of adequate asphalt concrete surface performance over waterproofing must be considered during the design, specification, and construction, such as: maximize waterproofing (membrane)/asphalt concrete basal shear resistance at high ambient temperatures; place high performance hot-mix asphalt over waterproofing; place adequate thickness of asphalt concrete (minimum properly compacted thickness of 65 mm, preferably 80 mm to allow for rehabilitation, unless a special mix is used); and strict HMA production, placement, and particularly compaction quality inspection and testing; and
- the lack of effective deck and joint drainage, resulting in water/salt (chlorides) rundown and penetration of reinforced concrete bridge components such as ballast walls, barrier walls,

girders, and piers for some bridges is surprising, given the pronounced role of water (particularly with chlorides) in concrete damage, and the CHBDC drainage requirements.

Throughout this report, the following working definitions are adopted (SHRP, 1993):

- protection method – a non-electrochemical method used to significantly reduce the rate of ingress of chloride ions into concrete components. Protection methods are limited to new decks and decks that are not critically contaminated with chlorides. Deck waterproofing systems are typical protection methods;
- repair method – a method that restores a deteriorated deck to a service level similar to the as-built condition, but with no effort to prevent or significantly slow deterioration mechanisms. A typical example is patching with concrete where the surrounding concrete is above the chloride threshold level and corrosion will accelerate along the patch perimeter. While sometimes considered a rehabilitation method, overlaying a deck where the top 15 mm is milled off, delaminated, spalled and patched areas repaired, and the deck overlaid with low-permeability concrete is actually a repair method, as chloride contaminated concrete is left in place and corrosion continues under the overlay;
- rehabilitation method – a method that corrects the deficiency that resulted in deteriorated concrete. A typical example is overlaying a deck with silica fume concrete where the top 15 mm is milled off, delaminated and spalled areas are repaired, deteriorated concrete is removed and repaired, all areas where the half-cell corrosion potentials are more negative than 250mV are removed and repaired, and the concrete overlay is placed over the entire deck. The original deficiency has been corrected, the more chloride-permeable as-built concrete has been replaced with low-permeability concrete, and the deck service life increased significantly;
- critical chloride contamination – the degree of cover concrete chloride contamination such that after the concrete is protected the chloride content at the reinforcing steel level will come to an equilibrium value of at least 0.12 kg/m^3 of acid-soluble chloride less than the corrosion threshold level; and
- corrosion chloride threshold level – the degree of chloride contamination of concrete that will activate the corrosion process, estimated to be about 0.71 kg/m^3 of acid-soluble chloride (total minus background). The acid-soluble chloride content of concrete aggregates is commonly referred to as the background chloride content, typically about 0.29 kg/m^3. A reasonable corrosion chloride threshold level estimate is thus about 1.0 kg/m^3 of concrete.

Canadian experience with structural waterproofing systems (mainly liquid-applied polymer membranes, hot-applied rubberized asphalt membranes, and torch-applied and self-adhering rubberized asphalt sheet membranes), and the SCDPS technical literature, offer common strategies for corrosion control and rules for membrane waterproofing systems, as shown in Tables 1 and 2, respectively.

Table 1 Common Strategies for Concrete Deck Reinforcement Corrosion Control (Adapted from TRL, 1998; SHRP 1993; FHWA, 2000; NACE 2001; CSA, 2006a; CSA, 2006b; FHWA, 2007)

- Provide proper deck drainage
  - most concrete deterioration mechanisms are primarily influenced by water and chloride ions making effective drainage critical
    - water held on or in the HMA surfacing
    - leaks through expansion joints
    - leaks from drainage and service duct systems
    - water held on bearing shelves
    - drips from through deck drains
    - drips from deck edges
    - airborne water (traffic spray and wind, marine environments)
- Prevent salt solution (chlorides) from penetrating concrete
  - high performance concrete, adequate reinforcement cover, impermeable waterproofing system
  - quality materials and construction of overall system
- Reinforcement coating
  - epoxy, zinc, nickel, combinations
- Corrosion resistant reinforcement
  - stainless steel, fibre reinforced polymer
- Addition of corrosion inhibitors to concrete
- Cathodic protection
- Electrochemical chloride extraction
- Multiple corrosion protection systems

Table 2 Some Practical Rules for Concrete Deck Waterproofing Systems Liquid-Applied Polymer Membranes, Hot-Applied and Spray-Applied Rubberized Asphalt Membranes, and Torch-Applied and Self-Adhering Rubberized Asphalt Sheet Membranes (Adapted from NCHRP, 1995; TRL, 1998)

- There should be no horizontal surfaces on the deck or surfacing
- Surface drainage should be designed to complement waterproofing membrane and expansion joints
- Water must not be allowed to accumulate within the asphalt concrete surfacing
- Through-deck drains with grates should be provided at all low points
- Drainage should be provided under all open expansion joints (sealed joints preferred)
- Leakage often occurs at the interface between expansion joints and waterproofing membrane
- All horizontal (pourbacks for instance) and vertical (chases for instance) waterproofing details must be functional (watertight) and constructible
- The concrete surface must be sound, properly finished, uncontaminated, dry, and dust free before priming
- The installed waterproofing membrane must:
  - prevent intrusion of water, moisture, and salts (chlorides)
  - bond very well to properly prepared and primed deck surface
  - effectively bridge joints and cracks in concrete
  - remain sufficiently elastic over all ambient temperatures to prevent failure by cracking
  - remain sufficiently stable to prevent distortion or shoving
  - be straightforward to place
- There is a risk of waterproofing blistering or pinholing due to outgassing unless the deck is dry and weather favourable for membrane installation
- Proper compaction of surfacing (HMA) is essential, particularly adjacent to horizontal (expansion joints for instance) and vertical (barrier walls for instance) details, which are vulnerable locations
- Basic expansion joint requirements associated with waterproofing
  - integrated with waterproofing as installed
  - solid anchorage to structure and firm support over gap
  - resistant to wear, weathering, aging, and plow and traffic damage
  - long maintenance-free service life with ease of replacement

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2 CORROSION AND CONCRETE DETERIORATION

2.1 Concrete Deterioration and Durability Requirements

Among the main causes of deterioration of reinforced concrete, prestressed (pre- or post-tensioned) reinforced concrete, and steel bridge components, chloride ion induced corrosion of conventional reinforcing and tendon steel ('black' rebar) is clearly the most destructive (SHRP, 1993; FHWA, 2000; NACE, 2001). Chapter 2 of the CHBDC sets out requirements for durability to be considered during the design of new bridges, as well as during repair and rehabilitation, in terms of materials, structural defects, bearing seals, drainage, utilities, birds and other animals, access, construction, inspection and maintenance, structural materials, aluminum, polychloroprene and polyisoprene, polytetrafluoroethylene, waterproofing membranes, backfill material, soil and rock anchors, and other materials (CSA, 2006a). The specific CHBDC durability requirements for concrete are comprehensive and given in Clause 8.11, Durability, that requires the following deterioration mechanisms, among others, to be considered:

- carbonation-induced corrosion without chloride;
- chloride-induced corrosion due to seawater;
- chloride-induced corrosion from sources other than seawater;
- freeze-thaw deterioration;
- alkali-aggregate reaction;
- chemical attack; and
- abrasion.

There are excellent concrete technology references available that provide a detailed treatment of concrete durability requirements with comprehensive design and control of concrete mixes information to meet these requirements, such as the Canadian edition of the PCA *Design and Control of Concrete Mixtures* (CAC, 2002).

The CHBDC also provides important specific protective measures requirements to be followed in Clause 8.11, Durability, for: concrete quality (composition, placement, compaction, cold joints, slip-form construction, finishing, curing, and exposure to chlorides); concrete cover and tolerances (noting that much tighter tolerances are recommended, ±10mm) for steel reinforcement, strands and ducts; corrosion protection for reinforcement, ducts and metallic components, sulphate-resistant cements; alkali-reactive aggregates; drip grooves; and waterproofing (CSA, 2006a). Only the concrete composition requirements will be emphasized here: satisfies all specified performance criteria; contains durable materials; can be placed, compacted, and cured to form a dense cover to the reinforcement; is free of harmful internal reactions such as alkali-aggregate reactions; withstands the action of freezing and thawing, including the effects of de-icing salts, where applicable); withstands external exposures (weathering, gases, liquids, and soils, for example); and withstands mechanical attack such as abrasion. It is very clear from the CHBDC and concrete technology literature that good deck drainage, high quality dense concrete, and appropriate concrete cover for reinforcing, strand and duct steel are critical to satisfactory concrete deck performance under all operating conditions.

The combination of a generally cold, snowy, and icy Canadian winter climate, and the need for all-season safe pavement surfaces, results in the use of considerable road salt. As a consequence, and combined with marine environments in Atlantic and Pacific areas of Canada, there are significant salt attack zones for bridge concrete components as indicated in Figure 1 (adapted from Pritchard, 1992).

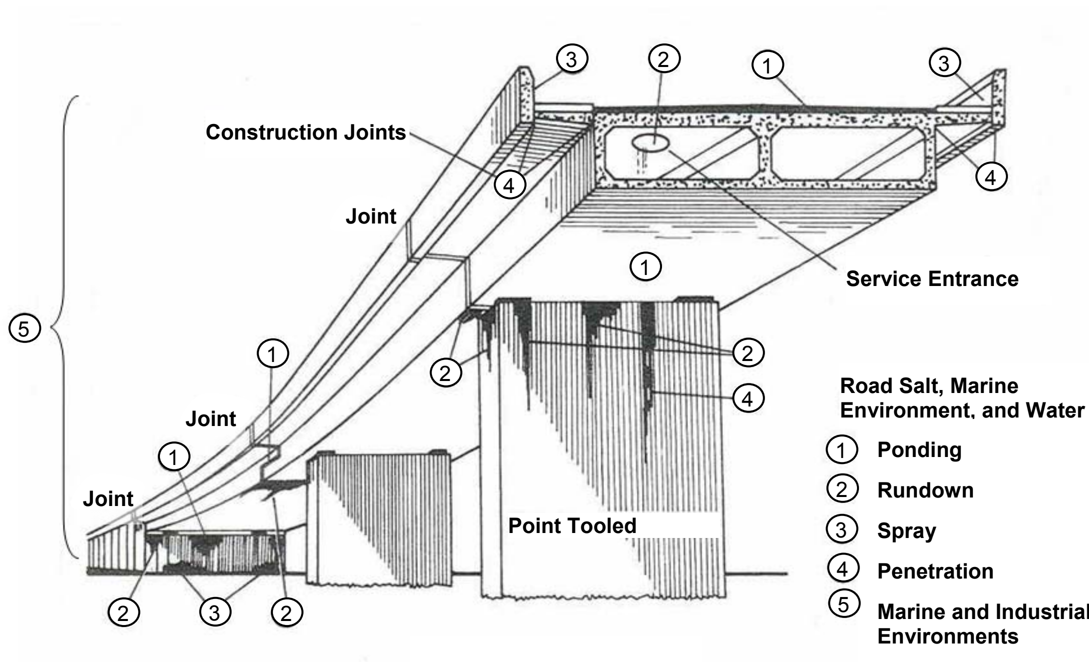

Figure 1 Typical Salt Attack Zones for Concrete Bridges (Adapted from Pritchard, 1992)

2.2 Corrosion Damage to Reinforced Concrete Decks

The specific concrete property of low tensile strength compared to compressive strength requires conventional steel reinforcement (rebar) and prestressed (pre- or post-tensioned) steel strands (tendons) in the tension zones of bridge concrete components such as decks and girders. Most of the concrete deterioration leading to reduced bridge service is associated with conventional reinforced concrete structures as they make up the majority of concrete bridges and generally have longer in-service times. While conventional reinforced and prestressed reinforced concrete bridges have specific design and corrosion-related concerns, the basic corrosion mechanism is similar and many control methods are applicable to both (NACE, 2001).

Concrete bridge decks are subjected to heavy truck loadings, weather extremes, and chloride-induced corrosion of the reinforcement. Corrosion products have three to six times greater volumes than the original steel, which results in expansive tensile forces that crack, delaminate, and spall the concrete, as shown in Figures 2 and 3 (SHRP, 1993; FHWA, 2000; NACE, 2001; Young, 1998). The corrosion of steel reinforcing bars and strands (tendons) is an electrochemical process that requires an electron flow and chemical reactions (galvanic corrosion cell) involving: an anode (oxidation reaction (Fe^{++}) location where corrosion is taking place and metal is being lost - anodic reaction); a cathode (reduction reaction (OH^{-}) location where metal is not consumed - cathodic reaction); and an electrolyte (facilitates flow of electrons - concrete, when exposed to wet-dry cycles, has sufficient conductivity to serve as an electrolyte). Concurrent anodic and cathodic reactions are necessary for corrosion to occur; the anode and cathode can be close together on individual steel bars or strands (microcells) or on separate steel bars or strands (macrocells) as shown in Figure 2 for a typical reinforced concrete deck where the chloride ions typically penetrate from the top surface (NACE, 2001). Corrosion of steel reinforcing bars and strands (tendons) embedded in concrete components is typically due to a combination of microcells and macrocells. Steel in high pH concrete, in the absence of chloride ions, is normally passive with negligible corrosion and, in theory, a very long service life. However, in practice, steel corrosion in concrete is accelerated by two primary mechanisms:

1. breakdown of the passive layer on the steel by chloride ions; and, to a lesser extent
2. carbonation due to carbon dioxide reactions with the cement phase of the concrete.

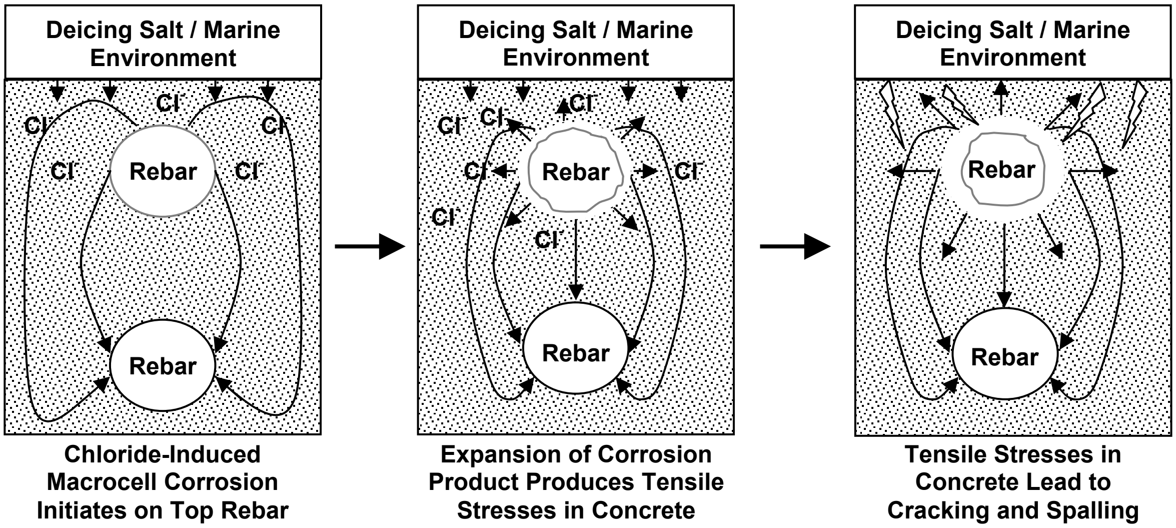

Figure 2 Schematic of Corrosion Damage to Reinforced Concrete Bridge Decks Exposed to Chlorides (Adapted from NACE, 2001)

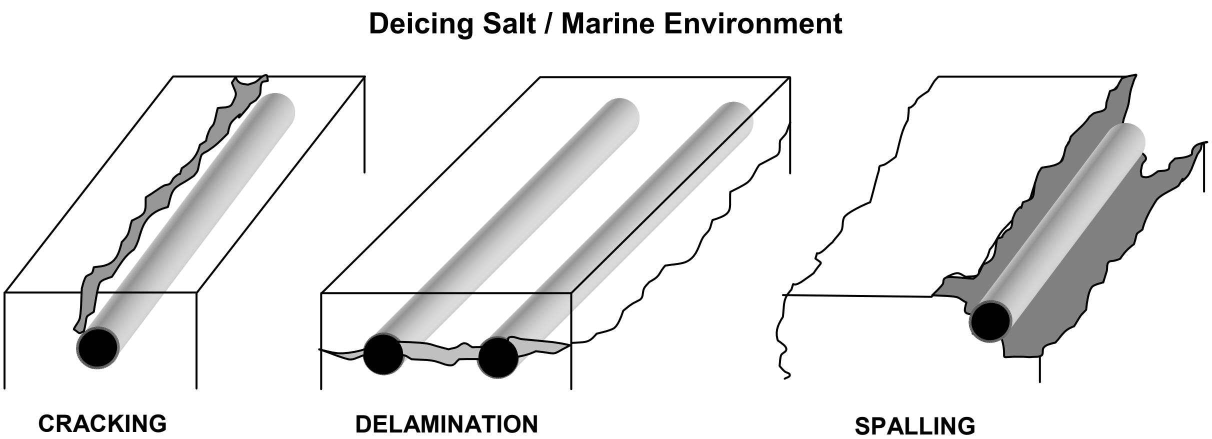

Figure 3 Cracking, Spalling and Delamination of Reinforced Concrete Due to Corrosion Damage (Adapted from Young, 1998)

For bridge reinforced concrete components designed and constructed in accordance with the CHBDC, the concrete cover over the reinforcing steel protects against carbonation, and virtually all corrosion related problems are caused by chloride ion migration (deicing salts and marine exposure) reaching the threshold level and the steel spontaneously rusting (Figure 2). The rate of corrosion is influenced by: chloride ion content (the higher the soluble chloride content at the reinforcing steel the higher the rate of corrosion); moisture content (pore water continuity) of concrete (as concrete dries its electrical resistance increases and the corrosion rate decreases); and oxygen available at the noncorroding site (reduced oxygen content at the noncorroding site reduces the corrosion reaction because the noncorroding and corrosion reactions must take place at the same rate (SHRP, 1993)).

Chloride ions migrate directly to the reinforcing steel through water-filled cracks such as plastic concrete subsidence cracks. Otherwise, the chloride ion diffuses through the cement matrix's water-filled pores. Where surface cracking occurs, such as plastic and drying shrinkage cracking, the diffusion path is shortened and corrosion begins sooner. Also, the higher the temperature the faster the corrosion reaction (faster during warm, moist spring and fall days, and slower during cold winter and dry summer days). The corrosion process and causes of concrete deterioration must be fully understood and addressed when rehabilitating a deck damaged by chloride ion induced corrosion.

2.3 Service Life of Reinforced Concrete Decks

The four stages of chloride ion induced deterioration of bridge reinforced concrete components are:

- Stage 1 - Chloride contamination and corrosion initiation;
- Stage 2 - Cracking – Occurs when the corrosion-induced tensile stresses exceed the tensile strength of the concrete (can be inclined or parallel to the deck surface);
- Stage 3 - Delamination – Occurs when cracks are parallel to the deck surface and result in a fracture plane (often at the top reinforcement level);
- Stage 4 - Spalling – Occurs when inclined cracks reach the deck surface, freeze-thaw cycles and traffic loading cause the cracked, delaminated portions to break away (accelerates the corrosion process).

Service-life models for reinforced concrete components (used in rehabilitation method selection and life-cycle costing, for instance) must realistically depict and predict the time to corrosion initiation (Stage 1) and the subsequent deterioration propagation rate (Stages 2, 3, and 4) (Tuutti, 1980).

The process of chloride corrosion deterioration (damage) accumulation for a bridge reinforced concrete component can be represented schematically in states, such as the discrete seven damage state durations that make up the Mean Service Life, proposed by Lounis (National Research Council of Canada) for the reliability-based life prediction of decks shown in Figure 4 (Lounis, 2000; Lounis, 2001).

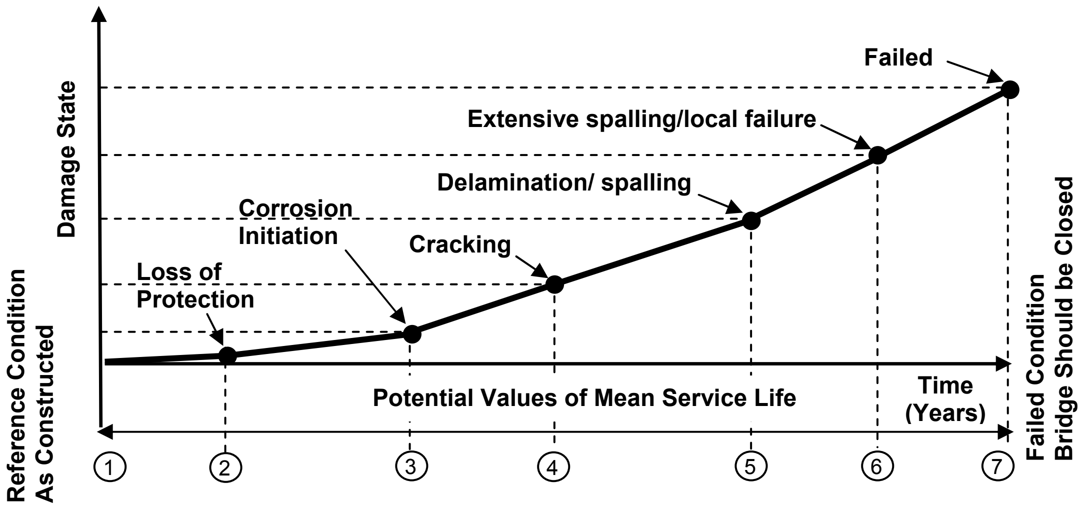

Figure 4 Typical Service Life Model of Reinforced Concrete Bridge Decks Exposed to Chlorides (Adapted from Lounis, 2000)

State 1 - reference state representing the initial deck condition with effective protection system and no damage;

State 2 - following the aging and failure of the protection system, the deck becomes exposed to chloride ingress (initiation time now followed by propagation time);

State 3 - chloride accumulation around the reinforcement reaches the threshold level and initiation of corrosion becomes probable;

State 4 - corrosion products start accumulating and induce tensile stresses that lead to longitudinal cracking (minor cracks, light scaling on less than 10 percent of the deck, and no spalling);

State 5 - rate of corrosion is accelerated by the generation of longitudinal cracks along the reinforcement (about 20 to 30 percent of the deck is contaminated, including any repaired areas, delamination and spalling on about 5 percent deck, and some full depth failures);

State 6 - advanced loss of reinforcement cross-sectional area and spalling of concrete on more than 15 percent of the deck (about 30 to 50 percent of the deck is deteriorated or contaminated, extensive and wide cracking with local overstresses that make some deck sections not capable of supporting heavy wheel loads, and the deck surface is rough with difficult vehicle control); and

State 7 - deck in failed condition and should be closed (full depth fractures over much of the deck, some deck sections have punched through, and the deck surface is irregular producing a rough ride with extreme difficulty in vehicle control).

It should be noted that the corrosion-related deterioration of a conventional reinforced concrete bridge component is a relatively slow process and should be detected through a bridge inspection program long before structural integrity is compromised (again noting CHBDC requirements). However, undetected corrosion resulting in failure of high-strength prestressing steel can compromise the integrity of a prestressed concrete component (bridge fracture critical component (NCHRP, 2005b) and merits close attention to construction details (ensuring void-free grouting of tendons, for instance) and subsequent systematic monitoring and inspection of prestressed concrete bridge components is critical (NACE, 2001).

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3 CURRENT STRUCTURAL CONCRETE DECK PROTECTION SYSTEMS TECHNOLOGY

3.1 Technology Resources and Sources

The deterioration of concrete bridge decks, mainly from chloride-induced corrosion of the reinforcement, is a worldwide costly problem fostering significant research and development activities, numerous technical publications, and a large materials and construction sector with a multitude of methods and materials for durable deck construction, maintenance, repair, and rehabilitation. As long as salt is used as an anti-icer/deicer, the ingress of chlorides will be the primary deck durability focus. It is not a new problem (RTAC, 1977; Ryell, 1983; Banks, 1986), and even with the wide availability of proven performance SCDPS, it is still a costly problem (NACE, 2001).

As a starting point for construction materials and bridge engineers using this report and the CHBDC, a list of recommended current technical resources is provided:

- Bridges, Concrete, Code, and Standards
  - *Concrete Bridges - Inspection, Repair, Strengthening, Testing and Load Capacity Evaluation* (Raina, 1994)
  - *Handbook of Concrete Bridge Management* (Branco, 2004)
  - *Bridge Management* (Yanev, 2007)
  - *Concrete - Microstructure, Properties, and Materials* (Mehta, 2006)
  - *Manual on Concrete Practice* (ACI, 2008a)
  - *Repair and Protection of Concrete Structures*, (Mailvaganam)
  - *Canadian Highway Bridge Design Code,* CAN/CSA-S6-06 (CSA, 2006a)
  - *Commentary on CAN/CSA-S6-06, Canadian Highway Bridge Design Code,* S6.1-06 (CSA, 2006b)
  - *Standard Recommended Practice – Design Considerations for Corrosion Control of Reinforcing Steel in Concrete,* NACE Standard RP0187-2005 (NACE, 2005a)
  - *Joint Surface Preparation Standard – Surface Preparation of Concrete,* NACE No. 6/SSPC-SP13 (NACE, 2003a)
  - *Standard Recommended Practice - Inspection of Linings on Steel and Concrete,* NACE Standard RP0288-2004 (NACE, 2004)
  - *Standard Recommended Practice – Fusion-Bonded Epoxy Coating of Steel Reinforcing Bar,* NACE Standard RP0395-99 (NACE, 1999)
  - *Sacrificial Cathodic Protection of Reinforced Concrete Elements – A State-of-the-Art Report*, (NACE, 2005a)
  - *State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures*, (NACE 2002)

- *Standard Practice – Electrochemical Realkalization and Chloride Extraction for Reinforced Concrete*, NACE Standard SP0107-2007 (NACE, 2007)
- *Standard Recommended Practice – Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures*, NACE Standard RP0390-2006 (NACE, 2006)
- *Guide for Maintenance of Concrete Bridge Members*, ACI 345.1R-06 (ACI, 2008j)

- TAC Guides
  - *Guide to Bridge Management* (TAC, 2004)
  - *Guide for Bridge Repair and Rehabilitation* (TAC, 2006)
- NACE/FHWA, SHRP, FHWA and NCHRP (TRB) Reports
  - *Corrosion Costs and Preventive Strategies in the United States*, FHWA-RD-01-156 (NACE, 2001)
  - *Concrete Bridge Protection, Repair and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual*, SHRP-S-360 (SHRP, 1993)
  - *Materials and Methods for Corrosion Control of Reinforced and Prestressed Concrete Structures in New Construction,* FHWA-RD-00-081 (FHWA, 2000)
  - *Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Components*, FHWA-HRT-07-043 (FHWA, 2007)
  - *Waterproofing Membranes for Concrete Bridge Decks*, Synthesis 220 (NCHRP, 1995)
  - *Concrete Bridge Deck Performance*, Synthesis 333 (NCHRP, 2004)
  - *Bridge Life-Cycle Cost Analysis*, Report 483 (NCHRP, 2003c)
  - *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements*, Report 558 (NCHRP, 2006b)
  - *Bridge Inspection Practices*, Synthesis 375 (NCHRP, 2007a).

3.2 North American Standards for Deck Protection Systems and Their Use

The CSA and AASHTO highway bridge design standards provide a background for current Canadian SCDPS practices, with focus on structural waterproofing systems (SWS):

- Canadian Highway Bridge Design Code (CSA, 2006a; CSA, 2006b)[1]
  - only waterproofing membrane requirements are provided with no associated specifications

    "2.7 Waterproofing membrane:

    Waterproofing membranes shall prevent the ingress of water and shall not crack during their service life.

[1] With agency Approval, other Approved SCDPS may be specified for the bridge.

Only Approved waterproofing membranes shall be specified.

Where a hot applied rubberized asphalt waterproofing membrane is used, it shall be protected with an asphalt-impregnated protection board to prevent it from being punctured. The membrane shall terminate in a chase in the curb or barrier wall.

The top surface of a waterproofing membrane shall be drained to prevent ponding of water on the membrane.

8.11.2.7

Unless otherwise Approved, concrete decks that are expected to be salted for winter maintenance or are exposed to a marine environment shall be waterproofed with an Approved waterproofing system.

C2.7 Waterproofing membranes:

Some of the waterproofing membranes in use are as follows:

(a) hot rubberized asphalt membrane;

(b) sheet membranes; and

(c) polymer membranes.";

- AASHTO LRFD Bridge Design Specifications (AASHTO 2008a; AASHTO 2008b)
  - mainly combined systems requirements are provided with associated specifications (AASHTO 2007b; AASHTO 2008c)

"2.5.2.1 Durability

2.5.2.1.1 Materials

…Reinforcing bars and prestressing strands in concrete components, which may be expected to be exposed to airborne or waterborne salts, shall be protected by an appropriate combination of epoxy and/or galvanized coating, concrete cover, density, or chemical composition of concrete, including air-entrainment and a nonporous painting of the concrete surface or cathodic protection….

C2.5.2.1.1

…Other than the deterioration of the concrete deck itself, the single most prevalent bridge maintenance problem is the disintegration of beam ends, bearings, pedestals, piers, and abutments due to percolation of waterborne road salts through the deck joints. Experience appears to indicate that a structurally continuous deck provides the best protection for components below the deck….

2.5.2.3 Maintainability

…Where the climate and/or traffic environment is such that a bridge deck may need to be replaced before the required service life, provisions shall be shown on the contract documents for:

- a contemporary or future protective overlay;
- a future deck replacement; or
- supplemental structural resistance….

C2.5.2.3

…Microsilica and/or calcium nitrite additives in the deck concrete, waterproofing membranes, and overlays may be used to protect black steel.";

- both the CHBDC and AASHTO emphasize the importance of bridge deck drainage, including the use of interlayer drainage tubes; and
- both the CHBDC and AASHTO emphasize the importance of quality deck concrete (CSA, 2003; CSA, 2004; AASHTO, 2007b; ACI, 2008a; ACI, 2008b; ACI, 2008d; ACI, 2008h).

The NCHRP Synthesis 333 *Concrete Bridge Deck Performance* (NCHRP, 2004a), that involved a survey of 38 state and seven provincial highway agencies (Alberta, Saskatchewan, Ontario, Québec, New Brunswick, Nova Scotia, and Newfoundland and Labrador), provides a fairly recent, comprehensive review of North American SCDPS, again noting the general Canadian use of waterproofing membranes (SWS) compared to the general American use of combined systems with little hot-applied rubberized asphalt membrane use. Responses to the NCHRP Synthesis 333 survey are summarized below and in Tables 3, 4 and 5 (NCHRP, 2004a). The number of respondents (out of a total of 45) identifying each item is shown in brackets ().

<u>concrete</u>

- strategies to provide low-permeability concrete
  - minimum clear cover (40), epoxy-coated rebar (38), low permeability concrete (29), protective barrier (19), high-strength concrete (14), corrosion inhibitor (10), stainless steel rebar (4), metallic-coated rebar (4), other rebar (3), FRP (2), no rebar (1), other (6);
- strategies to provide a concrete resistant to freeze-thaw damage and deicer scaling
  - air content (39), air void parameters (9), freeze-thaw test (5), deicer scaling test (2), other (5);
- strategies to provide abrasion resistant concrete
  - none (26), high-strength concrete (4), abrasion test (4), other (6);

<u>cracking</u>

- strategies to minimize cracking in bridge decks
  - minimum curing (42), maximum slump (40), maximum temperature (36), fogging (30), maximum cementitious materials (15), evaporation retarders (13), wind breaks (10), maximum strength (2), and other (17);
- types of curing specified
  - water-saturated cover (40), fog spray (19), liquid membrane (16), waterproof cover (10), waterponding (5), and none (0);

corrosion

- strategies to prevent corrosion of reinforcement in bridge decks
  - minimum clear cover (40), epoxy-coated rebar (38), low permeability concrete (29), protective barrier (19), high-strength concrete (14), corrosion inhibitor (10), stainless steel rebar (4), metallic-coated rebar (4), other rebar (3), FRP (2), no rebar (1), and other (6);
- strategies to provide a protective barrier for the deck concrete
  - overlays (24), sealers (19), membranes (17), and other (3);

design

- minimum clear cover specified for the top layer of reinforcement
  - 63 mm (23), 50 mm (13), 75 mm (4), 60 mm (3), and 70 mm (2);

deck reinforcement material

- epoxy-coated reinforcement specified
  - deck top layer (37), deck bottom layer (32), and projecting from top girder (19);
- types of reinforcement with metallic coating used
  - none (25), zinc coated (10), stainless clad (9), and other (3);
- other types of corrosion-resistant reinforcement used
  - FRP (10), solid stainless steel (9), and microcomposite (6).

Table 3 North American Use of Sealers on Concrete Decks (Adapted from NCHRP, 2004a)

Sealer Type	Number of Respondents[a]		Performance Rating[b]	
	Past Use	Current Use	Range	Average
None	4	7	—	
Silanes, Siloxanes	17	19	1 to 5	2.8
Epoxies	10	9	1 to 4	3.0
Linseed Oil	24	7	1 to 5	3.6
Other	11	8	1 to 5	4.2

Notes: a. Total number of respondents was 45, including Alberta, Saskatchewan, Ontario, Québec, New Brunswick, Nova Scotia, and Newfoundland.
b. Rating scale: 1-excellent; 5-poor; and — not applicable.

Table 4 North American Use of Overlay Systems on Concrete Decks (Adapted from NCHRP, 2004a)

Overlay Type	Number of Respondents[a]		Performance Rating[b]	
	Past Use	Current Use	Range	Average
None	6	5	—	—
Asphalt Concrete Without Membrane	28	16	1 to 5	3.6
Latex-Modified Concrete	26	20	1 to 5	2.4
Low-Slump Dense Concrete	26	12	1 to 5	2.4
Fly Ash Concrete	4	11	1 to 4	2.4
Silica Fume Concrete	10	21	1 to 3	2.0
Epoxy	11	11	1 to 5	2.6
Polyester	4	2	1 to 5	2.5
Other	5	4	1 to 5	2.8

Notes: See Table 3

Table 5 North American Use of Waterproofing Membrane Systems on Concrete Decks (Adapted from NCHRP, 2004a)

Membrane Material	Number of Respondents[a]		Performance Rating[b]	
	Past Use	Current Use	Range	Average
Preformed Systems				
None	10	10	—	—
Asphalt-Impregnated Fabric	15	9	2 to 5	3.0
Polymer	4	0	2 to 5	2.8
Elastomer	3	4	1 to 5	3.2
Asphalt-Laminated Board	7	3	2 to 4	3.0
Other	2	2	2 to 4	2.7
Liquid Systems				
Asphalt	11	10	1 to 5	2.8
Resinous	3	3	1 to 5	3.3
Other	4	3	1 to 4	2.6

Notes: a. Total number of respondents was 45, including Alberta, Saskatchewan, Ontario, Québec, New Brunswick, Nova Scotia, and Newfoundland.
b. Rating scale: 1-excellent; 5-poor; and — not applicable.

3.3 Canadian Concrete Deck Protection Systems Use and Experience

The NCHRP Synthesis 332 (NCHRP, 2004a) and available Canadian SCDPS technical information was supplemented with a questionnaire (Appendix C) to provide more comprehensive Canadian SCDPS methods, materials, and performance information, with focus on SWS. Based on these various resources, current Canadian experience can be summarized as follows, where performance ratings are given on a scale of [1] (excellent) to [5] (poor):

- Alberta (Carter, 1989; Stidger, 2005)
  - sealers – silanes, siloxanes, and siliconates; silane sealer [1] applied every four years to exposed deck surfaces, curbs, and barriers (Alberta, 2001; Alberta, 2008)
  - waterproofing membrane – hot-applied rubberized asphalt [1] is standard practice (Alberta, 2007)
  - overlay systems – HPC (flyash/silica fume/steel fibre) [1] is current practice (also epoxy [3] and none [3])
  - experience – 1. hot-applied rubberized asphalt membrane system (two 40 mm HMA lifts) used for the last 25 years has been performing very well and 2. polymer overlays historically had bonding problems which created maintenance issues
  - cathodic protection – tried on two decks in the 80s with limited success and then abandoned
  - key technology references (available at www.infratrans.gov.ab.ca - use latest version)

    Best Practice Guidelines for Selecting Concrete Bridge Deck Sealers (Alberta, 2001)
    Approved Products for Sealers Used on Concrete Bridge Elements (Alberta, 2008)
    Bridge Deck Waterproofing, Specifications for Bridge Construction (Alberta, 2007).
- Calgary
  - sealers – silanes, siloxanes, and siliconates [3]
  - overlay system – polymer-modified HMA [1] (Calgary, 2006; Calgary, 2007)
  - cathodic protection – tried two systems; conductive coating is still active and Ferex 100 failed
  - experience – liquid applied membrane used to 70s, switched to Iowa high density overlay in early 1980s, switched to polymer-modified asphalt overlay (20 mm membrane/30 mm HMA) in late 1980s, and further modified to single 50 mm polymer-modified HMA which remains standard (some site specific requirements).
- Edmonton
  - sealers – silanes, siloxanes, and siliconates [3]
  - overlay system – polymer-modified HMA [3]
  - cathodic protection – have used impressed current type in one bridge and system seemed to work well
  - experience – 1. not convinced hot-applied rubberized asphalt membrane system provides desired protection (noted membrane had been compromised when repairing some decks) and 2. have switched to polymer-modified HMA overlay (see Calgary above), but too early to judge effectiveness.
- British Columbia
  - sealers – silane sealers have been applied on new exposed cast in place concrete bridge barriers on some bridges.

- linseed oil – used on concrete bridge decks by maintenance crews in some areas of the province
- waterproofing membranes – rubberized asphalt prefabricated membranes overlaid with hot mix asphalt pavement have been used on many bridges in the Vancouver and Vancouver Island areas over the last 15 to 20 years. Hot applied rubberized asphalt and liquid applied polymer membranes are now being used on some bridges in the Vancouver and Vancouver Island areas. Bridges in other areas of the province usually do not have membranes on the decks.
- experience – some performance problems (poor bond, trapped water action, and asphalt concrete overlay deterioration) with self-adhering rubberized asphalt sheet/HMA systems.

- Manitoba
  - sealers, waterproofing membranes (hot-applied rubberized asphalt and self-adhering rubberized asphalt sheet), and cathodic protection given in Products Standards List (Manitoba, 2002; Manitoba, 2004).
- Winnipeg
  - sealers – silanes [2] are used to seal concrete decks, barriers and subway walls on a four year cycle
  - overlay systems – silica fume concrete [2], epoxy [3], and methyl methacrylate [2] (Winnipeg, 2006)
  - experience – 1. stopped using hot-applied rubberized asphalt membranes in about 1980 due to poor performance, 2. Iowa dense concrete overlays used in 80s have performed well, but chlorides now reaching reinforcement at 20 years for some, 3. reinforced high density/high performance concrete overlays (new and rehabilitated decks) have similar performance to Iowa dense concrete, but significantly more cracking (addressed by adding fly ash and microfibres), 4. epoxy-aggregate wearing systems (Flexolith, Degusso, Traffic Guard EP-35, and E-Bond 526) installed on new and rehabilitated decks 2 to 10 years after construction (crack sealing and preventative maintenance) have experienced some failures (usually stripping off in sheets) as soon as seven years (anticipated life expectancy 15 years); and 5. methyl methacrylate (MMA) system (Degusso Degadeck) similar to 4 (MMA instead of epoxy resin) trial in early 90s has performed very well (more expensive than epoxy) and specifically specified for 2005 project which is being evaluated
  - cathodic protection – two bridges with impressed cathodic systems: 1987 Ferex not working by 1995; and 1990 titanium mesh working when monitored in 2002 and to be monitored again in 2007
  - key technology reference:

    Skid Resistant P*olymer Wearing Surface*, (Winnipeg, 2006).

- New Brunswick (NCHRP, 2004a)
  - waterproofing membrane – self-adhering rubberized asphalt sheet [3] (New Brunswick, 2006)
  - overlay systems – silica fume concrete [1] and Rosphalt 50 HMA [2].
- Newfoundland and Labrador
  - sealers – silanes, siloxanes, and siliconates [3]
  - waterproofing membranes – self-adhering rubberized asphalt sheet [3], hot-applied rubberized asphalt [3] (Newfoundland, 2002), and torch-applied rubberized asphalt sheet (Soprema and Bakor) on project by project specific basis
  - overlay systems – silica fume concrete [4]
  - experience – 1. waterproofing system is generally hot-applied rubberized asphalt membrane/protection board/HMA, 2. have localized and sometimes premature failures with both membrane systems (sometimes in asphalt concrete and sometimes with both membrane systems (sometimes in asphalt concrete and sometimes in membrane), and 3. moved towards exposed concrete decks (universally in Labrador) with silica fume concrete (some feel cracking more of a problem prior to silica fume use).
- Nova Scotia (NCHRP, 2004a)
  - waterproofing membrane – hot-applied rubberized asphalt [2]
  - cathodic protection – impressed current system with coke breeze layer used on one structure in early 80s and the system seems to be effective.
- Ontario (NCHRP, 2004a)
  - sealers – silanes, siloxanes, and siliconates as a primer followed by an acrylic top coat
  - waterproofing membrane – hot-applied rubberized asphalt [1] (MTO, 2004; OPSS, 1998; OPSS, 2008; MTO, 2008)
  - overlay systems – latex-modified concrete [1] and silica-fume concrete [2]
  - experience – the single most cost-effective protective system is the waterproofing membrane, it generally lasts about 25 years before replacement, and a study has shown very little chloride penetration through the waterproofing after 18 to 20 years in service (MTO 1997)
  - cathodic protection – conductive asphalt system used until late 80s, but performance was very poor, and from early 90s titanium mesh system has been used with good performance so far
  - key technology references (available at www.mto.gov.on.ca – use latest version)

    Ontario Provincial Standard Specifications, (OPSS, 2008)

    Construction Specification for Waterproofing Bridge Decks with Hot Applied Asphalt Membrane (OPSS, 1998; OPSS, 2008)

    Designated Sources Materials Manual, (MTO, 2008)

Field Guide for the Acceptance of Hot Mix and Bridge Deck Waterproofing, (MTO, 2007).

- Ottawa
  - sealers – silanes, siloxanes, and siliconates [3]
  - waterproofing membrane – hot-applied rubberized asphalt [4]
  - overlay systems – silica fume concrete [3]
  - experience – 1. hot-applied rubberized asphalt membrane/protection board/HMA used extensively and works well except where exposed to high percentage of buses and trucks (worst areas are idling area and deceleration areas on downgrades) and 2. several bus idling areas have been protected with 90 to 100 mm of high performance concrete, which when properly placed and cured have performed very well.
- Toronto
  - sealers – silanes, siloxanes, and siliconates [3] (Toronto, 2001b)
  - waterproofing membranes – hot-applied rubberized asphalt [1] (Toronto, 2001a; Toronto, 2006a) and liquid-applied polymer [3] (Toronto, 2006b)
  - overlay systems – silica fume concrete
  - experience – 1. generally use hot-applied rubberized asphalt membrane/protection board/HMA (two ply with polyester fabric reinforcement, special membrane requirements – maximum cone penetration of 120 mm at 50ºC and no flow at 60ºC, and high performance HMA) over the entire deck and including 2 m on the approach slabs – this system has worked very successfully (Toronto, 2001a; Toronto, 2006a), 2. have used the Stirling Lloyd Eliminator system on some bridge decks with heavy bus traffic – the Eliminator has not performed any better than the hot-applied asphalt membrane system in the heavy braking areas (still have shear plane failures and have learned that the performance will be improved by broadcasting aggregate into the second coat of the Eliminator membrane), and 3. have recently used Decseal on a pedestrian bridge which has performed quite well (Toronto, 2006b)
  - cathodic protection – one system installed as a trial some time ago but abandoned for unknown reasons
  - key technology references

    Amendment to OPSS 914 - Construction Specification for Waterproofing Bridge Decks – Asphaltic Membrane, (Toronto, 2001a)

    "Decseal" Waterproofing S.1 (Toronto, 2006b).
- Public Works and Government Services Canada (PWGSC)
  - sealers – silanes, siloxanes, and siliconates [3]
  - waterproofing membrane – weldable prefabricated sheet membrane [2]
  - overlay systems – silica fume concrete [2]
  - experience – most bridges located in far north where access to protective systems not

readily available at competitive costs – best design technique is excellent drainage, quality concrete, and proper reinforcing bar clear cover.

- Québec (NCHRP, 2004a)
  - waterproofing membrane – torch-applied rubberized asphalt sheet (Soprema) [2]
  - experience – 1. the expected life of the torch-applied rubberized asphalt sheet membrane/HMA system (Soprema) is about 20 years when it is possible to remove the asphalt concrete without affecting the membrane (not always possible) and 2. HPC (ternary mixes) have been used for all decks for some time with a minimum cement content (325 kg) requirement to assure durability.
- Saskatchewan
  - sealers – silanes, siloxanes, and siliconates [3]
  - waterproofing membrane – hot-applied rubberized asphalt [2]
  - experience – 1. blister problems with Soprema torch-applied rubberized asphalt sheet membrane/microsurfacing system (required HMA overlay to keep blisters down), 2. numerous debonding locations with liquid-applied polymer membrane, 3. used high density concrete overlays in late 70s and early 80s with only 20 year life and poor ride, and 4. currently use hot-applied rubberized asphalt membrane/protection board/HMA (seepage drains important)
  - cathodic protection – used two systems in the early 80s; Ferex system failed and switched to Elgard system which worked well.

It is of interest to note that the 1972 OECD Report *Waterproofing of Concrete Bridge Decks* also indicated that hot-applied (poured) rubberized asphalt membrane/protection board/HMA was the most commonly used Canadian SWS (OECD, 1972). Of course, significant improvements have been made to SWS since 1972, particularly with respect to deck and membrane interface drainage requirements, membrane bond to the deck, and overlay asphalt concrete performance.

3.4 American Concrete Deck Protection Systems Use and Experience

As indicated in previous chapters, the American SCDPS focus is on multiple corrosion protection systems (silica fume HPC/epoxy-coated rebar/sealed surface, for instance) with little current use of membrane systems for new decks (NCHRP 2004a; NCHRP, 2004a; FHWA, 2000; FHWA, 2007). Bridge deck reinforcement corrosion and concrete distress is one of the leading causes of structural deficiency and most significant maintenance problems in the US National Bridge Inventory (NACE, 2001; NCHRP, 2004a; NCHRP, 2004b; NCHRP, 2007b). Concrete bridge deck durability and deterioration has been a major US bridge performance concern since the late 60s (road salt was not commonly used to the 50s) to the present (AASHTO, ACI, FHWA, NACE, and NCHRP, for instance) (AASHTO, 2008a; ACI, 2008a; FHWA, 2000; FHWA, 2005a; FHWA, 2007; NACE, 2001; NCHRP, 1970; NCHRP, 1979; NCHRP, 1987; NCHRP, 1995; NCHRP, 2004a; NCHRP, 2004b). An overview of current US SCDPS was provided in Section 3.1, particularly strategies to prevent corrosion of reinforcement in bridge decks (NCHRP, 2004a).

The conclusions of NCHRP Synthesis 333 provide a good overview of current US SCDPS practices (NCHRP, 2004a) that are covered in detail by AASHTO, ACI, ASTM, FHWA, NACE, NCHRP, and TRB publications, as summarized below:

- good deck drainage, adequate cover over reinforcement, quality concrete, and proper concrete curing (preferably continuous water-saturated cover for a minimum of seven days) are emphasized for all SCDPS (AASHTO, 2008a; AASHTO, 2008b);
- low-permeability, high-performance concrete (HPC), generally achieved with low water-cementitious material ratios (w/cm) and supplemental cementitious materials (fly ash, silica fume, and slag cement) is in regular use, with good practices adopted to control cracking (FHWA, 2000; FHWA, 2005a; FHWA, 2007; Holland, 2005; Jaber, 2005; Lwin, 2006; NCHRP, 2007b; TRB, 2006)
  - use of low w/cm and supplementary cementitious materials result in HPC with higher compressive and tensile strengths, higher elastic modulus, and less creep
  - incorporating a high-range, water-reducing admixture allows the HPC to be placed and finished without too much difficulty
  - although the HPC tensile strength is higher, the higher elastic modulus and lower creep can result in increased cracking, which then provides chlorides with an easier path to the reinforcement, offsetting the durability benefits of the HPC
  - important to design a HPC with a reasonably low chloride permeability (1500 to 2500 coulombs) while not increasing the cracking potential (ASTM C1202 chloride ion penetrability based on charge passed in coulombs: negligible <100; very low 100-1000; low 1000-2000; moderate 2000-4000; and high >400 (ASTM, 2007a))
  - require close attention to ambient conditions and fogging during placement, and adequate curing of the hardened concrete (particularly important when supplemental cementitious materials used because of tendency for less bleed water on the surface); typically specified as a continuous water-saturated cover immediately after finishing for a minimum of seven days, followed by a white pigmented curing compound application after the wet curing period to slow down the shrinkage and enhance the concrete properties (Lwin, 2006)
  - the FHWA *High Performance Concrete Structural Designer's Guide* provides current, comprehensive technical information on the use of HPC, and is kept current (www.knowledge.fhwa.dot.gov/cops/hpcx.nsf/home) (FHWA, 2005).
- early age cracking, typically within the first few months, of newly constructed reinforced concrete bridge decks, with transverse cracking the most prevalent, is a nationally recognized problem that must be addressed for satisfactory deck durability and performance (FHWA, 2005a; Holland, 2005; Lwin, 2006; NCHRP, 2004a)
  - cracks perpendicular to the reinforcement hasten corrosion by facilitating the ingress of moisture, oxygen, and chloride ions

  - crack widths of less than 0.3 mm have little effect on the overall corrosion of reinforcement; wider cracks accelerate the onset of corrosion by several years, but crack width has little effect on the rate of corrosion (at the level of transverse reinforcement, the chloride content at crack locations can exceed the corrosion threshold level in as little as three years) (NCHRP, 2004a)
  - cracks that follow the line of reinforcement are more serious as the length of bar below the crack is exposed to the ingress of moisture, oxygen, and chloride ions, and the crack also reduces the concrete's resistance to spalling as the reinforcement corrodes (BRE, 1993)
  - strategies currently used to minimize bridge deck cracking include (Lwin, 2006):
    - decreasing the volume of water and cementitious paste consistent with achieving properties
    - using the largest practical maximum size aggregate
    - using aggregates that result in lower concrete shrinkage
    - using the smallest transverse bar size and minimum spacing that are practical
    - avoiding high concrete compressive strengths
    - designing the concrete mix to produce a low modulus of elasticity and high creep (allows for some reduction of shrinkage tensile stress development)
    - implementing surface evaporation requirements and using windbreaks and fogging equipment, when necessary, to minimize surface evaporation from plastic concrete
    - applying wet curing immediately after finishing and curing continuously for at least seven days
    - applying a curing compound, preferably white pigmented, to slow down the shrinkage and enhance the deck concrete properties
  - the most effective strategies appear to be fogging and adequate curing (NCHRP, 2004a).
- epoxy-coated reinforcement continues to be the most common reinforcement used to reduce the potential for deck deterioration from corrosion
  - using epoxy-coated reinforcement in both layers of deck reinforcement provides better corrosion performance than when used in the top layer only
  - epoxy-coated reinforcement must be properly manufactured, stored, handled, installed, and carefully repaired, as necessary (NACE, 1999)
  - epoxy-coated reinforcement cannot be relied on to not corrode in a wet (marine) environment
  - use of alternative reinforcement coatings (zinc coated and stainless clad, for instance) and materials (FRP, stainless steel, and microcomposite, for instance) is increasing with long-term performance evaluations in progress (FHWA, 2007; NCHRP, 2003a; NCHRP,

2003d; NCHRP, 2006a)

- bridge deck protective system used to protect the deck concrete and reinforcement include sealers, SWS (overlays and membranes), and cathodic protection
  - sealing of exposed concrete deck surfaces is used as a low-cost approach to delay deterioration
  - latex-modified and low-slump dense concrete overlays have generally performed satisfactorily
  - membranes (typically hot-applied rubberized asphalt) have a mixed performance; states with more experience have better results (life of membrane system is limited more by the life of the asphalt concrete surface)
  - cathodic protection systems have been used, but they have generally not proven to be maintenance-free or cost-effective.

It is clear that the US has now generally adopted multiple corrosion protection systems, based on HPC, for new reinforced concrete bridge decks, in order to achieve the FHWA mandated 75-year service life (AASHTO, 2008a). A high profile example is the new Woodrow Wilson Bridge, part of the Washington DC area Capitol Beltway, that incorporates HPC in all concrete components (Kite, 2006). The design objective for the bridge deck was a cost-effective and durable HPC with a low chloride permeability (less than 2000 coulombs) and minimal cracking potential for the moderate-to-aggressive environment with extensive winter road salt use. High performance concrete (up to 75 percent slag cement), epoxy-coating for all reinforcement in the 250 mm thick deck, calcium nitrate corrosion inhibitor (Cusson, 2007), wet burlap curing (seven days), and silane sealing were specified. Service life modeling for uncracked HPC provided an estimated 60 years for chloride ingress to initiate corrosion and an additional 20 years for corrosion propagation time, providing a service life in excess of the required 75 years. For a movable deck section, lightweight HPRC with stainless steel reinforcement was specified. The life-cycle performance and cost (advantages of better corrosion resistance, extended service life, and reduced maintenance/repair costs) offset the higher initial cost of the SCDPS, that will also have significantly lower user costs (Kite, 2006).

3.5 International Concrete Deck Protection Systems Use and Experience

Internationally, snowy winter areas with road salt use have similar reinforced concrete bridge deck performance problems as Canada, and extensive SCDPS experience since the 70s, for instance: OECD which includes Canada (OECD, 1972; OECD, 1989); Europe (NCHRP, 1996; NCHRP, 2001; FHWA, 2004; FHWA, 2005b); Nordic (Wegan, 1994; Wøhlk, 1995); France (Sétra, 1991; Sétra, 2007a; Sétra, 2007b; Sétra, 2007c); Italy (AIPCR, 2006); South Africa (Hoppe, 1999); United Kingdom (Clarke, 1974; Pritchard, 1992; BRE, 1993; Mallet, 1994; TRL, 1998; Vassie, 2000); and Asia (NCHRP, 1998; Clark, 1998; FHWA, 2005b; MOC, 2004; Morito, 2007).

The European SCDPS experience is particularly relevant to Canada, as European specialist construction materials and bridge engineers have taken over 20 years to develop detailed Eurocode bridge design and construction requirements. These Eurocodes are applicable to engineering structures in all European Union (EU) countries, with 2010 the time limit for full implementation; Eurocode 1 – Designing concrete structures, Part 2: Concrete bridges, has detailed waterproofing requirements (AIPCR, 2006: Sétra, 2007). Effective bridge deck and waterproofing system drainage, high-performance concrete (with specific precautions, particularly curing, similar to US HPC), adequate concrete cover of the reinforcement, and proven, mainly membrane/HMA, waterproofing systems are generally European multiple SCDPS policy (FHWA, 2001; FHWA, 2004; FHWA, 2005b).

While there are some country-specific SCDPS practices, the European multiple corrosion protection system practices to optimize deck life-cycle durability and cost can generally be summarized as follows:

- a life-cycle deck durability and cost analysis, with a 100 to 120 year design life of bridge reinforced concrete components, is the engineering basis of SCDPS selection;
- the deck continuity, with minimization of deck joints (integral abutments for instance), is an important factor contributing to durability and maintainability;
- the deck drainage system (surface drainage, joint drainage, drainage of water seeping through the surfacing, and drainage discharge away from bridge components) is essential to durability;
- the high performance concrete deck mixes (HPC) are designed with prime consideration given to durability, not strength (epoxy-coated reinforcement not generally used);
- the HPC is subject to specific use, production, placement, finishing, and curing requirements to reduce the risk of cracking, with very strict crack width limitations under dead loadings:
  - 0.1 mm for systematic cracking (average width for multiple, evenly-distributed cracks);
  - 0.2 mm for the average width of an individual crack;
  - 0.3 mm in localized cases for the width of an individual crack;
- the use of a waterproofing membrane 80 to 120 mm high-performance HMA surface (SMA, for instance) structural waterproofing system (mastic asphalt, rubberized asphalt steel membrane, and hot-applied rubberized membrane with sprayed systems favoured); and
- the implementation of effective deck maintenance (including alternative deicers and salt management), repair, and rehabilitation program as part of overall bridge management is emphasized.

The Asian SCDPS technology (NCHRP, 1998; Clark, 1998: FHWA, 2005b; MOC, 2006; Morito, 2007), with focus on Japan and China, is largely based on American and European SCDPS experience. It should be noted that both fatigue damage (particularly shear of thin reinforced concrete decks designed before 1968) and chloride damage (since 80s – salt contained in concrete and/or from deicing) are of concern in Japan (Morito, 2007). Concrete bridge decks in areas of

Japan where road salts are used generally have a multiple-level corrosion protection system (HPC, adequate concrete cover, waterproofing membrane, and HMA surfacing).

Road salt is not generally used in China, although more use is anticipated with the expanding expressways, which is a real potential problem as SCDPS not installed as yet. China does have a detailed bridge design code and specifications for deterioration prevention (MOC, 2006). There are a number of very large bridges in China typically with orthotropic steel decks protected by epoxy asphalt that is performing very well (essentially based on California experience and supply). It is of interest that some of Hong Kong's major bridges, with waterproofing membrane/HMA surfacing systems, have had severe blistering and debonding problems, probably related to water seeping through the HMA and/or vapour pressure (Clark, 1998). These costly performance problems highlight the importance of effective waterproofing systems drainage and close attention to waterproofing systems installation – even the highest quality waterproofing materials will not perform as intended if water/salt can accumulate in the system and/or the membrane is not properly bonded to the concrete deck – two key practices emphasized throughout this report.

4 COMPARATIVE FEATURES AND PERFORMANCE OF STRUCTURAL CONCRETE DECK PROTECTION SYSTEM OPTIONS

4.1 Comparative Advantages and Disadvantages of Current Canadian SCDPS

The Canadian, American, and international SCDPS use and experience, related extensive SCDPS technology information, and practical experience, particularly with structural waterproofing system performance problems and their resolution, provide a basis to outline the features, advantages, and disadvantages of Canadian SCDPS, with focus on SWS in new deck construction and replacement (also generally applicable to major repairs and rehabilitation). The current Canadian SWS are mainly sealers (actually dampproofing), bonded rigid (low-permeability concrete) overlays, liquid-applied polymer membranes, hot-applied rubberized asphalt membranes, and torch-applied and self-adhering rubberized asphalt sheet membranes, with hot-applied rubberized asphalt membrane/asphalt concrete surfacing (HMA) the most widely used. This can be compared to the European similar general (often mandated) use of polymer and asphalt-based sheet membrane SWS and little American use of membrane systems (some sheet) for new decks (NCHRP 1995; NCHRP 2004b). It should be noted that Canadian SWS technology and experience are reflected in the SWS state-of-the-art such as the ACI 345.1R *Guide for Maintenance of Concrete Bridge Members* (ACI, 2008h) and NCHRP Synthesis 220 *Waterproofing Membranes for Concrete Bridge Decks* (NCHRP 2005).

Three basic SWS options can be considered for protecting a new or replacement concrete bridge deck against water and chloride ingress:

- use the concrete deck as the road surface after sealing (dampproofing) its surface (this could also be a component of an exposed concrete deck multiple corrosion protection system – HPC/epoxy-coated reinforcement/silane sealer, for instance);
- use a rigid, low chloride permeability, bonded overlay for waterproofing, and to provide a road surface; and
- use a membrane for waterproofing, with an asphalt concrete (HMA) road surface.

The structural and functional requirements for hot-applied rubberized asphalt membrane system materials and construction, summarized in Table 6, can be used as a general basis to compare the advantages and disadvantages of SWS, as it is the most widely used Canadian system with detailed material and construction specifications, quality requirements, and performance monitoring (OPSS, 1998; MTO, 1997; MTO, 2004; MTO, 2007; MTO, 2008, for instance).

Table 6 Structural and Functional Requirements for Hot-Applied Rubberized Asphalt Membrane Waterproofing System Materials and Construction (NCHRP, 1995; TRL, 1998; NCHRP, 2004a)

The waterproofing system (including surfacing) must meet the following structural and functional requirements under the traffic loadings and climatic conditions involved at the bridge site: • Watertightness under the traffic loadings and climatic conditions. This must also apply along all edges, limiting faces, flashings, etc., over the entire waterproofed area. • Mechanical stability and strength to withstand effects from traffic such as stress and strain, also in bends, on superelevation, and under braking and acceleration conditions. • Resistance to cracking, or separation, in layers under traffic loadings or due to movement of lower layers (lifts). • Watertightness integrity and material strength to resist action from traffic loadings, severe weather, deicing chemicals, spills, and other factors causing potential damage or deterioration. • Compatibility between the placed and compacted hot-mix asphalt material and with the substrate at which the waterproofing surfacing is in contact. • Ability to withstand thermal and mechanical influences during construction of subsequent layer or layers (lifts). • Maintainability in terms of preventive maintenance, repair, and rehabilitation.

4.2 Penetrating Water-Repellent Sealers

Sealing a concrete deck surface slows the absorption of water and chlorides that penetrate cracks or migrate through the concrete surface to cause reinforcement corrosion and concrete deterioration. Treating concrete to reduce absorption is termed dampproofing, while waterproofing is a treatment to prevent all water penetration. Sealers used for concrete are of two general types (AASHTO, 2007c; ACI, 2008j; Alberta, 2001; Henry, 2004):

- penetrating deck sealers are generally silanes, siloxanes, or silane-siloxane combinations, that react with the hardened cement paste to create a nonwettable surface (water-repellent layer); and
- surface coating sealers are generally acrylics, epoxies, and urethanes that are used on concrete element surfaces not exposed to traffic (curbs, walls, and piers, for instance) to protect new concrete or prolong the life of sound, in-service concrete.

The features and performance of concrete deck surface penetrating sealers is summarized in Table 7.

Table 7: Features and Performance of Surface Penetrating Sealers

Advantages	Disadvantages	Life Expectancy/ Determining Parameter(s)
No increase in dead load. Reduced permeability of concrete. Easy to apply. Require minimal finished deck surface preparation. Allow ready inspection of deck condition. Easily reapplied. Replacement requires limited traffic disruption. Require minimal monitoring.	Not waterproof (dampproof). Require the concrete deck to be accurately profiled for drainage and textured for friction. Concrete must be very dry for application. May reduce frictional resistance. May not penetrate high performance concrete (low permeability concrete). Will not bridge cracks. Difficult to verify quality of application. Variable effectiveness. Subject to wear by traffic. Must be reapplied at five to seven year (depending on traffic level) intervals on riding surfaces.	Assuming adequate penetration, approximately five to seven years. Typically six years. ――――― Sealer subject to aging and removal, mainly through traffic wear. ――――― Note: Sealer will have a short life expectancy in wheel paths subject to winter studded tire and chain use.
Price (Estimated Third Quarter 2007): \$14. to \$16./m², inclusive of deck preparation and application.		

Treatment of a concrete deck riding surface with a penetrating water-repellent (hydrophobic) sealer is the most basic waterproofing (dampproofing) option to protect against water and chloride ingress by effectively reducing the permeability of the concrete. The five key features of an effective penetrating sealer are: breathability (let water vapour out without letting liquid water in); penetrability (soaks in and lines the concrete pores); serviceability (chemically bonds with concrete for a protective life, without traffic wear, of at least ten years); invisibility (should not create a surface film or darken the concrete); and supportability (the sealer should come from a qualified product list) (Henry, 2004). Deck sealers have been used extensively in Alberta since 1985 and the Alberta penetrating deck sealer best practices and approved products list are recommended to agencies that have not developed their own deck sealer specifications (Alberta, 2001; Alberta, 2008; ACI, 2008j). It should be noted that penetrating sealers are not generally considered to be a primary method of protecting decks. There have been many studies of the wide range of available penetrating sealers for decks, with silanes, siloxanes, and silane-siloxane combinations demonstrating the best overall performance (SHRP, 1993; ACI, 2008j).

4.3 Concrete Deck With Rigid Bonded Overlay

Rigid, low-permeability, bonded overlays perform the dual function of protecting the structural concrete deck from the ingress of water and chlorides and providing a durable riding surface. Two types of rigid overlay systems are commonly used: Portland cement based low-permeability concrete overlays (40 to 70 mm thick high performance concrete) (ACI, 2008j; ACI, 2008k; ACI, 2008m; NCHRP, 2004a; NCHRP, 2007b; PCA, 2002; RTAC, 1977; TRB, 2006a); and thin, polymer-based overlays (6 to 20 mm thick) (ACI, 2008c; ACI, 2008j; ACI, 2008n; Cargill, 2006; Dimmick, 1997; NCHRP, 2004b; Winnipeg, 2006). Portland cement based low-permeability concrete overlays have been the most common rigid bonded overlay type in Canada for new decks and deck rehabilitation. However, the use of thin, polymer-based overlays for new decks (structural concrete, high performance concrete, stressed precast (NCHRP, 2008) and cast-in-place concrete, and orthotropic) and deck rehabilitation is growing (Winnipeg, 2006).

4.3.1 Portland Cement Based Low-Permeability Concrete Overlays

Rigid, low-permeability, bonded concrete overlay types include:

- low slump dense concrete (LSDC);
- latex modified concrete (LMC);
- silica fume concrete (SFC);
- fibre reinforced superplasticized concrete, dense concrete, or silica fume concrete.

All of these overlay types demonstrate much lower water and chloride permeability than conventional structural concrete. However, none is impervious. These overlays can be considered a form of 'sacrificial' protection, absorbing contaminants (typically chlorides) that might otherwise deleteriously affect the structural concrete deck, and therefore need to be rehabilitated when the chloride permeates through the overlay. Based on the chloride permeability, this could take as long as 50 years (NCHRP, 1987). However, cracking of the overlay can substantially reduce the degree of protection provided to the underlying deck slab. Physical deterioration of the overlay (cracking, debonding, and spalling) can also significantly reduce its life. Increasing the overlay thickness generally improves both the degree of protection offered to the deck slab and the durability of the overlay. However, the overall thickness is generally restricted to about 70 mm to limit the risk of cracking and for dead load considerations. Surface features which may be difficult to achieve in large, precast deck sections (such as frictional properties, profiling for positive drainage, and smoothness for riding quality) can be attained using a cast-in-place overlay. However, complex surface profiles (such as at drains) and profiles that differ from the deck are difficult to achieve. For stressed structural concrete decks (pre- or post-stressed), a rigid bonded 'sacrificial' overlay also allows for future deck surface rehabilitation (simple overlay removal and replacement) without impacting on the decks structural functionality.

Proper deck slab surface preparation and curing are essential to minimize the risks of debonding and shrinkage cracking of the rigid, low-permeability, concrete overlay. The substrate concrete surface must be clean and free of laitance, dust, oil, and curing compound. High pressure water or abrasive cleaning provide superior surface preparation and allow the best possible bond to develop. Practical experience has shown cracking to be more prevalent than debonding and consequently of greater concern. Cracks develop primarily due to plastic shrinkage (within days of placement), drying shrinkage (takes place over years), and traffic induced deflection reversals on flexible superstructures. The strategies to minimize bridge deck cracking given in Section 3.4 should be followed for rigid, low-permeability, concrete overlays.

The frictional characteristics of concrete overlays are determined by the aggregate properties (particularly polishing resistance and abrasion resistance) and the texture imparted to the surface. Good frictional properties are obtained through the use of 'hard' aggregates and texturing (steel tines and/or turf drag) to produce striations in the plastic concrete. The frictional properties deteriorate with traffic wear; however, they can generally be restored by 'retexturing' (shotblasting, for instance).

Diligent, regular preventive maintenance is required to seal any cracks and to repair physical defects that may allow ingress of surface water and chloride into the deck slab. A tolerable crack width is approximately 0.2 mm. Fortunately, overlay-quality concrete overlays in repair and rehabilitation applications perform satisfactorily for at least 20 years. Greater service life can be expected from overlays applied to new decks with diligent maintenance. Fibre-reinforced overlays should achieve even longer service lives. The features and performance of rigid, low-permeability, bonded concrete overlays are summarized in Table 8.

Table 8 Features and Performance of Rigid, Low-Permeability, Bonded Concrete Overlays 40 to 70 mm Thick

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Substantially reduce ingress of water and chlorides into deck. Allow ready inspection of overlay. Minor defects (cracks, minor delaminations) can be readily repaired. Durable. No special treatment required at upstands. Good stability and durability with respect to heavy vehicles.	Increased dead load. Not impervious. Not able to inspect structural deck slab surface. Require special equipment and expertise for construction (particularly with latex, silica fume, and fibres). Require special attention to curing. Finishing difficult. Cannot bridge active cracks. Prone to cracking and debonding. Require routine maintenance (crack sealing). Surface requires texturing for frictional resistance. Surface requires periodic retexturing (10 to 15 years) to maintain frictional resistance. Higher tire noise. Overlay replacement requires extensive traffic closure.	Twenty years or more with preventive maintenance program. __________ Cracking, delamination/spalling, and chloride contamination. __________ Note: Depending on wear, the surface will require periodic retexturing to maintain frictional characteristics.
Examples: Low-slump dense, latex modified, silica fume modified, fibre-reinforced combinations (low permeability, high performance concretes).		
Price (Estimated Third Quarter 2007): \$60. to \$66./m², inclusive of preparation, materials, and construction.		

- Low Slump Dense Concrete (LSDC) overlays (typically 475 kg/m³ minimum cement content and w/cm <0.35, commonly termed Iowa dense concrete) were used in the rehabilitation of bridges in British Columbia from the mid 70s to approximately 2004, and LSDC was included as an integral component of the deck protection system for the Alex Fraser Bridge, one of the world's longest cable-stayed bridges. LSDC is difficult to place and consolidate due to its low workability. Improved workability can be attained through the appropriate use of superplasticizers (mid-range or long-range water reducers), subject to meeting chloride permeability requirements. The use of an epoxy bonding agent provides additional barrier protection against the ingress of chlorides into the deck slab; British Columbia has bridge decks in the Vancouver area that are over 30 years old using epoxy bonding agents under deck overlays that are performing very well.

- Latex Modified Concrete (LMC) overlays (typically containing 15 percent polymer (solids) by mass of cement) have generally been limited to deck rehabilitation rather than new construction. The LMC overlay materials and procedures are now well established with standard specifications (ACI, 2008m). The Ontario Ministry of Transportation has completed over 100 rehabilitation applications since the mid 70s; most are still in service and considered to be performing well. LMC overlays have generally demonstrated superior chloride penetration resistance and better frictional properties than LSDC overlays. However, specialized on-site volumetric batching equipment is required and finishing LMC can be difficult, particularly in conditions of high evaporation which lead to rapid formation of a latex film on the overlay surface.
- Silica Fume Concrete (SFC) overlays (typically containing five to ten percent silica fume by mass of Portland cement) have a similar permeability to LMC and have several advantages over LSDC and LMC for overlay use: less costly than LMC; can be placed with conventional equipment; and, because it is superplasticized (mid-range or long-range water reducer), it is easier to consolidate than LSDC. However, proper curing of SFC is imperative to minimize the risk of shrinkage cracking (FHWA, 2005a).
- Synthetic fibre reinforcement is commonly incorporated to reduce the potential cracking and spalling of overlays. The appropriate use of a superplasticizer in the fibre reinforced mixes contributes to the satisfactory placement and performance of the overlay.

4.3.2 Polymer-Based Thin Overlays

Polymer (generally epoxy, methyl methacrylate, urethane, or polyester resins) based overlays are of two basic types: seeded; and concrete. The seeded form is made up of layers of resin into which select aggregates are 'seeded' in-place, with a total thickness of about 6 mm. Polymer concrete is a polymer and aggregate mix that is placed as a screeded layer (thin systems approximately 6 mm thick based on methyl methacrylate or epoxy resin, and 10 to 20 mm thick overlays using less costly polyester resin) in a similar manner to rigid concrete overlays. More than 60 bridges in Alberta have been treated with remedial thin polymer overlays since 1985 (Carter, 1989; Stidger, 2005). The low mass contribution of the relatively thin polymer overlay makes it an attractive option for resurfacing bridges having minimal reserve load-carrying capacity.

Polymer-based thin overlays have a low permeability and excellent adhesive properties. The 'seeded' application is relatively simple and requires little special equipment; select aggregates are simply broadcast into the liquid resin which is spread on the substrate using a squeegee. However, the performance of some early polymer-based overlays was inconsistent, with numerous problems and short service lives (OECD, 1989). Loss of frictional resistance due to traffic wear can occur within five to ten years (NCHRP, 1979); although with select aggregates (calcined bauxite, for instance) up to a 20-year service life may be achieved (Carter, 1989). Problems of blistering, cracking associated with brittleness at low temperatures, and debonding were common with early thin polymer overlays (NCHRP, 1989). However, with new generation low-modulus polymers and rigorous quality control of applications, the incidence of failure is now very low.

The primary mode of thin polymer overlay failure is debonding. High interfacial shear stresses develop due to the large difference in thermal expansion coefficients of the polymer overlay and concrete deck substrate; a very high standard of surface preparation is necessary to ensure that adhesion is not impeded. As well as being sound, clean, and roughened to an 'anchor' profile, the substrate must be very dry. Performance is also very sensitive to the proportioning of the polymer components and timing of the application. Considerable care and experience are necessary to ensure in-place materials quality and overlay performance. The early performance of thin polymer overlays indicate a relatively short life (approximately ten years); but better performance is indicated by recent installations. Preventative maintenance requirements include crack sealing (low viscosity resin) and patching to block avenues for chloride ingress (ACI, 2008j; ACI, 2008k). The features and performance of thin polymer overlays are summarized in Table 9.

Table 9 Features and Performance of Thin Polymer Overlays, Six to Twenty mm Thick Epoxy, Methyl Methacrylate, and Polyester Resins

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Small increase in dead load. Seamless. Rapid curing and strength development. Excellent adhesion to concrete deck. Virtually impervious. Replacement requires limited traffic disruption. Good frictional performance. Wear resistance can be enhanced with select aggregates (calcined bauxite, for instance).	Loss of frictional properties after about seven to ten years due to traffic wear (with standard aggregates). Not able to inspect deck subsurface. Requires very high standard of surface preparation. Limited crack bridging capabilities. Degraded by UV radiation. Incompatible thermal movement with deck. Specialized application expertise required. Special safety precautions must be followed with resins.	Approximately ten years with standard aggregates. Approximately twenty years with select aggregates. Shorter life if exposed to heavy winter sanding, studded tires, and chains. ——— Loss of frictional resistance due to traffic wear. ——— Note: Prone to snow plow damage.
Price (Estimated Third Quarter 2007): $80. to $100./m², inclusive of preparation, materials and construction (10 mm thick).		

4.4 Waterproofing Membrane With Hot-Mix Asphalt Concrete Surfacing Systems

The most widely used and oldest structural concrete deck protection system is a waterproofing membrane adhered to the concrete deck and surfaced with hot-mix asphalt (HMA) concrete. This waterproofing membrane system is widely used throughout northern Europe, some northeast

American states, and on many new Canadian bridge decks, and also extensively as a component of deck rehabilitations, as summarized in Chapter 3 (NCHRP, 1995; NCHRP, 2004a). The waterproofing membrane provides barrier protection to the deck against the ingress of water and chlorides. The asphalt concrete surfacing provides the required riding surface (smooth, quiet, and good frictional properties), positive drainage for surface water, and protection of the membrane against mechanical damage from heavy traffic and deterioration from ultraviolet radiation. Pavement surface profiles (slopes to deck drains, for instance) can be readily constructed using hot-mix asphalt. To withstand the rigours of the construction site as well as the temperatures and mechanical forces of hot-mix asphalt paving, most waterproofing membranes must be covered with a layer of protective material. Good adhesion must be assured between all components of the waterproofing system to ensure satisfactory performance. In the extreme, lack of adhesion can result in slippage which can lead to membrane damage and/or deformation of the asphalt concrete surface. The typical steps for a hot-applied (poured) rubberized asphalt membrane waterproofing system installation are shown in Appendix B.2. Some typical protection system distresses, including cracking, blistering and potholing of asphalt concrete surfaces, are shown in Appendix B.3. Membranes should be applied when the properly prepared and dry substrates temperature is stable or dropping in order to preclude outgassing (blistering) due to expanding air and/or water vapour from the surface pores of the concrete.

Surveys of the in-service performance of bridge deck protective systems reveal that waterproofing membranes can be highly effective in preventing water and chloride ingress and have the potential to provide more than 40 years of corrosion protection for conventional reinforced concrete bridge decks (NCHRP, 1995; MTO, 1997). However, the life of waterproofing membrane systems has typically been limited by the functional service life of the asphalt concrete surfacing which, for conventional hot-mix asphalt mixes, is about 15 to 20 years. Longer functional serviceability can be attained by using high performance HMA (Bhutta, 2006; Infraguide, 2003; NCHRP, 1995; TAC, 2007). Constructing a two-course asphalt concrete surfacing (overall thickness of 70 to 90 mm), in which the surface course is 'renewed' on a regular rehabilitation basis (binder (lower) course and waterproofing membrane left in place), permits optimization of component life, reducing both the cost and disruption associated with rehabilitation (NCHRP, 1995). However, in such an approach, consideration must be given to the membrane condition at each surface course replacement, since waterproofing membranes may also age and deteriorate with time and traffic action (particularly with starting and stopping). Comprehensive guidance on the inspection and evaluation of waterproofing membranes is given in the *Manual of Low-Slope Roof Systems* (Griffin, 1996), noting that the material science of roofing systems is often applicable to SWS membranes.

The bridge deck surface (asphalt concrete or exposed Portland cement concrete) condition can be determined through visual condition surveys using a pavement condition index (PCI) method of quantifying its condition (type, severity, and extent of distresses), such as the ASTM D6433 *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* (ASTM, 2007b). It is important that the recently recognized asphalt concrete top-down cracking (TDC) distress is included during visual surveys, as TDC development is fairly common for asphalt concrete surfacings over Portland cement concrete pavements (Emery, 2005). The readily available, ASTM D6433 based, APWA supported, MicroPAVER pavement management system is recommended for bridge deck surface condition (PCI) rating. The PCI provides a measure of the present condition of the surface based on the observed distresses (cracks, rutting, and weathering for example), which also indicate the distress cause(s), surface integrity, and surface operational condition. The PCI also provides an objective basis for determining maintenance and repair needs and priorities, and with regular monitoring, the rate of surface deterioration and early identification of rehabilitation needs, including validation of improved maintenance, repair, and rehabilitation materials and methods (ASTM, 2007b).

Debonding and stripping of asphalt concrete surfacings (which are permeable) as a result of water and chloride accumulation below the surfacing and on top of the waterproofing membrane (interface) has been a major problem for some agencies (Appendix B.4, Photographs 17 and 18, for instance) (NCHRP, 1995). Interlayer drains (above the membrane) must be incorporated to alleviate this problem (NCHRP, 1995); examples of interlayer drains used in Alberta and Ontario (and Ontario drip channel) are shown in Figure 5 (Alberta, 2007; OPSS, 1998). Most performance problems are likely to arise from poor drainage and poor quality asphalt concrete, rather than the waterproofing membrane itself; good performance can be expected with proper drainage and quality, high performance HMA. It is important to note that the opening to the drains must not be covered by the membrane or the protection board or sheet.

Unlike exposed rigid overlay systems, defects in the waterproofing membrane and deterioration of the underlying concrete deck are difficult to detect. Although leakage can usually be identified by damp patches and efflorescence on the soffit of the bridge deck, the deck slope and crossfalls make it difficult to ascertain the point of membrane leakage. In the event that water and chlorides become trapped under the waterproofing membrane, the risk of migration is exacerbated by the action of traffic which creates high pressures ('pumping', approximately three times greater than tire pressures) within water filled voids (TRRL, 1998). The risk of water and chloride migration under the membrane is reduced by ensuring good adhesion to the concrete substrate. However, strong adhesion increases the risk of membrane rupture due to movement at cracks in the concrete substrate. It is always prudent to consider the possibility of some crack development and movement; the waterproofing membrane should have sufficient flexibility to withstand concrete crack widths of up to 0.25 mm at its coldest service temperature (NCHRP, 1995).

Repairing a waterproofing membrane requires the removal and reinstatement of both the asphalt concrete surfacing and membrane in the affected area. Consequently, considerable care is required during waterproofing system construction to avoid any defects that can lead to premature membrane failure. Blistering (due to the expansion of water vapour in the pores of the substrate concrete) is probably the most serious difficulty associated with waterproofing membranes.

Pinhole blistering generally occurs during the application of liquid membranes, while dome blistering (which may occur after the system has been in service for some time) is generally associated with manufactured sheet membranes. The risk of blistering can be reduced by requiring a good finish of the concrete substrate (minimize the risk of vapour pockets under the membrane), adequate air drying, good membrane adhesion, and sufficient mass (thickness) of the asphalt concrete surfacing. Special consideration must also be given to membrane vertical, horizontal, and termination details (particularly at curbs, parapets and drains) to minimize the risk of water and chloride entry at edges and subsequent leakage under the membrane.

Replacement of waterproofing membrane/HMA surfacing systems can generally be completed with far less disruption to bridge operations than with rigid overlay systems. With careful replacement operations coordination, it is possible to limit lane traffic closures to night work.

Six waterproofing membrane types have been, or are still, used in Canada, as follows:

- hot-applied rubberized mastic membrane;
- hot-applied (poured) rubberized asphalt membrane (plain and reinforced) with protection boards;
- liquid-applied polymer membrane;
- self-adhering manufactured sheet membrane with integral protection layer;
- torch-on manufactured sheet membrane with integral reinforcement and protection layer; and
- spray-applied polymer-modified asphalt membrane (proprietary).

Except for the manufactured sheet membranes, all membranes are applied in a liquid or semi-liquid state.

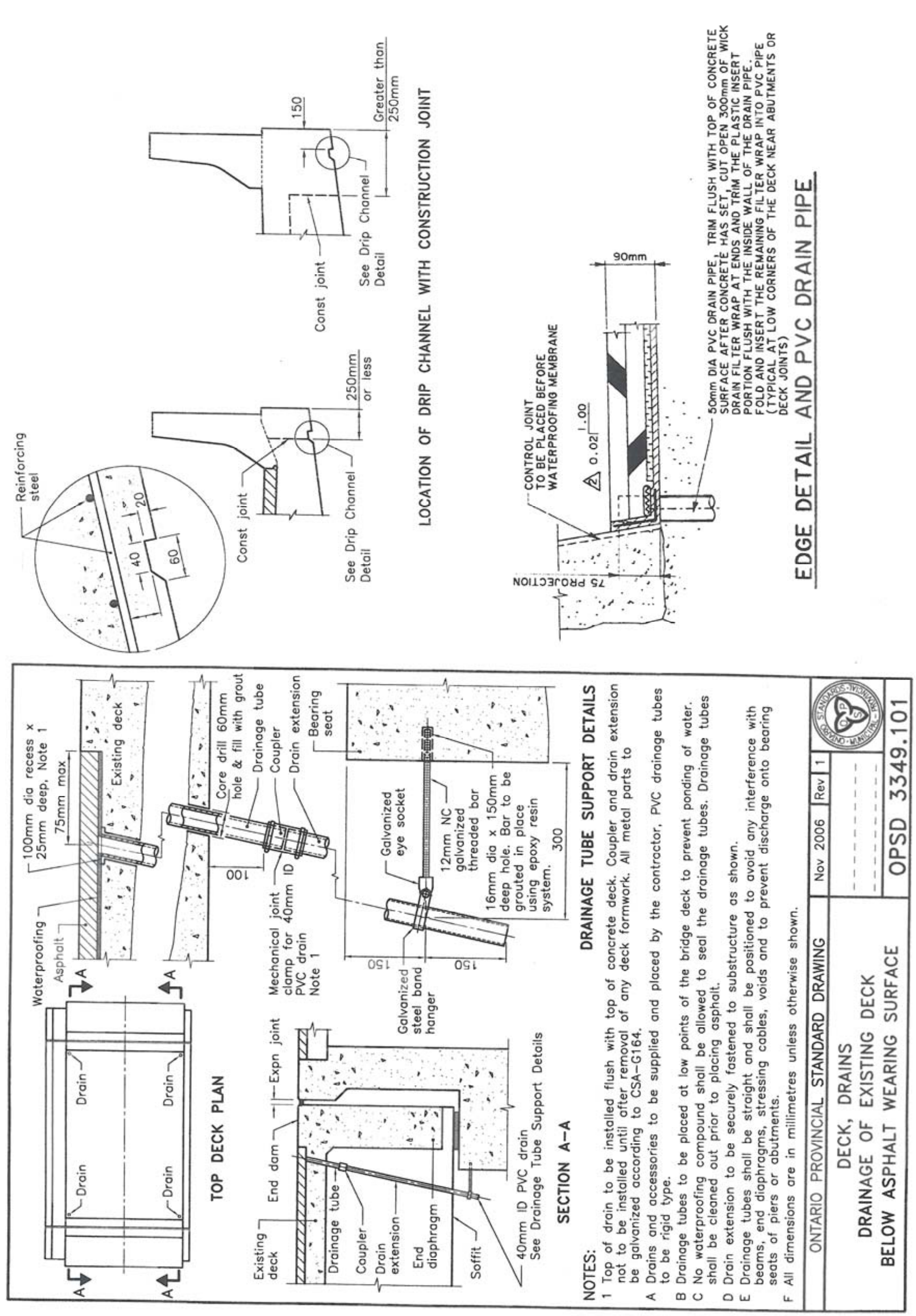

Figure 5 Alberta and Ontario Deck Drain Systems for the Very Important Drainage of the Concrete Deck Below the Asphalt Concrete Wearing Surface, and Ontario Drip Channel Location (Adapted from Alberta, 2007 and OPSS, 1998)

Liquid and semi-liquid applied membranes can be made continuous and readily conform to substrate profile and geometry. However, the membrane thickness (which directly affects permeability and crack spanning capacity) is controlled by the applicator and is therefore subject to variance. The Ontario end result specification (ERS) for membrane thickness has proven to be very effective in controlling hot-applied rubberized asphalt membrane thickness and quality (MTO, 1997; MTO, 2007). Nevertheless, membrane thickness is difficult to control on rough surfaces, with ponding in substrate depressions (increasing the risk of shear deformation), and a tendency to be thin at substrate peaks (reducing degree of protection offered). Considerable quality control is also required with site batching, mixing and, where applicable, heating of liquid membranes, to ensure adequate and consistent materials quality. Pinhole blistering during application is a common problem with liquid applied membranes, particularly with thin or single ply, hot-applied systems. Construction defects (typically inadequate thickness and pinholing) can usually be repaired by simply adding more membrane material to the affected area prior to applying the protection boards and HMA surfacing.

With manufactured sheet membranes, consistent materials quality and thickness are generally assured through the manufacturer's plant quality control. The need for batching, mixing, and heating of materials at the site is eliminated. Hence, the requirement for specialized equipment and site thickness quality control testing are reduced. An integral protection layer on the membrane surface permits construction traffic and HMA paving without the need for additional protection. Field evaluations of membrane systems indicate that they are potentially the most effective membranes in protecting against chloride ingress (NCHRP, 1995). However, seams and laps between sheets present weaknesses for potential leakage. Lap joints are particularly difficult to make at irregular details such as at drains and gulleys, edges of curbs, parapets, expansion joints, and at the base of fixings for street hardware. Multiple layer lap joints can also become so thick that they can reflect through the asphalt concrete surfacing. Sheet membranes are less compliant with irregular substrate profiles than liquid applied membranes, bonding well at peaks but bridging over depressions; blistering is a common consequence. Repair of construction defects (typically blisters and wrinkles) is more difficult than with liquid applied membranes, requiring that the affected area of membrane be cut out and replaced prior to HMA placement. One major manufactured sheet membrane producer has recently been withdrawn from the bridge deck waterproofing market due to these performance problems (MTO, 2008).

Most membrane systems rely on a tack coat, applied to the concrete substrate, to promote adhesion. Polymer-modified emulsion tack coats are generally more tolerant of application conditions and provide more reliable performance than cut-back asphalt tack coats (care must also be taken to ensure complete volatilization of solvent). Surface preparation is a critical parameter affecting the performance of all bonded systems. Inadequate bonding can lead to blistering, leakage, and, in extreme cases, slippage which can damage the membrane. It is therefore essential that the membrane be applied to a substrate that is sound, free of loose material, and not contaminated with oil, grease, or curing compound that could inhibit adhesion, and dry. Substrate profile roughness should be minimal to reduce the risk of inadequate membrane bonding (sheet membranes) or thickness (liquid-applied membranes). The substrate tolerances permitted by various agencies range from 10 mm in 3 m with no abrupt irregularities greater than 3 mm (UK) to 6 mm in 3 m (Ontario) (OPSS, 1998). Small voids (blowholes) on the concrete substrate surface should be filled to avoid membrane bridging and the risk of subsequent pinholing and blistering. Excessive profile roughness can occur in the form of stepping at the bonded joints of precast decks sections. In such cases, localized grinding should be considered to provide a more gradual transition.

4.4.1 Hot-Applied Mastic Membrane

Hot-applied rubberized mastic membranes (typically 5 mm thick), with improved properties (particularly low temperature flexibility) over the traditional European asphalt mastics from which they are descended, were commonly used with very rigid structure decks from the 60s until the early 80s (NCHRP, 1995). However, they have largely been displaced during the past 30 years by waterproofing membranes that have improved technical properties and are easier to apply, typically hot-applied rubberized asphalt membranes (NCHRP, 1995).

Continuously bonded to the concrete substrate using a tack coat, the seamless mastic membrane can be surfaced with HMA. However, material quality is difficult to control (requires considerable quality control over site batching, mixing, and heating) and requires specialized equipment (melter and mixer). The mastic membrane is prone to embrittlement and cracking at low temperatures, shear deformation at high temperatures, and is subject to fatigue from traffic loading. Mastic membranes slump when applied to vertical surfaces, hence special termination details are required at curbs and parapets; flexible joint sealant is normally used to seal edges. Because the rubberized mastic asphalt membrane deteriorates with time (aging, low temperature cracking, and fatigue) it is unlikely to provide more than about ten years service for Canadian road salt use and cold winter conditions. Hot-applied rubberized mastic membranes will not be considered further here.

4.4.2 Hot-Applied Rubberized Asphalt Membrane

Hot-applied (poured) rubberized asphalt membrane with protection board systems have been used extensively in Ontario since the 70s and are now used widely across Canada as summarized in Chapter 3 (MTO, 1997; NCHRP, 1995; NCHRP, 2004a). Blended and mixed under factory conditions, rubberized asphalt membrane material quality (from any approved source) should be consistently 'reliable'. However, products may differ between manufacturers. Rubberized asphalt has good low temperature flexibility and is not prone to embrittlement cracking. It is capable of spanning working cracks equal in width to the waterproofing membrane thickness.

The hot-applied rubberized asphalt membrane waterproofing system used in Ontario, and by most other Canadian agencies, consists of a tack coat (fully cured cut-back asphalt primer or polymer-modified emulsion, which is preferred) applied to the concrete substrate, hot-applied rubberized asphalt membrane (5 mm thick) and semi-rigid protection boards (3.6 mm thick, asphalt impregnated glass-fibre felt), and HMA surfacing. The protection boards are lapped to ensure that the membrane is completely covered. Prior to placing the HMA, an emulsified asphalt tack coat is applied to the protection board (fully cured) to ensure a good bond. These waterproofing steps are shown and explained in the Appendix B.2 photographs.

Table 10 Hot-Applied (Poured) Rubberized Asphalt Membrane Specifications Comparison of Test Requirements (Adapted from MTO and City of Toronto Special Provisions (Toronto, 2001a))

Test	Specification		
	CAN/CGSB 37.50-M89	MTO OPSS 1213	High Performance/ Superelevation
Flash Point (°C)	min 260	min 260	min 260
Cone Penetration @ 25 °C (dmm)	max 110	max 110	max 110
Cone Penetration @ 50 °C (dmm)	max 200	**max 160**	**max 120**
Flow @ 60°C (mm)	max 3.0	max 3.0	**max 1.0**
Toughness (J)	min 5.5	min 5.5	min 5.5
Touchness/Peak Load	min 0.040	min 0.040	min 0.040
Water Vapour Permeance (ng/Pa.s.m²)	max 1.7	max 1.7	max 1.7
Water Absorption (g)	max 0.18 loss max 0.35 gain	max 0.18 loss max 0.35 gain	max 0.18 loss max 0.35 gain
Pinholing (No.)	max 1	max 1	max 1
Low Temperature Flexure (original)	Pass	Pass	Pass
Low Temperature Flexure (aged)	No Requirement	Pass	Pass
Crack Bridging Capability	Pass	Pass	Pass
Viscosity (s)	2 to 15	2 to 15	2 to 15

Note: The High Performance/Superelevation Specification is covered by Ontario Ministry of Transportation Special Provisions for decks with four percent, or greater, grade or superelevation. This hot-applied rubberized asphalt membrane High Performance/Superelevation Specification, in a two-ply system, is recommended for all bridge decks, and particularly those carrying heavy traffic (trucks and buses).

The performance of this waterproofing system has generally been good (MTO, 1997; NCHRP, 1995). However, membrane pinholing is quite common. The hot-applied rubberized asphalt membrane is also prone to shear deformation on steep slopes, superelevations, and in areas of vehicle braking and acceleration. Spun bonded polyester fabric can be incorporated in the membrane (two-ply application) to provide reinforcement in such cases. This can be complemented by using a high performance/superelevation specification for the membrane as given in Table 10. The incidence of pinholing (and consequential risk of water and chloride penetration) is also reduced by applying the membrane in two layers, incorporating the spun bonded polyester fabric between them (two-ply application). Earlier problems of asphalt concrete deformation associated with volume changes in cellulose felt protection boards (due to water absorption or post-construction compaction) have been resolved by using glass fibre felts (MTO, 2008; OPSS, 1998). Unlike asphalt mastics, rubberized asphalt has a low susceptibility to embrittlement and fatigue. A potential life expectancy of at least 40 years for hot-applied (poured) rubberized asphalt membranes, when adequately protected from mechanical damage, is considered reasonable. The functional life of the waterproofing system will be governed by the asphalt concrete surfacing. The features and performance of hot-applied (poured) rubberized asphalt membrane waterproofing systems are summarized in Table 11.

4.4.3 Liquid-Applied Polymer Membrane

Liquid-applied polymer membranes for concrete, high performance concrete, steel, orthotropic, and Tee deck (Appendix B.3, Photograph 16) waterproofing (typically propriety) include those based on methyl methacrylate resin ('Eliminator'), polyuretheane/polyurea polymer ('Sinoprene'), and polyurethane/methyl methacrylate polymer ('Puma', at trial stage in Canada). The typical liquid-applied polymer is applied in two coats, giving a membrane thickness of 2 to 3 mm, with aggregate broadcast into the membrane to provide a shear key, or a mechanical bond coat, to enhance the bond of the subsequently placed HMA surfacing (HMA slippage was an early performance problem before the broadcasted aggregate (scatter), or bond coat, was used). The North American use of liquid-applied membranes is based on extensive European experience (Sterling Lloyd Eliminator developed in UK, for instance) (Lloyd, 2004). While developed for concrete floor systems, NACE has design, installation and maintenance guidelines that are appropriate for deck concrete liquid-applied polymer membrane specification and quality control (NACE, 2003b). As proprietary systems are involved, with special equipment and skilled applicator requirements, it is imperative that the manufacturer/supplier materials and construction specifications and procedures are closely followed. A life expectancy of at least 40 years is considered reasonable for a liquid-applied polymer membrane. Again, the functional life of the waterproofing system will be governed by the asphalt concrete surfacing. The features and performance of liquid-applied polymer membranes are summarized in Table 12.

Table 11 Features and Performance of Hot-Applied Rubberized Asphalt Membrane (5 mm Nominal Thickness) with Protection Boards (3.2 mm Nominal Thickness). Hot-Mix Asphalt Concrete Surfacing (Two Lifts, 80 to 90 mm Total Thickness)

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Seamless membrane. Virtually impervious. Good bond to deck concrete. Good bond to asphalt pavement. Capable of bridging cracks equal to membrane thickness. Good low temperature flexibility. Resistant to prolonged exposure. Provide good riding surface. With two course HMA paving, the surface course can be replaced without damaging the membrane. Surface course replacement requires limited traffic closure.	Increased dead load. Not able to inspect deck slab surface. Not all products are equivalent. Not suited to rough deck surfaces. Thickness controlled by applicator. Two 40 mm lifts of asphalt concrete recommended minimum. Special considerations required for grades > 4% or where heavy vehicles brake or accelerate. Potential for cracks in binder (lower) course asphalt pavement at board perimeters if proper compaction methods are not followed. Requires special detail at upstands. Not generally suitable for concrete decks < 150 mm in thickness.	Up to 40 years for membrane. 15 to 20 years for standard asphalt concrete surfacing. 20 to 25 years for high performance asphalt concrete surfacing. ____________ Asphalt pavement deterioration through post-construction compaction, oxidation, fatigue, deformation, stripping, and slippage.
Price (Estimated Third Quarter 2007): $48. to $54./m² for system, inclusive of preparation, materials, and construction.		

Table 12 Features and Performance of Liquid-Applied Polymer Membranes (Two to Three mm Nominal Thickness (Typically Two Coats) Acrylic Resin, Polyurethane/ Polyurea Polymer, Polyurethane/Methyl Methacrylate Polymer Hot-Mix Asphalt Concrete Surfacing

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Seamless membrane. Membrane conforms to substrate. Excellent adhesion to concrete deck. Virtually impervious. Capable of bridging minor cracks. Can be applied to upstands. Possible single course paving. With two course paving, the surface course can be replaced without damaging the membrane. Surface course replacement requires limited traffic closure. Provides good riding surface.	Increased dead load. Not able to inspect deck slab surface. Requires very high standard of surface preparation. Application restricted to dry weather conditions. Specialized equipment and qualified applicators required. High standard of control required during site mixing. Requires special bond coat or aggregate treatment between membrane and asphalt concrete surfacing to avoid slippage. Two 40 mm lifts of asphalt concrete minimum recommended.	Up to 40 years for membrane. 15 to 20 years for standard asphalt concrete surfacing. 20 to 25 years for high performance asphalt concrete surfacing. ——— Asphalt pavement deterioration through post-construction compaction, oxidation, fatigue, deformation, stripping, and slippage.
Price (Estimated Third Quarter 2007): $125. to $135./m² for system, inclusive of preparation, materials, and construction.		

4.4.4 Self-Adhering Manufactured Sheet Membrane

Self-adhering rubberized asphalt sheet membranes (typically 1.5 mm to 2.0 mm thick), with integral protection layer, have been used in Canada since the 70s, typically with a single 50 mm thick lift of HMA surfacing as summarized in Chapter 3 (NCHRP, 1995; NCHRP, 2004a). It appears that the use of sheet membrane waterproofing systems is declining due to continuing concern with, particularly, the bond to the concrete substrate (NCHRP, 1995), and the increasing use of hot-applied rubberized asphalt membranes with their generally excellent bond to the concrete substrate.

Self-adhering sheet membranes are quite easy to apply, consistent in material quality, and require minimal site installation equipment. The HMA can be placed, using rubber-tired rollers for compaction, without the need for additional membrane protection. The sheet membranes have similar technical properties to hot-applied rubberized asphalt membranes, but are substantially thinner and offer less resistance to chloride ingress or crack bridging. Sheet membranes have seams (potential leakage) and do not conform to substrates with rough texture or irregular geometries as well as liquid-applied membranes. Adhesion of the self-adhering sheet membrane to the concrete deck is promoted by a tack coat similar to that used with hot-applied membranes. Although the sheet membrane is easily placed, it is prone to puckering, wrinkling, deformation and blistering (NCHRP, 1995). The bond between the sheet membrane protection layer and HMA has also been of concern. Self-adhering sheet membranes have generally been replaced during the asphalt concrete pavement resurfacing. A life expectancy of 15 to 20 years is considered reasonable for a self-adhering rubberized asphalt sheet membrane waterproofing system. The features and performance of self-adhering sheet membrane waterproofing systems is given in Table 13.

Table 13 Features and Performance of Self-adhering Manufactured Sheet Membrane With Integral Protection Layer (Typical Thicknesses 1.5 to 3 mm) (Rubberized, Filled Asphalt/Woven Polypropylene). Hot-Mix Asphalt Concrete Surfacing

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Factory controlled thickness and quality. Virtually impervious. Good adhesion to concrete deck. Capable of bridging minor cracks. Low temperature flexibility. No protection boards required. Can use single course HMA paving. Provides good riding surface.	Increased dead load. Quality of installation very dependent on workmanship. Continuous bonding not assured. Potential seam leakage. Potential for water migration under membrane through discontinuities in bond. Potential for blistering unless pavement dead load is sufficient. Requires special detail at upstands. Potential for pavement slippage at membrane. Not to be left exposed/subjected to UV degradation. Subject to damage by paving equipment. With single course paving, the entire system must be replaced when resurfacing. Minimum application temperature 10ºC.	Determined by functional life of asphalt concrete surfacing. 5 to 20 years for standard asphalt concrete surfacing. 20 to 25 years for high performance asphalt surfacing. ――――――― Asphalt pavement deterioration through post-construction compaction, oxidation, fatigue, deformation, stripping, and slippage.
Price (Estimated Third Quarter 2007): \$43. to \$49./m² for system, inclusive of preparation, materials, and construction.		

4.4.5 Torch-on Manufactured Sheet Membrane

Torch-on (thermofusible) manufactured sheet membrane with integral reinforcement and protection layer waterproofing systems use is increasing since their introduction from France and manufacture in Québec since the 80s. The adhesion of torch-on membranes to the concrete deck (Appendix B.3 Photograph 13) is similar to hot-applied membranes and superior to self-adhering sheet membranes (NCHRP, 1995). The technical features and performance of torch-on rubberized (polymer-modified asphalt) asphalt sheet membrane is generally quite similar to hot-applied rubberized asphalt membranes. The torch-on sheet membrane consists of polymer-modified asphalt on a woven polyester core and is protected with mineral granules. Following polymer-modified emulsion tack coat application, the underside of the sheet membrane is heated to a partially molten state (using a torch or specialized installation equipment) as it is unrolled and placed on the deck. As the performance of the membrane is sensitive to the uniformity and temperatures of the torch heating it is important to have qualified applicators complete the work. Two lifts of HMA (minimum recommended total thickness of 80 mm) is then placed with the mineral granules providing both protection and enhanced HMA bond. A life expectancy of at least 40 years is considered reasonable for a torch-on sheet membrane. Again, the functional life of the waterproofing system will be governed by the asphalt concrete surfacing. The features and performance of torch-on sheet membranes are summarized in Table 14.

4.4.6 Spray-Applied Polymer-Modified Asphalt Membrane

A spray-applied polymer-modified asphalt membrane waterproofing system (proprietary Etanplast bridge deck waterproofing system) developed in France (Jean Lefebvre Group, used on major bridges such as le Pont de Normandie) was used for the waterproofing of the Confederation Bridge in 1997 (Lauzier, 1996; Prades, 1997). The Etanplast bridge deck waterproofing system consists of an emulsion primer on the prepared deck surface (cationic emulsion), Microplast (25 mm of low in-place air voids, fine, EVA polymer-modified asphalt binder HMA), Evatech membrane (about two to five mm of hot EVA polymer-modified asphalt containing resins and antistripping additive, spray applied with a high pressure distributor), slate chippings (about 2.5 mm of one to three mm flat slate chippings, rolled with a pneumatic tired roller), and two 40 mm lifts of high performance HMA (heavy duty binder course/stone mastic asphalt (SMA) surface course). Etanplast does not appear to be in current Canadian use.

Table 14 Features and Performance of Torch-On (Thermofusible) Manufactured Rubberized (Polymer-Modified) Asphalt Sheet Membrane with Integral Reinforcement and Protection Layer (Typical Thickness Four to Five mm), Polymer-Modified, Filled Asphalt on a Spun-Bonded Polyester or Glass Scrim, Topped with Mineral Granules Hot-Mix Asphalt Concrete Surfacing

Advantages	Disadvantages	Life Expectancy/ Determining Parameters
Virtually impervious. Factory controlled thickness. Good bond to concrete when properly installed. Capable of bridging cracks. Low temperature flexibility. High tear resistance. No protection boards required. Resistant to prolonged exposure. Possible single course HMA paving. With two course HMA paving, the surface course pavement can be replaced without damaging the membrane. Surface course replacement requires limited traffic closure. Provides good riding surface.	Increased dead load. Not able to inspect deck slab surface. Quality of installation very dependent on workmanship. Torch-on process must be to high quality. Continuous bonding not assured. Potential seam leakage. Potential for water migration under membrane through discontinuities in bond. Potential for blistering unless pavement dead load is sufficient. Two 40 mm lifts of asphalt concrete is recommended minimum.	Up to 40 years for membrane. 15 to 20 years for standard asphalt concrete surfacing. 20 to 25 years for high performance asphalt concrete surfacing. ______________ Asphalt pavement deterioration through post-construction compaction, oxidation, fatigue, deformation, stripping, and slippage.
Price (Estimated Third Quarter 2007, Soprema Antirock): $40. to $58./m² for system, inclusive of preparation, materials and construction.		

4.5 High Performance Hot-Mix Asphalt for Waterproofing Systems

The functional service life of the asphalt concrete surface course generally determines the time from waterproofing system construction to the required rehabilitation of the deck riding surface. While most properly installed waterproofing membranes have an anticipated service life of up to 40 years, the asphalt pavement deteriorates with the surface course typically reaching its functional serviceability limit in 15 to 20 years for standard asphalt concrete and 20 to 25 years for high performance asphalt concrete. This is similar to the functional life expectancy for quality highway asphalt pavements. It is clear that there is about a ten year performance advantage in going to high performance asphalt concrete (InfraGuide, 2003) which is the essential concept for long-life flexible pavements with structural service lives of 50, or more, years; with the parallel functional service life anticipated through 'renewing' the surface course (40 mm to 50 mm) to maintain the required pavement performance level (AI, 2000; Emery, 2005; TAC, 2007).

The functional and structural performance requirements, and materials, mix design, and construction requirement, for HMA heavy duty applications (heavily trafficked bridge deck, for example) are summarized in Table 15. It is recommended that high performance HMA technology be adopted for major route bridge deck asphalt concrete surfacing and for all bridge decks with grade, superelevation, braking and accelerating truck/bus traffic, and/or heavy truck traffic. This can be accomplished by adopting Superpave asphalt technology (AASHTO, 2007d; AASHTO, 2007e; AASHTO, 2007f). The life-cycle performance (technical) and cost (economic) advantages of using high performance HMA for bridge deck surfacings become even clearer if the resulting reduced user costs are also considered.

Table 15 Dense Graded Hot-Mix Asphalt Checklists: HMA Materials, Mix Design Requirements, and Construction for Heavy Duty Applications that Consider Resistance to Top-Down Cracking (Adapted from InfraGuide, 2003 and TAC, 2007)

A. General Functional and Structural Performance Requirements
• workable during placement and compaction • contributes to strength of pavement structure • resists permanent deformation (rutting) • resists fatigue cracking • resists thermal cracking • resists the effects of air and water (durability) • low permeability to protect pavement structure from water • easily and cost-effectively maintained – plus for surface (wearing) course • resistance to top-down cracking and associated distresses • adequate frictional properties (skid resistance) • acceptable level of tire-pavement noise • acceptable riding quality (smoothness)
B. Materials, Mix Design and Construction Requirements
• aggregate physical characteristics and quality heavy duty performance (heavy traffic and/or slow speed - intersections and bridge decks for example) - incorporate 100 percent crushed (100 percent), cubical and clean coarse and fine (manufactured sand) aggregates (practical experience has shown that a limited amount of natural fine aggregate (asphalt sand), not exceeding ten percent of total aggregate, assists in achieving surface course compaction and mat quality) • asphalt cement (binder) performance grade heavy traffic and/or slow speed - increase high temperature grade and use engineered polymer-modified asphalt cement as necessary. • Superpave mix design system – build on practical Marshall method mix design experience, particularly for heavy duty performance requirements. – consider any fines generation (minus 75 μm) during test-mix production. – check potential HMA performance with rutting resistance test (asphalt pavement analyzer for instance). • contractor quality control (testing/inspection of HMA production/placement/compaction) and agency quality assurance • proper construction techniques – prepare substrate properly (clean and tack), avoid segregation, place uniform and smooth mat, construct joint properly, and meet compaction (density requirements).

4.6 Quality of Waterproofing System Construction

A number of potential problems with waterproofing system construction have been identified in Section 4.4 and these are summarized in Table 16; concrete deck surface preparation is imperative to satisfactory membrane performance. A brief outline of the recommended inspection and testing requirements for waterproofing systems (membrane and HMA surfacing) is given in Table 17. The TAC *Synthesis of Quality Management Practices for Canadian Flexible Pavement Materials and Construction* (TAC, 2007) provides detailed guidelines on HMA quality requirements and management. The importance of using qualified and experienced inspectors, testing technicians, and testing laboratories must be recognized.

Table 16 Preparation is the Key to Successful Waterproofing

The most frequent problems with liquid hot-applied membranes are: • pinholes caused by the membrane not covering holes in the concrete • vapour pressure blisters • thin areas over high spots and sharp corners • damage by following trades prior to commissioning
The most frequent problems with sheet membranes are: • vapour pressure blistering • pinholes in joints between adjacent sheets • damage by following trades prior to commissioning
Most failures of membranes stem directly from inadequate surface preparation and this is particularly true for concrete surfaces: • surface laitance • honey combing and blow holes, often hidden by surface laitance introduced by all too frequent floating/finishing (cement slurry rubbing up) after stripping formwork • surface irregularities, (ridges, fins, depressions, broken areas, etc.) • cracking

Table 17 Inspection and Testing Requirements
Waterproofing System (Membrane and Surfacing)

- Qualified Inspection and Testing Technicians/Testing Laboratory
  - experience with the materials and construction of waterproofing system
- Review Specifications
  - good construction practices
  - demonstrated satisfactory performance
  - on approved designated sources list
  - high stability hot mixes
- Complete Pre-Placement Compliance Checks of Material
  - checked for current listing if approved source list required
  - tested for compliance if generic required
- Asphalt Technology Site Inspection and Related Testing
  - surface preparation, including moisture checks
  - placing prime (conditioner)
  - placing membrane
  - placing protection boards
  - hot-mix production, transportation, paving and compaction
- Reporting

4.7 Special Materials and Active Corrosion Mitigation Systems

There are two special materials, Rosphalt 50 very low air voids HMA, and Safelane™, polymer anti-icing overlay systems (Cargill, 2006), that were not considered previously in this Chapter. While Rosphalt 50 (HMA modified with mineral filler and polymer-modified asphalt cement) has been used in the past, it does not appear to be in widespread use in Canada. The Cargill Safelane™ system does not appear to have been used in Canada to date but could be an enhanced anti-icing, thin bonded overlay waterproofing system (Section 4.3.2).

Finally, active corrosion mitigation systems (cathodic protection) were not considered in this section and are beyond the scope of this report. However, for completeness, an overview comparison of active corrosion mitigation systems for concrete components is given in Table 18. It should be noted that the responses to the questionnaire conducted in the development of this report generally indicated poor Canadian experience with active corrosion mitigation systems.

Table 18 Comparison of Active Corrosion Mitigation Systems for Concrete Components (Systems that Supply a Protective Current to the Reinforcing Steel) (Adapted from Whitmore, 2004)

Performance Category	Corrosion Prevention	Corrosion Control	Cathodic Protection
Objective	Preventing corrosion initiation in contaminated areas	Significantly reducing on-going corrosion activity	Stopping on-going corrosion activity
Typical Application	Localized protection around patches, joints, and other interfaces between new and existing concrete	Targeted use in areas with active corrosion, but concrete still sound or can not be practically removed	Global protection for specific structural components or over the entire structure
Current Required per m^2 of Steel Surface Area	0.25 to 2 mA	1 to 7 mA	2 to 20 mA
Typical System	Embedded galvanic anodes	Embedded galvanic anodes	Impressed current or galvanic cathodic protection systems
Protection Level	Good	Better	Best
Initial investment	Low	Moderate	High

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5 TECHNICAL AND FINANCIAL COMPARISON OF STRUCTURAL CONCRETE DECK PROTECTION SYSTEMS

5.1 Evaluation of Current Canadian SCDPS

The evaluation of the generally available current Canadian SCDPS, with focus on SWS, for a specific new bridge deck project, involves three main components: feasibility assessment (suitability); comparative rating of the features and performance (technical comparison); and life-cycle cost analysis (financial comparison). A worked example of the evaluation is presented in this chapter.

- Feasibility Assessment (Suitability)

  The feasibility of the alternative SCDPS (SWS) are broadly considered with respect to their suitability for the specific deck involved. For the purposes of this chapter, the main five SCDPS considered in detail in Chapter 4 will be considered for an illustrative project:

  1. Bonded-Concrete Overlay
     – bonded 70 mm silica fume concrete overlay with fibre reinforcement;
  2. Hot-Applied Membrane
     – hot-applied rubberized asphalt membrane, two ply, 80 mm HMA;
  3. Liquid-Polymer Membrane
     – liquid-applied polymer membrane, bond treatment, 80 mm HMA;
  4. Self-Adhering Membrane
     – self-adhering rubberized asphalt sheet membrane, 50 mm HMA; and
  5. Torch-On Membrane
     – torch-on rubberized (polymer-modified) asphalt sheet membrane, 80 mm HMA.

- Comparative Rating of the Features and Performance (Technical Comparison)

  The comparative rating of the features and performance is made in terms of four assessment criteria and a rating scale (equal, better, much better, worse, and much worse):

  1. risk, based on performance history and potential for 'failure' (Table 19, with rating scale shown);
  2. technical, with regard to properties (Table 20);
  3. constructability, with focus on reliability (Table 21); and
  4. maintenance, including rehabilitation (Table 22).

  Weightings reflecting relative importance (low, moderate, high, and extremely high) are assigned to the features or properties as shown in Table 19. Overall weightings are also assigned to each of the primary assessment criteria: risk (20 percent); technical (40 percent); construction (20 percent); and maintenance (20 percent) (Table 23).

It is very important to note that the overall technical comparison of SCDPS for a specific deck is very sensitive to these parameters. An agency should evaluate these ratings, criteria, importance, and weightings in terms of their own experience and applicability for a specific deck, and modify or adjust them accordingly.

Table 19 Risk – Comparative Rating of Features or Properties and Importance

Risk Feature or Property	Importance
• Previous Successful Similar Applications	H
• Leakage due to Pinholes, Punctures or Cracking	EH
• Redundancy against Component Failure	H
• Leakage due to Blowholes or Blisters	EH
• Variable/Inadequate Material Quality	EH
• Variable/Inadequate Application Thickness	EH

Rating Scale		Importance		Weighting Factors
Equal	0	Low	L	0.7
Better	1	Moderate	M	1.0
Much Better	2	High	H	1.3
Worse	-1	Extremely High	EH	1.6
Much Worse	-2			

The rating scale, importance, and weighting factors are applied to risk, technical, construction, and maintenance features or properties.

Table 20 Technical – Comparative Rating of Features or Properties and Importance

Technical Feature or Property	Importance
• Positive Water Drainage	H
• Water and Chloride Permeability	EH
• Adhesion to Concrete	EH
• Durability (Water Action, Chemicals, Aging, Etc.)	H
• Stability (Resistance to Sliding/Deformation)	H
• Crack Spanning Capabilities	H
• Frictional Properties	H
• Influence of Service Temperature	H

Table 21 Construction – Comparative Rating of Features or Properties and Importance

Construction Feature or Property	Importance
• Specialty Plant/Equipment requirements	M
• Special Trades/Skills Required	M
• Number of Steps or Layers	L
• Conformance to Irregular Geometry, Appurtenances, Etc.	H
• Special Termination Details	M
• Surface Preparation Requirements	M
• Tolerance to Substrate Unevenness/Roughness	M
• Accommodation of Surface Profile Requirements	M
• Tolerance to Ambient Temperatures	M
• Tolerance to Moisture Conditions	H
• Propensity for Blowhole/Blister Development	H
• Curing Requirements	M
• Safety and Health Precautions	M
• Construction Quality Control	H
• Repair of Construction Deficiencies	M

Table 22 Maintenance – Comparative Rating of Features or Properties and Importance

Maintenance Feature or Property	Importance
• Inspection/Identification of Defects/Deterioration	H
• Defect Repair Requirements	H
• Traffic Disruption for Defect Repairs	H
• Traffic Disruption/Closure for Resurfacing	H
• Riding Quality – Smoothness	M
• Riding Safety – Frictional	H
• Routine Maintenance Requirements	H

Table 23 Overall Evaluation Criteria Weightings

Criterion	Weighting
• Risk	0.20
• Technical	0.40
• Construction	0.20
• Maintenance	0.20

- Life-Cycle Cost Analysis (Financial Comparison)

  A life-cycle cost analysis is required to evaluate the cost of alternative SCDPS over the design service life of a specific concrete deck (generally at least 75 years, CHDBC, CSA, 2006a). It is necessary to consider not only the initial costs, but the total costs including maintenance, rehabilitation, and user costs (typically not included by agencies) over the design life (Table 25). The probabilistic life-cycle cost analysis methodology developed by the FHWA for pavements is recommended for major projects (it can also be used for deterministic analyses if the input data are well defined) (FHWA, 1998). The illustrative life-cycle cost analysis of the five main SCDPS has been completed on a deterministic basis as the component initial costs and maintenance/rehabilitation schedules are quite well defined. Also, user costs are not considered as they will be quite similar for each of the SCDPS.

Table 24 Life Cycle Cost Analysis Summary

A Life-Cycle Cost Analysis, Including Value Engineering, is an Important Component of Selecting a Waterproofing System for a Specific Project

• Economic Assessment of Competing, Technically Suitable Systems Over Design Life
• Cost Components - initial costs (capital cost) - maintenance costs - rehabilitation costs - residual/salvage value - user costs (traffic delays for instance)
• Present-Worth Method - discount rate - analysis period
• Deterministic and Probabilistic Methods - recommend probabilistic methods based on FHWA and Crystal Ball software for major projects (FHWA, 1998)

5.2 Technical Comparison of the Five Main SCDPS

For this example, the technical comparison of the five main SCDPS was completed through a comparative rating of each SCDPS with respect to the hot-applied rubberized asphalt system, based on the SCDPS technology reviewed for this report, the current practices and experience summarized in Chapter 3, and practical experience. This comparative rating is summarized in Table 25: Table 25a – risk; Table 25b – technical; Table 25c – construction; and Table 25d – maintenance. The features and properties for risk, technical, construction, and maintenance are described in more detail in Table 25 for the illustrative example. The comparative overall ratings are then summarized in Table 26. The ranking based on total comparative ratings indicates a slightly higher rating (0.02) for the liquid-applied polymer membrane compared to the hot-applied rubberized asphalt membrane ('control'; 0.00):

1. Liquid-Applied Polymer Membrane, HMA (0.02).
2. Hot-Applied Rubberized Asphalt Membrane, Two Ply, HMA (0.00).
3. Torch-On Rubberized Asphalt Sheet Membrane, HMA (-0.91).
4. Bonded Latex or Silica Fume modified, Fibre Reinforced, Concrete Overlay (-2.01).
5. Self-Adhering Rubberized Asphalt Sheet Membrane, HMA (-2.90).

It must be noted that the performance of any concrete deck protection system is very sensitive to the actual quality of materials, work, maintenance, repairs involved, and rehabilitation involved.

A blank form for the comparative rating of candidate SCDPS for a specific deck project is provided in Table 27. It is important that an agency evaluate the applicability of Table 27 for a specific bridge deck project and modify it as necessary to reflect their own experience.

Table 25 Comparative Rating of Concrete Deck Protection Systems With Respect to Hot-Applied (Poured) Rubberized Asphalt Membrane System (Two Ply, Reinforced, Protection Board, 70 to 80 mm High Performance HMA)

Table 25a Risk

Risk Feature or Property	Importance	Rating	Rating x Importance Weighting Factor	Rating	Rating x Importance Weighting Factor	Rating	Rating x Importance Weighting Factor	Rating	Rating x Importance Weighting Factor
		Bonded Concrete Overlay[a]		Liquid Polymer Membrane[b]		Self Adhering Membrane[b]		Torch On Membrane[b]	
1. Previous successful application on heavily trafficked decks in northern climates.	H	0	0.00	-½	-0.65	-½	-0.65	-½	-0.65
2. Risk of water leakage due to pinholes, punctures, cracking, or around edges.	EH	-1½	-2.40	0	0.00	-1	-1.60	-½	-0.80
3. Redundancy to minimize risk of water leakage in the event of component failure.	H	-2	-2.60	-½	-0.65	-½	-0.65	-½	-0.65
4. Risk of leakage and/or premature failure due to blowholes or blisters developing.	EH	+2	3.20	0	0.00	-1½	-2.40	-1	-1.60
5. Risk of variable/inadequate material quality.	EH	-1	-1.60	-½	-0.80	+1	1.60	+1	1.60
6. Risk of variable/inadequate thickness of waterproofing protection.	EH	+½	0.80	0	0.00	+1½	2.40	+1½	2.40
Total Risk Comparative Rating			-2.60		-2.10		-1.30		0.30

Notes:

Rating Scale		Importance		Weighting Factors
Equal	0	Low	L	0.7
Better	1	Moderate	M	1.0
Much Better	2	High	H	1.3
Worse	-1	Extremely High	EH	1.6
Much Worse	-2			

a. Latex or silica fume modified concrete, 50 to 70 mm thickness.
b. High performance HMA, two lifts, 70 to 80 mm total thickness.

Table 25b Technical

Technical Feature or Property		Importance	Rating: Bonded Concrete Overlay[a]	Rating x Importance Weighting Factor	Rating: Liquid Polymer Membrane[b]	Rating x Importance Weighting Factor	Rating: Self Adhering Membrane[b]	Rating x Importance Weighting Factor	Rating: Torch On Membrane[b]	Rating x Importance Weighting Factor
1.	Positive water drainage.	H	0	0.00	0	0.00	0	0.00	0	0.00
2.	Water and chloride permeability.	EH	-1	-1.60	0	0.00	-½	-0.80	0	0.00
3.	Adhesion to concrete.	EH	-½	-0.80	+1	1.60	-1	-1.60	-½	-0.80
4.	Durability (resistant to degradation from water absorption, freeze thaw, deicing chemicals, UV and aging, abrasion).	H	-½	-0.65	0	0.00	0	0.00	0	0.00
5.	Stability (resistance to sliding and deformation).	H	+2	2.60	+1	1.30	-1	-1.30	0	0.00
6.	Crack spanning capability.	H	-2	-2.60	-½	-0.65	-½	-0.65	-½	-0.65
7.	Frictional properties (wet skid resistance).	H	-½	-0.65	0	0.00	0	0.00	0	0.00
8.	Influence of service temperature.	H	0	0.00	0	0.00	-½	-0.65	0	0.00
Total Technical Comparative Rating				-3.70		2.25		-5.00		-1.45

Table 25c Construction

Construction Feature or Property		Importance	Rating: Bonded Concrete Overlay[a]	Rating x Importance Weighting Factor	Rating: Liquid Polymer Membrane[b]	Rating x Importance Weighting Factor	Rating: Self Adhering Membrane[b]	Rating x Importance Weighting Factor	Rating: Torch On Membrane[b]	Rating x Importance Weighting Factor
1.	Specialty plant/equipment requirements.	M	0	0.00	-1	-1.00	+2	2.00	0	0.00
2.	Special trades/skills required.	M	0	0.00	-1	-1.00	+1	1.00	0	0.00
3.	Number of steps or layers.	L	+½	0.35	+½	0.35	+½	0.35	+½	0.35
4.	Conformance to irregular geometry, appurtenances, etc.	H	0	0.00	+1	1.30	-1	-1.30	-½	-0.65
5.	Special termination details.	M	+1	1.00	+1	1.00	-½	-0.50	-½	-0.50
6.	Surface preparation requirements.	M	-½	-0.50	-1	-1.00	0	0.00	0	0.00
7.	Tolerance to substrate unevenness/ roughness.	M	+2	2.00	+½	0.50	-1	-1.00	-½	-0.50
8.	Accommodation of complex surface profile requirements.	M	-1½	-1.5	0	0.00	0	0.00	0	0.00
9.	Tolerance to ambient temperatures during application.	M	-½	-0.50	+½	0.50	0	0.00	0	0.00
10.	Tolerance to moisture conditions during application.	H	1	1.30	-1	-1.30	0	0.00	0	0.00
11.	Propensity for blowhole/blister development during construction.	H	2	2.60	0	0.00	-1	-1.30	-½	-0.65
12.	Curing requirements.	M	-2	-2.00	0	0.00	0	0.00	0	0.00
13.	Safety and health precautions.	M	+1	1.00	-1	-1.00	+1	1.00	+½	0.50
14.	Monitoring and control of construction quality.	H	-1	-1.30	-½	-0.65	-1	-1.30	0	0
15.	Repair of construction deficiencies.	M	-2	-2.00	0	0.00	-1½	-1.50	-½	-0.50
Total Construction Comparative Rating				0.45		-2.30		-2.55		-1.95

Table 25d Maintenance

Maintenance Feature or Property	Importance	Rating: Bonded Concrete Overlay[a]	Rating x Importance Weighting Factor: Bonded Concrete Overlay[a]	Rating: Liquid Polymer Membrane[b]	Rating x Importance Weighting Factor: Liquid Polymer Membrane[b]	Rating: Self Adhering Membrane[b]	Rating x Importance Weighting Factor: Self Adhering Membrane[b]	Rating: Torch On Membrane[b]	Rating x Importance Weighting Factor: Torch On Membrane[b]
1. Inspection and Identification of faults.	H	2	2.60	0	0.00	0	0.00	0	0.00
2. Repair of faults.	H	+½	0.65	0	0.00	0	0.00	0	0.00
3. Traffic disruption for resurfacing.	H	+½	0.65	0	0.00	0	0.00	0	0.00
4. Traffic disruption for fault repairs.	H	-2	-2.60	0	0.00	+½	0.65	0	0.00
5. Riding quality - smoothness.	M	-½	-0.50	0	0.00	0	0.00	0	0.00
6. Maintenance of frictional properties – wet skid resistance.	H	-½	-0.65	0	0.00	0	0.00	0	0.00
7. Routine remedial maintenance requirements.	H	-½	-0.65	0	0.00	0	0.00	0	0.00
8. Frequency of resurfacing	H	0	0.00	0	0.00	-1	-1.30	0	0.00
Total Maintenance Comparative Rating			-0.50		0.00		-0.65		0.00

Table 26 Comparative Overall Rating of Concrete Deck Protection Systems With Respect to Hot-Applied (Poured) Rubberized Asphalt Membrane System (Two Ply, Reinforced, Protection Board, 70 to 80 mm High Performance HMA)

Criterion Category	Weighting	Rating x Criterion Category Weighting Factor: Bonded Concrete Overlay	Liquid Polymer Membrane	Self Adhering Membrane	Torch On Membrane
Risk	0.20	-0.52	-0.42	-0.26	0.06
Technical	0.40	-1.48	0.90	-2.00	-0.58
Construction	0.20	0.09	-0.46	-0.51	-0.39
Maintenance	0.20	-0.10	0.00	-0.13	0.00
Total Comparative Rating		-2.01	0.02	-2.90	-0.91

Ranking Based on Total Comparative Rating

1. Liquid-Applied Polymer Membrane, HMA (0.02)
2. Hot-Applied Rubberized Asphalt Membrane, Two Ply, HMA (0.00)
3. Torch-On Rubberized Asphalt Sheet Membrane, HMA (-0.91)
4. Bonded Latex or Silica Fume Modified, Fibre Reinforced, Concrete Overlay (-2.01)
5. Self-Adhering Rubberized Asphalt Sheet Membrane, HMA (-2.90)

The actual performance of any concrete deck protection system is very sensitive to the quality of materials, work, maintenance, repairs involved and rehabilitation involved.

Table 27 Form for Comparative Rating of Candidate Concrete Deck Protection Systems With Respect to a Selected 'Standard' Waterproofing System (Typically Hot-Applied Rubberized Asphalt Membrane, Two Ply, Reinforced, Protection Board, 70 to 80 mm High Performance HMA – See Tables 25 and 26)

FEATURE OR PROPERTY	IMPORTANCE	SYSTEM 1		SYSTEM 2		SYSTEM 3	
RISK							
		RATING	WEIGHTE	RATING	WEIGHTED	RATING	WEIGHTE
1. PREVIOUS SUCCESSFUL APPLICATION ON HEAVILY TRAFFICKED BRIDGE DECKS IN NORTHERN CLIMATES	H						
2. RISK OF WATER LEAKAGE DUE TO PINHOLES, PUNCTURES, CRACKING, OR AROUND EDGES	EH						
3. REDUNDANCY TO MINIMIZE RISK OF WATER LEAKAGE IN THE EVENT OF COMPONENT FAILURE	H						
4. RISK OF LEAKAGE AND/OR PREMATURE FAILURE DUE TO BLOWHOLES OR BLISTERS DEVELOPING	EH						
5. RISK OF VARIABLE/INADEQUATE MATERIAL QUALITY	E						
6. RISK OF VARIABLE/INADEQUATE THICKNESS OF WATERPROOFING PROTECTION	EH						
TECHNICAL							
1. POSITIVE WATER DRAINAGE	H						
2. WATER AND CHLORIDE PERMEABILITY	E						
3. ADHESION TO CONCRETE	E						
4. DURABILITY (RESISTANT TO DEGRADATION FROM WATER ABSORPTION, FREEZE THAW, DEICING CHEMICALS, UV AND AGING,	H						
5. STABILITY (RESISTANCE TO SLIDING AND DEFORMATION)	H						
6. CRACK SPANNING CAPABILITY	H						
7. FRICTIONAL PROPERTIES (WET SKID RESISTANCE)	H						
8. INFLUENCE OF SERVICE TEMPERATURE	H						
CONSTRUCTION							
1. SPECIALTY PLANT/EQUIPMENT REQUIREMENTS	M						
2. SPECIAL TRADES/SKILLS REQUIRED	M						
3. NUMBER OF STEPS OR LAYERS	L						
4. CONFORMANCE TO IRREGULAR GEOMETRY, APPURTENANCES, ETC.	H						
5. SPECIAL TERMINATION DETAILS	M						
6. SURFACE PREPARATION REQUIREMENTS	M						
7. TOLERANCE TO SUBSTRATE UNEVENNESS/ROUGHNESS	M						
8. ACCOMMODATION OF COMPLEX SURFACE PROFILE REQUIREMENTS	M						
9. TOLERANCE TO AMBIENT TEMPERATURES DURING APPLICATION	M						
10. TOLERANCE TO MOISTURE CONDITIONS DURING APPLICATION	H						
11. PROPENSITY FOR BLOWHOLE/BLISTER DEVELOPMENT DURING CONSTRUCTION	H						
12. CURING REQUIREMENTS	M						
13. SAFETY AND HEALTH PRECAUTIONS	M						
14. MONITORING AND CONTROL OF CONSTRUCTION QUALITY	H						
15. REPAIR OF CONSTRUCTION DEFICIENCIES	M						
MAINTENANCE							
1. INSPECTION AND IDENTIFICATION OF FAULTS	H						
2. REPAIR OF FAULTS	H						
3. TRAFFIC DISRUPTION FOR FAULT REPAIRS	H						
4. TRAFFIC DISRUPTION FOR RESURFACING	H						
5. RIDING QUALITY – SMOOTHNESS	M						
6. MAINTENANCE OF FRICTIONAL PROPERTIES – WET SKID RESISTANCE	H						
7. ROUTINE REMEDIAL MAINTENANCE	H						
8. FREQUENCY OF RESURFACING	H						
TOTAL (0.20, 0.40, 0.20, 0.20)							

Rating Scale		Importance		Weighting Factors
Equal	0	Low	L	0.7
Better	1	Moderate	M	1.0
Much Better	2	High	H	1.3
Worse	-1	Extremely High	EH	1.6
Much Worse	-2			

NOTE: The actual performance of any concrete deck protection system is very sensitive to the quality of materials, work, maintenance, and repair.

5.3 Financial Comparison of the Five SCDPS

The illustrative life-cycle cost analysis (LCCA) financial comparison of the main five SCDPS is summarized in Table 28 for a 100 year analysis period, four percent discount rate, and SCDPS unit prices given below Table 28. These first quarter of 2008, typical, Canadian unit prices are sensitive to specific bridge deck projects and locations, and based on project, agency, supplier, and contractor cost information, and technical literature cost information, adjusted for the first quarter of 2008. It should be noted that the discounted cost (net present value) of rehabilitation and replacement costs are not significant after about 50 years. The ranking based on the net present value LCCA (100 years, four percent discount rate) is:

1. Hot-Applied Rubberized Asphalt Membrane, ($8,232).
2. Torch-On Rubberized Asphalt Sheet Membrane, ($8,608).
3. Bonded 70 mm Silica Fume Concrete Overlay, ($9,310).
4. Self-adhering Rubberized Asphalt Sheet Membrane, ($9,567).
5. Liquid-Applied Polymer Membrane, ($18,240).

It must be noted that the life-cycle cost of any SCDPS is very sensitive to the actual project specific initial costs and discount rate at the time of construction.

While the liquid-applied polymer membrane system has a slightly higher comparative technical rating compared to the hot-applied rubberized asphalt membrane system, it has the highest life-cycle cost, nearly double that of the hot-applied rubberized asphalt membrane system. On this basis, the hot-applied rubberized asphalt membrane waterproofing system would be considered the prime SCDPS candidate for the project deck waterproofing. **Again, it should be noted that this is an illustrative evaluation and the technical ranking and life-cycle cost for the specific deck are sensitive to the comparative ratings assigned, materials and construction quality, and initial costs and discount rate at the time of construction for a specific bridge deck.**

Table 28 Life-Cycle Cost Analysis of Concrete Deck Protection Systems 100 Years, Four Percent Discount Rate, Net Present Value

Cost For 100 m², Net Present Value, $						
Year	Discount Rate 4%	Bonded Concrete Overlay	Hot Applied Membrane	Liquid Polymer Membrane	Self Adhering Membrane	Torch On Membrane
0	Construction	6300.	5112.	13112.	4640.	5412.
20	0.456	Friction 182.	Replace SPF 845.	Replace SPF 845.	Replace System 2481.	Replace SPF 845.
35	0.253	Replace System 1771.				
40	0.208		Replace System 1271.	Replace System 2935.	Replace System 1132.	Replace System 1334.
55	0.116	Friction 46.				
60	0.095		Replace SPF 178.	Replace SPF 178.	Replace System 517.	Replace SPF 178.
70	0.064	Replace System 448.				
80	0.043		Replace System 263.	Replace System 607.	Replace System 234.	Replace System 276.
Subtotal	$	8747.	7669.	17677.	9004.	8045.
Maintenance	$	563.	563.	563.	563.	563.
TOTAL	$	9310.	8232.	18240.	9567.	8608.

Ranking Based on Net Present Value Life Cycle Cost Analysis, 100 Years, 4% Discount Rate

1. Hot-Applied Rubberized Asphalt Membrane, Two Ply, 40 mm SP12.5/40 mm SP12.5F ($8232.)
2. Torch-On Rubberized Asphalt Sheet Membrane, 40 mm SP12.5/40 mm SP12.5F ($8608.)
3. Bonded 70 mm Silica Fume Concrete Overlay with Fibre Reinforcement ($9310.)
4. Self-Adhering Rubberized Asphalt Sheet Membrane, 50 mm SP12.5F ($9567.)
5. Liquid-Applied Polymer Membrane, Bond Treatment, 40 mm SP12.5/40 mm SP12.5F ($18240.)

Unit Prices: SP12.5 HMA, $100./t; SP12.5F HMA (Frictional), $120./t; Milling 40mm, $5./m²; Milling 50mm, $6./m²; Milling 80mm, $8./m²; Removing Membrane, $2./m²; Texturing (Friction), $4./m²; Hot-Applied Membrane, 2 ply, Reinforced (Materials/Installation), $30./m²; Torch-On Membrane (Materials/Installation), $33./m²; Bonded Concrete Overlay (Materials/Installation), $63./m²; Self-Adhering Membrane (Materials/Installation), $32./m²; and Liquid-Applied Membrane (Materials/Installation), $110./m². Project specific pricing information should be used for the deck(s) involved. The life-cycle cost of any concrete deck protection system is sensitive to the actual initial costs and discount rate at the time of construction.

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6 MAINTENANCE, MAJOR REPAIR, AND REHABILITATION OF DECKS

6.1 Maintenance of Decks

Concrete bridge maintenance, with focus on decks and SCDPS, involves relatively inexpensive systematic activities and minor repairs that prevent or minimize concrete deterioration and extend the service life of structural concrete elements such as decks (ACI, 2008j; Dunn, 2001; NCHRP, 2006b; TAC, 2004; TAC, 2006). The ACI *Guide for Maintenance of Concrete Bridge Members* provides detailed information on bridge maintenance, concrete bridge deterioration, considerations in bridge design, drainage and washing, sealing, maintenance patching, joints, cracks, and control joints, potentially promising techniques for bridge maintenance, and references, with focus on decks (ACI, 2008j). It is recommended as a hands-on manual for bridge engineering, operations, and maintenance staff. The maintenance activities are generally divided into preventive maintenance procedures that are done before deterioration is visible (concrete element in good condition) and responsive maintenance procedures at early stages of visible deterioration. Preventive maintenance procedures include sealing, washing, and crack repair, for instance. Responsive maintenance procedures include small repairs, establishment of positive deck drainage systems, and maintaining the functionality of deck joints, for instance (ACI, 2008j).

6.2 Repair and Rehabilitation of Decks

While there are many technical references providing guidance on the major repair and rehabilitation of structural concrete (ACI, 2008e; ACI, 2008f; ACI, 2008o; Bickley, 1986; NCHRP, 2002; Raina, 1994; TAC, 2006; Walker, 1999), little overall guidance is generally provided on selecting optimal repair and rehabilitation methods to cost-effectively extend the service life of deteriorated reinforced concrete elements such as bridge decks. The cost-effective preservation of concrete bridge elements such as decks form a key component of bridge management systems (BMS) integral to transportation asset management (Juntunen, 2003; NCHRP, 2005a; NCHRP, 2007a; TAC, 2004; Yanev, 2007).

6.2.1 Service-Life Model for In-Service Reinforced Concrete Elements Such as Decks

For concrete bridge decks, particularly in areas where road salts are used, the performance of the deck and SCDPS forms an important component of the agency's BMS. It is important to have BMS performance and service-life prediction models for reinforced concrete elements such as decks (ACI, 2008n; Daigle, 2006; Kaszynska, 2004; Lounis, 2000; Lounis, 2001; Lounis, 2004; NCHRP, 2006b; Nowak, 2004). These service-life models can be used for new deck service-life prediction and life-cycle costing (ACI Strategic Development Council Life-365, NIST Bridge LCC, and NCHRP BLCCA, for instance (FHWA, 2005a; Mitchell, 2004), or more importantly, in-service elements such as decks (NCHRP, 2006b). The NCHRP *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements* is recommended as it focuses primarily on bridge deck elements in terms of detailed procedures for the design of repairs and rehabilitation, including corrosion control systems, with detailed field evaluation procedures, laboratory evaluation procedures, and service-life model procedures for repair and rehabilitation design (NCHRP, 2006b; detailed Report and Manual available at the NCHRP site). It should also be noted that standard site and laboratory testing procedures are used throughout the Manual (ASTM, 2007b; ASTM, 2007c; ASTM, 2007d; ASTM, 2007e; ASTM, 2007f; ASTM, 2007g, ASTM, 2007h; ASTM, 2007i, for instance).

The NCHRP Manual is based on diffusion models developed for black reinforcing steel and epoxy-coated reinforcing steel. For epoxy-coated rebar, corrosion initiates only at defects where the chloride ion concentration has exceeded the threshold. On black rebar, corrosion initiates at all locations where the chloride ion concentration has been exceeded. The effectiveness of epoxy as a barrier is impacted by the presence of coating damage or defects in the form of ‘holidays,’ mashed areas, and bare areas (NACE, 1999). The distribution of chloride ions at the rebar depth can be used to quantify both the susceptibility of the reinforced concrete element (deck, for instance) to corrosion in areas not presently damaged and the future susceptibility to corrosion-induced damage. If sufficient chloride ions are present to initiate corrosion, then corrosion-induced damage is expected soon, and only 'aggressive' corrosion mitigation techniques (cathodic protection and electrochemical chloride extraction, for example) can be used to control the rebar (or steel strand) corrosion process (NACE, 2002; NACE, 2005a; NACE 2007). If the chloride ion concentration distribution at the rebar depth is low and corrosion is not expected to initiate in the near future, less expensive corrosion control systems (seals, membranes, and/or corrosion inhibitors, for example) can be used to either control or stop the rate of corrosion (NACE, 2005b; NACE, 2006). The Susceptibility Index (SI), based on the NCHRP Manual diffusion model, provides a good representation of the distribution of chloride ions at the rebar depth and is used in the Manual repair design and corrosion control system selection process. The SI value is 0 if the chloride ion concentration everywhere at the rebar depth is at the threshold ('severe condition') and is 10 if there are no chloride ions anywhere at the rebar depth ('good condition') (NCHRP, 2006b).

6.2.2 Designing Repair and Corrosion Control Systems

The distribution of chloride ions for a deck can be determined by collecting samples of the deck concrete and analyzing them for chloride ion content at the rebar depth. There are two methods of accomplishing this:

1. Locating the reinforcing steel on the deck surface, drilling down, measuring the clear concrete cover over the rebar, and then collecting a powdered concrete sample from concrete adjacent to the rebar. This method is often used, but has disadvantages and the amount of time required for sampling is large.
2. Using field data collected for Manual service life modelling. The diffusion coefficients, the surface chloride concentrations, and the clear concrete cover are then used in conjunction with the Manual diffusion model to determine the distribution of chloride ions at a given rebar depth at a given age (NCHRP, 2006b).

The NCHRP Manual should be referred to for the detailed site and laboratory testing procedures, including sampling and sample preparation, involved.

Full details on the service life modelling and SI are also given in the Manual to be used in conjunction with the Manual software *Service Life Model* (NCHRP, 2006b).

The overall methodology for designing repair and corrosion control systems for reinforced concrete elements (component) is summarized in Figure 6. A recommended testing program and recommended minimum sampling size or number of tests, used in conjunction with the overall methodology (Figure 5), are given in Tables 29 and 30, respectively. The repair types and selection, and corrosion control systems, for reinforced concrete elements (focus on deck) are given in Figure 6. Full details on selecting and designing the repair and corrosion control systems are provided in the NCHRP *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements* (NCHRP, 2006b). Practical agency experience should be reflected in the use of the Manual for selecting and designing the major repair or rehabilitation of a specific deck.

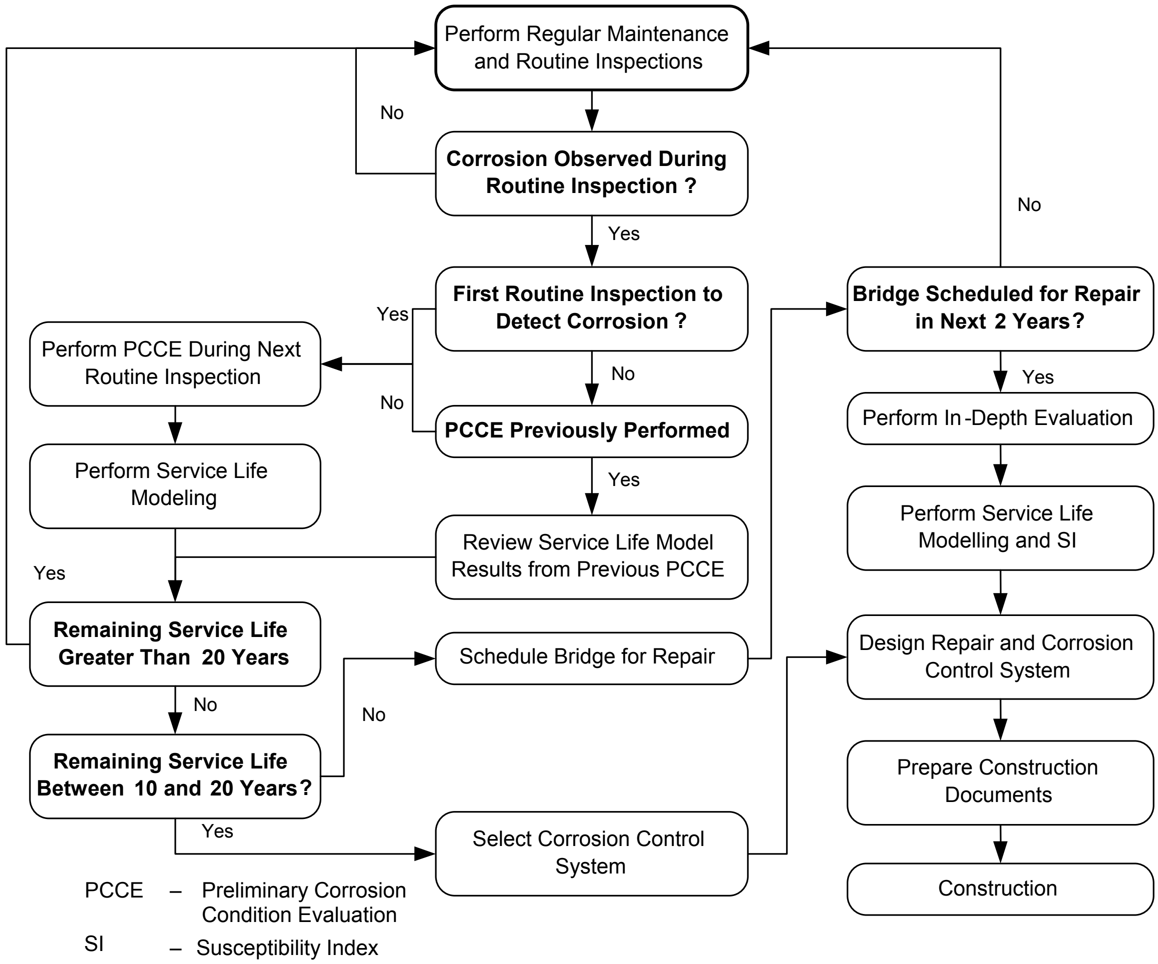

Figure 6 Methodology for Designing Repair and Corrosion Control Systems for Reinforced Concrete Elements (Adapted from NCHRP Manual, NCHRP 2006 b)

Table 29 Recommended Testing Programs for a Concrete Deck Preliminary Corrosion Condition Evaluation (PCCE) or In-Depth Corrosion Condition Evaluation (IDCCE) (Adapted From (NCHRP Manual, NCHRP, 2006b)

Deck	Visual - Deck[a]		Visual - Surfacing[a]		Cover[a]		Delamination[a]		Chloride Profile[a]		Epoxy-Coated Rebar Cores[a,b]		Continuity[a]		Carbonation[a]		Petrographic[a]		Half-Cell[a]		Corrosion Rate[a]	
	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE	PCCE	IDCCE
Bare	✓	✓	NA	NA	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	X	X	X	✓	+	X	+	X
Concrete Overlay	✓	✓	NA	NA	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	X	X	X	✓	+	X	+	X
HMA Overlay	NA	NA	✓	✓	✓	✓	NA	NA	✓	✓	✓	✓	X	✓	X	X	X	✓	NA	NA	NA	NA
Epoxy Overlay	NA	NA	✓	✓	✓	✓	NA	NA	✓	✓	✓	✓	X	✓	X	X	X	✓	NA	NA	NA	NA
Membrane	✓	✓	✓	✓	✓	✓	NA	NA	✓	✓	✓	✓	X	✓	X	X	X	✓	NA	NA	NA	NA
Sealer	✓	✓	✓	✓	✓	✓	✓	NA	✓	✓	✓	✓	X	✓	X	X	X	✓	NA	NA	NA	NA

Notes: ✓ - mandatory; X - recommended; + - optional; and NA - not applicable.
a. See Table 30 for recommended minimum sampling sizes or number of tests.
b. If epoxy-coated reinforcing is in the deck.

Table 30 Recommended Minimum Sampling Size or Number of Tests for a Concrete Deck Preliminary Corrosion Condition Evaluation (PCCE) or In-Depth Corrosion Condition Evaluation (IDCCE) (Adapted from NCHRP Manual, NCHRP, 2006b)

Test	Minimum Sampling Size or Number of Tests	
	PCCE	IDCCE
Visual Condition	Entire surface	Entire surface
Clear Concrete Cover (Nondestructive - NDT)[a]	Thirty measurements per span	Thirty measurements per span (previous PCCE can be used.)
Delamination Survey	Ten percent of surface[b]	Entire surface
Chloride-Profile Analysis	One location per 300 m² (minimum of five)	One location per 300 m² (minimum of five)
Epoxy-Coated Rebar Cores	Minimum of five	Minimum of five
Petrographic Analysis	—	One location per 300 m² (minimum of five)

Notes: a. Several actual core measurements should be taken to calibrate NDT.
b. If the surface is variable, use several representative test areas.

<table>
<tr><th>REPAIR TYPES</th><th>SI < 2</th><th>SI ≥ 2</th><th>SI ≥ 4</th><th>SI ≥ 5</th><th>SI ≥ 7</th><th>SI ≥ 8</th></tr>
<tr><td>WHEN REPLACEMENT IS MORE COST EFFECTIVE</td><td colspan="6">New Concrete Component (Corrosion Control can be Incorporated)</td></tr>
<tr><td>TOP LAYER CONCRETE REPLACEMENT</td><td colspan="3">Sealers, Membranes, Overlays</td><td colspan="3">SI Too High for Top Concrete Layer Replacement</td></tr>
<tr><td>PATCH REPAIR AND OVERLAY</td><td colspan="2">Cathodic Protection
Epoxy-Coated Rebars</td><td colspan="4">Overlay Serves as a Corrosion Control System</td></tr>
<tr><td rowspan="6">PATCH REPAIR</td><td colspan="5">NA</td><td>Do Nothing</td></tr>
<tr><td colspan="4">NA</td><td colspan="2">Sealers</td></tr>
<tr><td colspan="3">NA</td><td colspan="3">Membranes</td></tr>
<tr><td colspan="2">NA</td><td colspan="4">Overlays and Overlays Plus Membrane</td></tr>
<tr><td>NA</td><td colspan="5">Corrosion Inhibitors</td></tr>
<tr><td colspan="6">Cathodic Protection And Electrochemical Chloride Extraction</td></tr>
</table>

Figure 7 Selection of Corrosion Control System for Reinforced Concrete Elements (Components) Based on the Susceptibility Index (SI). SI is 0 if the Chloride Ion Concentration at the Steel Depth is at the Corrosion Threshold and 10 if there are no Chloride Ions at the Steel Depth, for Instance.) (Adapted from NCHRP Manual, NCHRP, 2006b)

The use of the web-based NCHRP *Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements* (NCHRP, 2006b) is recommended for construction materials and bridge engineers involved with the design, implementation, maintenance, and rehabilitation of structural concrete deck protection systems.

7 RECOMMENDATIONS AND SUMMARY OF BEST PRACTICES FOR STRUCTURAL WATERPROOFING SYSTEMS

7.1 Recommendations for Canadian Structural Concrete Deck Protection Systems

Based on the structural concrete deck protection systems technology (mainly structural waterproofing systems) presented in this report, the following technical recommendations are provided to assist construction materials and bridge engineers in Canada:

- the bridge deck drainage requirements of the CHBDC must be followed for any bridge construction, repair, or rehabilitation project;
- the use of combined deck corrosion protection systems, subject to Approval (CHBDC), should be considered (technical evaluation and life-cycle cost analysis) as an alternate to current structural waterproofing systems;
- the importance of minimizing concrete deck cracking (particularly early age cracking) must be recognized and dealt with through construction specification requirements;
- the rubberized asphalt high performance/superelevation specification and a two-ply system should be adopted, when a hot-applied rubberized asphalt waterproofing membrane is selected, for all decks, and particularly those with four percent, or greater, grade, superelevation, and/or heavy traffic;
- the use of high performance hot-mix asphalt (typically Superpave HMA designed for heavy traffic conditions) should be adopted for major route bridge deck asphalt concrete surfacing and all decks with grade, superelevation, and/or heavy traffic (see previous recommendation);
- the ACI *Guide for Maintenance of Concrete Bridge Members* should be considered as a hands-on manual for bridge engineering, operations, and maintenance staff; and
- the NCHRP *Manual on Service Life of Corrosion-Damaged Concrete Bridge Superstructure Elements* should be considered as a repair, rehabilitation, and corrosion control systems best practices guide for construction materials and bridge engineers involved with the repair and rehabilitation of reinforced concrete bridge decks.

7.2 Best Practices for Structural Waterproofing Systems

Best practices for structural concrete deck protection systems, with focus on Canadian structural waterproofing systems, are offered throughout this report. It is strongly recommended that the full report be consulted for the overall SWS best practices for any specific project. The relevant tables, figures, and lists, with key practices, are as follows:

- Table 1 Common Strategies for Concrete Deck Reinforcement Corrosion Control
  - provide proper deck drainage (CHBDC)
  - prevent water and salt (chlorides) from penetrating into the concrete deck (CHBDC)
    - high performance concrete, adequate reinforcement cover, impermeable waterproofing systems (SWS)
    - quality materials and construction of overall waterproofing system
  - additional strategies beyond this report's SWS scope (covered briefly and/or current references given in report)
    - reinforcement coating, corrosion resistant reinforcement, addition of corrosion inhibitors to concrete, cathodic protection, and electrochemical chloride extraction
    - multiple (combined) corrosion protection systems (see general recommendations above);
- Table 2 Some Concrete Deck Waterproofing System Practical Rules
  - there should be no horizontal surfaces on the deck or asphalt concrete surfacing (CHBDC); adequate slope drainage is needed
  - surface drainage should be designed to complement waterproofing membranes and expansion joints (CHBDC)
  - water must not be allowed to accumulate within the asphalt concrete surfacing (Figure 5)
  - the concrete surface must be sound, properly finished, uncontaminated, dry, and dust free before waterproofing system construction
  - the installed waterproofing system must
    - prevent intrusion of water and chlorides
    - bond very well to the properly prepared and primed deck surface
    - effectively bridge joints and cracks in the concrete
    - remain sufficiently elastic over all ambient temperatures to prevent failure by cracking
    - remain sufficiently stable to prevent distortion or shoving
    - be straightforward to place
  - there is a risk of waterproofing membrane blistering or pinholing due to outgassing unless the deck is dry and the weather is favourable for membrane installation
  - proper placement and compaction of the asphalt concrete surfacing (HMA) is essential, particularly adjacent to horizontal and vertical details (quality control and quality assurance);

- list of recommended current technical resources for construction materials and bridge engineering using the Guide and CHDBC
  - bridges, concrete, codes, and standards (ACI, CSA, and NACE)
  - TAC Guides (bridge management and bridge repair and rehabilitation)
  - NACE/FHWA, SHRP, FHWA and NCHRP (TRB) reports;
- Table 6 Structural and Functional Requirements for Hot-Applied Rubberized Asphalt Membrane Waterproofing System Materials and Construction (most common SWS currently used across Canada)
  - watertightness under the traffic loadings and climatic conditions
  - mechanical stability and strength to withstand effects of traffic loadings
  - resistance to cracking, or separation, in layers under traffic loadings or due to movement of lower layers
  - watertightness integrity and material strength to resist overall impact of traffic loadings, severe weather, deicing chemicals, spills, and other factors causing potential damage or deterioration
  - compatibility between the placed and compacted hot-mix asphalt (HMA) and the substrate
  - ability to withstand thermal and mechanical impacts during construction of the waterproofing system
  - maintainability in terms of preventive maintenance, repair, and rehabilitation;
- Table 15 Dense Graded Hot-Mix Asphalt Checklists: HMA Materials, Mix Design Requirements, and Construction for Heavy Duty Applications that Consider Resistance to Top-Down Cracking
  - general functional and structural performance requirements
  - materials, mix design, and construction requirements
- Table 16 Preparation is the Key to Successful Waterproofing
  - most frequent problems with liquid hot-applied membranes
  - most frequent problems with sheet membranes
  - most failures of membranes stem directly from inadequate surface preparation; and
- Table 17 Inspection and Testing Requirements for Waterproofing Systems (Membrane and Surfacing)
  - qualified inspection and testing technicians/testing laboratory
  - review specifications

- complete pre-placement compliance checks of materials
- asphalt technology site inspection and related testing
- reporting.

The overall best practice for the technical and financial comparison of SCDPS, with focus on SWS, including an example comparison of the SWS, is given in Chapter 5.

The practices summarized here, in conjunction with the technical recommendations, provide an overall best practice for Canadian SWS. It is recommended that the full report be consulted for any specific concrete bridge deck SWS selection, design, construction, maintenance, repair, and rehabilitation.

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APPENDIX A DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

A.1 DEFINITION OF TERMS FOR CONCRETE DECK PROTECTION SYSTEMS

These definitions are mainly based on AASHTO, ACI, ASTM, CSA, NACE, NCHRP, SSPC, TAC and TRB publications, standards, and practices that provide a fuller range of terms and notes on use.

abutment – a substructure that supports the end of a bridge superstructure and retains some or all of the bridge approach fill.

adhesion – the ability of waterproofing materials to bond to a substrate or other material during movement or stress.

admixture – an approved beneficial material, other than portland cement, supplemental cementitious material, aggregates, or water, which is added to a concrete batch prior to or during mixing.

alkali-aggregate reactivity – a chemical reaction in concrete between alkalies from portland cement or other sources and constituents of some aggregates; under some conditions, deleterious expansion of the concrete will occur.

anode – the electrode of an electrochemical cell at which oxidation occurs.

approach slab – a reinforced concrete slab used to prevent settlement of a bridge approach pavement.

Approval, Approved – the approval, or approved, in writing by the Regulatory Authority (federal, provincial, or territorial Minister having jurisdiction and control, nominee, or local authority to whom authority is delegated).

asphalt – a waterproofing material based on natural or petroleum based asphalt (bitumen) which liquefies when heated and is impervious to water.

asphalt cement (binder) – the hot cementitious material in which the predominant constituent is natural or petroleum based asphalt (bitumen), with or without the addition of organic modifiers (polymer-modified), used as the binder in hot-mix asphalt.

asphalt concrete – a designed mixture of asphalt cement and carefully graded coarse and fine aggregates (hot-mix asphalt).

asphalt mastic – a mixture of asphaltic material and graded mineral aggregate that can be poured when heated, but requires mechanical manipulation to apply.

asphalt modifier – an approved organic material, which is dissolved, dispersed or reacted in asphalt cement (binder) to enhance its performance.

ballast wall – the part of an abutment above the bearing seat used primarily to retain approach fill and to provide support for an approach slab and expansion joint.

barrier – an auxiliary component parallel to the roadway edge which acts as a vehicular, pedestrian, bicycle, or combination, barrier.

barrier wall – a barrier that is without openings and is not less than 800 mm high.

bead – a small amount of mastic, caulking or asphalt flashing cement applied to the waterproofing membrane at a termination.

bearing – a mechanical system which transmits loads from the bridge superstructure to the substructure.

bleeder drain – a hole, tube or pipe through a bridge deck to provide internal waterproofing system drainage (also see **drainage tube**, **seepage drain**).

blister – a pocket of air or water vapour between a waterproofing membrane and the deck surface caused by entrapped air, the volatilization of liquids applied to the concrete, or the vaporization of water on or in the concrete.

blowhole – a perforation in a liquid waterproofing membrane resulting from the escape of vapour from the concrete before the membrane has cured.

cast-in-place – refers to concrete which is placed and cured in its final location in the field.

catch basin – a box-type structure which is used to collect water and prevent debris from entering the drainage system.

cathode – the electrode of an electrochemical cell at which reduction is the principal reaction.

cathodic prevention – the application of cathodic polarization to passive steel to prevent or delay a transition to the active corroding condition.

chloride – a component in anti-icing and deicing agents which has adverse effects on concrete and steel bridge components.

component – a member of a structure requiring individual design consideration.

conductive asphalt concrete overlay – a first course hot-mix asphalt concrete overlay using aggregate or high-crystalline structure carbon, or equivalent, which is capable of distributing impressed current from the anodes to all parts of a bridge deck surface.

conductive coating – a coating that conducts electricity, or an electrically conductive, mastic-like material, used as an impressed current anode on reinforced concrete surfaces.

construction joint – a joint placed in a concrete slab at the end of an individual placement (planned or unplanned stoppage of placement).

contaminant (contamination) – any extraneous material on the concrete surface that will affect the adhesion of the applied membrane or protective coating to the concrete.

continuous spun bonded polypropylene mat – a sheet material, made from polypropylene plastic fibres, used in the manufacture of preformed membranes for waterproofing.

corrosion – the major type of deterioration of metals (often called oxidation); it is a chemical reaction of the metal with oxygen or other elements.

corrosion chloride threshold level – the degree of chloride contamination of concrete that will activate the reinforcing steel corrosion process (typically estimated at 0.17 kg of acid-soluble chloride (total minus background) per m^3 of concrete).

crack sealing – a maintenance treatment in which a properly prepared crack is filled with a sealant.

critical chloride contamination – the degree of chloride contamination of the cover concrete such that after the concrete is protected the chloride content at the reinforcing steel level will come to an equilibrium value of at least 0.12 kg of acid-soluble chloride per m^3 of concrete less than the corrosion threshold level (total minus background).

curing (of concrete) – the maintenance of a satisfactory moisture content and temperature in concrete during its early stages so that its desired properties will develop.

curing (of coating) – the chemical process that develops the intended properties of a polymeric material (resin, for instance).

curing agent – a catalyst, heat, or coating that assures, enhances, or accelerates curing.

curing compound (membrane curing compound) – a liquid that can be applied as a coating to the surface of newly placed concrete to slow the loss of moisture from the concrete; white pigmented curing compounds can also reflect heat, providing a more favourable curing temperature.

curing time – the period between application and the time when a material reaches its design physical properties.

dampproofing – the treatment of a surface to resist the passage of water in the absence of hydrostatic pressure.

deck – a component of a bridge superstructure that carries and distributes wheel loads; traffic riding surface.

deck joint – a structural discontinuity between two components that permits relative rotation or translation between the two, where at least one is a deck component.

delamination – a separation of the concrete (usually in layers) from the reinforcing steel at their interface as a result of corrosion.

design life – a period of time, specified by the owner, during which the structure is intended to remain in service.

disbondment – the loss of adhesion between a coating or membrane and the substrate (loss of adhesion between fusion-bonded epoxy coating and a steel reinforcing bar, for instance).

drainage tube – an interlayer drainage tube

efflorescence – a white crystalline or powdery deposit on the surface of concrete; leaching of lime out of a permeable concrete mass over time by water, followed by reaction with carbon dioxide or acidic pollutants.

elastomer – a natural or synthetic polymer that has the capability of recovering its original size and shape after deformation.

electrochemical cell – a system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit.

electrode – a conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

electrolyte – a chemical substance containing ions that migrate in an electric field; for reinforced concrete, electrolyte refers to the concrete, including moisture and contained chemicals.

embrittlement – the loss of ductility of a material resulting from a chemical or physical change.

end result specification – the specification of a result to be achieved in construction, such as a minimum density.

expansion joint – see **isolation joint**.

failure – a state in which rupture, severe distortion or displacement, or loss of strength has occurred as a result of the load-carrying capacity of a component or connection having been exceeded.

fatigue – the initiation or propagation of cracks caused by the repeated application of load.

finish – the texture of a concrete surface after consolidating and finishing operations have been performed.

finishing – refers to levelling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce the desired appearance and service.

floor system – the portion of a bridge superstructure which directly supports traffic, including, where present, the deck, floor beams, and stringers.

fracture critical component, fracture critical member – a component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function.

fusion-bonded epoxy coating – a protective coating containing pigments, thermosetting epoxy resins, crosslinking agents, and other additives that is applied in the form of a dry powder onto a clean, heated metallic substrate maintained at a sufficient temperature to cause the dry powder to fuse into a continuous barrier coating.

galvanic anode – a metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte.

glass felt – glass fibres bonded into a sheet with resin and suitable for impregnation in the manufacture of waterproofing membranes

grout, grouting – a plastic mixture of cementitious or polymer materials used as a filler for cracks or other voids in a concrete surface that is to be coated.

holiday – discontinuity in a protective coating or waterproofing membrane.

holiday detector – an electrical device that locates holidays.

impressed current – an electric current supplied by a device employing a power source that is external to the electrode system.

integral abutment bridge – a bridge in which there is no expansion joint between the bridge superstructure and its abutments(s); structural continuity is preserved with the abutment(s).

isolation joint , expansion joint – a joint used in concrete slab construction wherever complete freedom of vertical and horizontal movement is required between the slab and adjoining components.

joint seal – a poured or preformed elastomeric sealant designed to prevent moisture and debris from penetrating joints.

laitance – a thin, weak, brittle layer of cement and aggregate fines on a concrete surface; the amount of laitance is influenced by the degree of working and the amount of water in the concrete.

latex-modified portland cement concrete – refers to concrete that includes polymer emulsion, resulting in a dense hardened concrete resisting the movement of moisture and chloride ions; usually used as a relatively thin overlay (25 to 40 mm) on conventional concrete decks.

longitudinal crack – a distress manifestation where the crack or crack pattern in the slab or pavement is parallel to the direction of travel.

maintenance – refers to well timed and executed activities to ensure or extend component (deck, for instance) life until deterioration is such that a minimum acceptable level of serviceability is reached, and/or it is more cost effective to rehabilitate the component.

membrane – a continuous sheet of material, either preformed, cured from a liquid, or cooled from a hot melt, which is applied to the surface of a concrete bridge deck, and protected from the action of construction and traffic by a wearing course.

microsilica – an amorphous silica of high silica content and purity possessing high pozzolanic activity.

micro-surfacing – a surface treatment which uses a mixture of well graded fine aggregate, polymer-modified emulsified asphalt cement, portland cement, additives, and water, and which is applied as a slurry.

milling – the removing of the surface of a pavement (typically 25 to 75 mm in depth) with a traveling machine equipped with a transverse rotating cutter drum.

monolithic – a seamless protective coating or waterproofing membrane system.

orthotropic deck – a deck that is orthogonally anisotropic; normally a deck made of steel plate stiffened with open or closed steel ribs welded to the underside of the steel plate.

overlay – a new lift(s) placed on an existing pavement to restore its ride or surface friction, or strengthen the pavement structure.

passive – the positive direction of electrode potential, or a state of a metal in which a surface reaction product causes a marked decrease in the corrosion rate relative to that in the absence of the product.

pavement condition index – a numerical rating of pavement condition that ranges from 0 to 100, with 0 being the worst possible condition (failed) and 100 being the best possible condition (excellent); determined through a systematic pavement condition survey in terms of the type, severity, and extent of the distresses.

performance specification – a specification that describe how the finished product should perform over time.

pinhole – a very small perforation (barely visible to the naked eye) in a protective coating or waterproofing membrane caused by the formation of a void in the system.

polishing – the phenomena caused by the abrasive action of vehicle tires on aggregate particles which reduces the frictional properties of the surface.

polymer-modified asphalt, polymer-modified binder – an asphalt cement that has had its physical and chemical properties modified/enhanced by the addition of a polymer; results in enhanced durability, improved rutting resistance at high temperatures, and increased resistance to low temperature cracking.

prestressed concrete – a reinforced concrete with an average effective prestress of at least 1.50 MPa.

primer – a thin liquid asphalt applied to a surface to improve the adhesion of subsequently applied materials such as waterproofing membranes.

protection board – a layer of preformed sheet material placed between the waterproofing membrane and the asphalt pavement (surfacing) to prevent damage to the membrane by construction activities and traffic.

protection method – a non-electrochemical method used to significantly reduce the rate of ingress of chloride ions into reinforced concrete; protection methods are limited to concrete components that are not critically contaminated with chloride.

quality control plan – a document that demonstrates the capability to produce materials and/or work that will consistently meet specifications.

rehabilitation method – a method that corrects the deficiency or deterioration mechanism that resulted in the assessed deteriorated reinforced concrete condition.

repair method – a method that restores a deteriorated reinforced concrete element to a service level equal to or almost equal to the as-built condition with no effort made to prevent or significantly retard the deterioration mechanism(s).

scaling – the flaking or peeling away of the near-surface portion of concrete or mortar.

sealant, joint sealant – a compressible material used to exclude water and solid foreign materials from joints where moderate movement is expected.

sealer, sealing compound – a liquid that is applied as a coating to a concrete surface to prevent or decrease the penetration of liquid or gaseous media during exposure; some curing compounds also function as sealers.

sealed joint – a structural discontinuity that does not permit the passage of water and debris through the joint.

seepage drain – a tube or hole through the membrane and deck slab for the purpose of draining moisture from the surface of the membrane (also see bleeder drain).

service life – the actual period of time during which the structure performs its design function without unforeseen costs for maintenance and repair.

shoving – the permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic-induced shear forces.

silica fume – a microsilica generated as a by-product of the reduction of high purity quartz with other ingredients in an electric arc furnace.

soffit – the undersurface of a bridge or culvert slab or superstructure.

spalling – the cracking, breaking, chipping, or fraying of a concrete slab's surface; usually within a confined area less than 0.5 m^2.

specification limit(s) – the limiting value(s) established, preferably by statistical analysis, for evaluating material or construction acceptability within the specification requirements.

stripping – a phenomenon in asphalt concrete pavements, where the asphalt cement film debonds or strips from the aggregate particles in the presence of water.

substrate – the structure or envelope components to which waterproofing materials or systems are applied.

substructure – the piers, pier caps, or columns that support the superstructure elements.

superstructure – the beams or girders and diaphragms that support the deck.

surface preparation – the method, or combination of methods, used to clean a concrete surface, remove loose and weak materials and contaminants from the surface, repair the surface, and roughen the surface to promote adhesion of a waterproofing membrane or protective coating.

surface air voids – the cavities visible on the surface of a solid.

tackiness – the stickiness of a waterproofing material's exposed surface after installation or during its final curing stage.

ventilating sheet – a permeable, preformed sheet of material, applied between the waterproofing membrane and the deck surface for the purpose of preventing blisters.

waterproofing – the prevention of moisture flow due to water pressure.

waterproofing membrane – a protective material placed between a wearing surface and concrete deck to shield the concrete deck from water and chlorides which could cause concrete deterioration.

wearing surface – a layer of asphalt concrete (hot-mix asphalt) placed on top of a deck to protect the waterproofing system and deck from traffic action and to provide for a smooth riding surface.

workability – a subjective measure of the ease of installation of waterproofing materials.

A.2 ACRONYMS FOR AGENCIES AND ASSOCIATIONS

American Association of State Highway and Transportation Officials		Washington, DC
AASHTO	www.transportation.org	
American Concrete Institute		Farmington Hills, MI
ACI	www.aci-int.org	
American Public Works Association		Kansas City, OM
APWA	www.opwa.net	
American Society for Testing and Materials		West Conshohocken, PA
ASTM	www.astm.org	
Asphalt Institute		Lexington, KY
AI	www.asphaltinstitute.org	
Canadian Standards Association		Toronto, ON
CSA	www.csa.ca	
Cement Association of Canada		Ottawa, ON
CAC	www.cement.org	
Canadian Government Specification Board		Gatineau, QC
CGSB	www.tpsgc-pwgsc.gc.ca/cgsb	
Federal Highway Administration		Washington, DC
FHWA	www.fhwa.dot.gov	
(For State Specifications: www.specs.fhwa.dot.gov)		
HPC Bridge Views		Washington, DC
knowledge.fhwa.dot.gov		
www.cement.org/brfidges/brf-newsletter.asp		
International Concrete Repair Institute		Des Plaines, IL
ICRI	www.icri.org	
NACE International, The Corrosion Society		Houston, TX
NACE	www.nace.org	
National Concrete Bridge Council		Skokie, IL
NCBC	www.nationalconcretebridge.org ncbc@cement.org	
National Cooperative Highway Research Program		Washington, DC
NCHRP	www.fhwa.dot.gov	
National Research Council, Institute for Research in Construction		Ottawa, ON
NRC	www.nrc.ca	

Nordic Road and Transport Research		Linköping, Sweden
NORDIC	www.vti.se/nordic	
Portland Cement Association		Skokie, IL
PCA	www.cement.org	
Silica Fume Association		Lovettsville, VA
SFA	www.silicafume.org	
Society for Protective Coatings		Pittsburgh, PA
SSPC	www.sspc.org	
Strategic Highway Research Program		Washington, DC
SHRP	www.fhwa.dot.gov	
Transportation Research Board		Washington, DC
TRB	www.trb.org	
Transportation Association of Canada		Ottawa, ON
TAC	www.tac-atc.ca	

A.3 TECHNICAL TERMS

CHBDC – Canadian Highway Bridge Design Code

HMA – hot-mix asphalt

HPC – high performance concrete

IDCCE – in-depth corrosion condition evaluation

LCCA – life-cycle costing analysis

LMC – latex-modified concrete

LSDC – low slump dense concrete

LRFD – load and resistance factor design

MMA – methyl methacrylates

NDT – nondestructive test

OPSS – Ontario Provincial Standard Specifications

PCC – Portland cement concrete

PCCE – preliminary corrosion condition evaluation

PCI – pavement condition index

SBS – styrene butadiene styrene polymer

SCDPS – structural concrete deck protection systems

SFC – silica fume concrete

SHRP – Strategic Highway Research Program

SMA – stone mastic asphalt

SWS – structural waterproofing systems

TDC – top-down cracking

w/cm – water-cementitious material ratio

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APPENDIX B CONCRETE DECK PROTECTION SYSTEM PHOTOGRAPHS

B.1 CONCRETE DETERIORATION

This bridge is in a mild marine environment with some winter road salt use. A partial bridge deck rehabilitation was completed in 1995, with some subsequent sheet membrane waterproofing system performance problems (Cover and Photos 15 and 16). The bridge deck, sidewalk and joints are leaking, with staining, carbonation, bearing seat deterioration, seismic retrofit damage, rust, reinforcement corrosion and concrete component cracking.

1. Concrete Deterioration Under Bridge Deck With Water Rundown and Penetration. Oak Street Bridge, Vancouver, 1998.

This bridge is in a fairly cold and snowy winter environment with considerable road salt (wetted) use. The Bridge, and adjacent NB ramp Bridge, were constructed in 1995 with a hot-applied rubberized asphalt membrane and already show significant ballast wall, joint, deck and pier area corrosion damage (Cover and Photos 3 to 5). This includes deterioration of repaired concrete.

2. Concrete Deterioration at Ballast Wall, Joint and Under the Bridge Deck With Water Rundown and Penetration. Highway 407 to 427 SB Ramp Bridge at Albion Road, Toronto, 2008.

This close-up of the ballast wall area (Photograph 2) clearly shows progressive deterioration (severe) of unprotected concrete components with reinforcement corrosion due to chloride penetration with water rundown associated with road salt application, snow accumulation on the shoulder, and spray from the deck bleeder (seepage) drains. Salt (chloride) laden water must be suitably drained away from concrete components.

3. Severe Concrete Deterioration With Exposed Corroding Reinforcement in NW Ballast Wall Area. Highway 407 to 427 SB Ramp Bridge at Albion Road, Toronto, 2008.

This close-up of the repaired barrier and ballast wall area shows the saturation with salt (chloride) laden water. The deck bleeder (seepage) drain is not effective in directing water away from concrete components. There is also some lower severity cracking adjacent to the repair and under the deck. It appears that water is also penetrating below the barrier wall (Photograph 2).

4. Severe Concrete Deterioration With Cracking of Repaired NE Ballast Wall Area. Highway 427 to 407 NB Ramp Bridge at Albion Road, Toronto, 2008.

This barrier and ballast wall close-up shows similar, but more severe deterioration and cracking with exposed corroded reinforcement, to Photograph 4. The damaging action of salt (chloride) laden water is again very clear. There is also lower severity cracking under the deck. It should be noted that the older, Highway 427 Bridge at Albion Road is not showing any similar water rundown or concrete deterioration and cracking.

5. Very Severe Concrete Deterioration and Cracking of SE Repaired Barrier Wall and Ballast Wall. Highway 407 to 427 SB Ramp Bridge at Albion Road, Toronto, 2008.

B.2 HOT-APPLIED (POURED) RUBBERIZED ASPHALT MEMBRANE WATERPROOFING SYSTEM INSTALLATION. TYPICAL MTO NEW DECK, TORONTO AREA, 1996

Decks must have adequate slope to drains. The concrete surface should be wood float finished, uniform, cured for a minimum of 14 days, and dry. All surfaces to receive waterproofing must be clean, dry, smooth and free of depressions, voids, protrusions and surface contaminants. The surfaces should be lightly sandblasted and then air cleaned prior to primer application.

6. The Clean, Dust-Free Concrete Deck Surface and Curbs are First Tack Coated With an Approved Primer (0.1 to 0.2 l/m^2) in Accordance With CGSB-GP-15M (OPSS 914).

The kettle must be a double boiler, indirect fired, oil transfer type with a built-in mechanical agitator and calibrated thermometer to register the heating oil and membrane (180 to 200°C) temperatures. The maximum heating temperature must not be exceeded and/or maintained for extended periods to avoid deleterious effects on the membrane and its performance.

7. The Asphalt Waterproofing Membrane Material is Melted in an Approved Melting and Mixing Kettle at the Correct Temperature (OPSS 914).

The primer must be cured and details (cracks and joints, deck to vertical junctures, and drains) completed prior to membrane application. The membrane must form a monolithic coating (average thickness 4.5 mm, minimum thickness 3 mm). (Two ply application involves a first membrane layer of average thickness 2 mm, embedded polyester fabric reinforcement, and then second membrane layer of average thickness 3 mm).

8. The Hot Membrane is then Applied Evenly and Spread Using a Squeegee to an Average Thickness of 4.5 mm (Single Ply Application, OPSS 914).

The hot applied rubberized asphalt waterproofing is inspected and its thickness checked for specification compliance, and to ensure it is undamaged with a clean surface. An approved type protection board course is then applied to the still warm and tacky membrane in order to prevent membrane damage during the placement of the hot-mix asphalt surfacing (typically two lifts).

9. The Protection Board is then Placed While the Membrane is Still Warm, With Overlap (10 to 25 mm) on Both End and Side Laps (OPSS 314).

The protection boards have been laid into the warm and tacky membrane with their length running transversely. Subsequent rows have been placed with longitudinal joints staggered a minimum of 150 mm, and all joints overlapped about 10 mm (maximum overlap of 25 mm). The SS-1 tack coat provides a good bond between the board and hot-mix asphalt. (The use of primer on protection boards is not allowed.)

10. The Protection Board Surface is then Tack Coated With SS-1 Emulsion (Diluted With an Equal Volume of Water) at a Rate of 0.5 l/m^2 (OPSS 314).

It is recommended that a minimum of two 40 mm (compacted thickness) lifts of rut-resistant hot-mix asphalt be placed. This 80 mm minimum thickness of asphalt concrete pavement then allows for future surface milling and hot-mix asphalt overlay(s) to achieve the anticipated hot applied (poured) rubberized asphalt waterproofing system service life (at least 40 years for the membrane itself, if properly applied).

11. The Hot-Mix Asphalt Paving is then Completed With Care Taken, During Placement and Compaction, to Not Damage the Installed Waterproofing System (OPSS 314).

B.3 SOME OTHER CONCRETE DECK PROTECTION SYSTEMS

The concrete deck preparation (new, repaired or rehabilitated) is similar to that for hot-applied rubberized asphalt membranes. The prefabricated membrane is coated (bottom) with a polymer (SBS) modified asphalt that is heat melted (torch) for bond to the deck, and coated (top) with fine aggregate to provide protection from equipment damage and bond with the hot-mix asphalt surfacing (no protection board required).

12. Application of a Torch Applied Prefabricated Waterproofing Membrane (Sopralene Antirock) to the Rehabilitated Leaside Bridge Deck, Toronto, 1990.

The high performance concrete (silica fume based) deck has top epoxy coated reinforcing steel and bottom conventional reinforcing steel (cover) and was designed for a minimum service life of 75 years (2000 CHBDC), with no waterproofing system or separate wearing surface. Particular attention was paid to concrete curing and minimizing any cracking. The HPC deck surface was tined for friction.

13. HPC Deck Placement Completed, Nearly Ready for Traffic. Kicking Horse Canyon Brge, 2007.

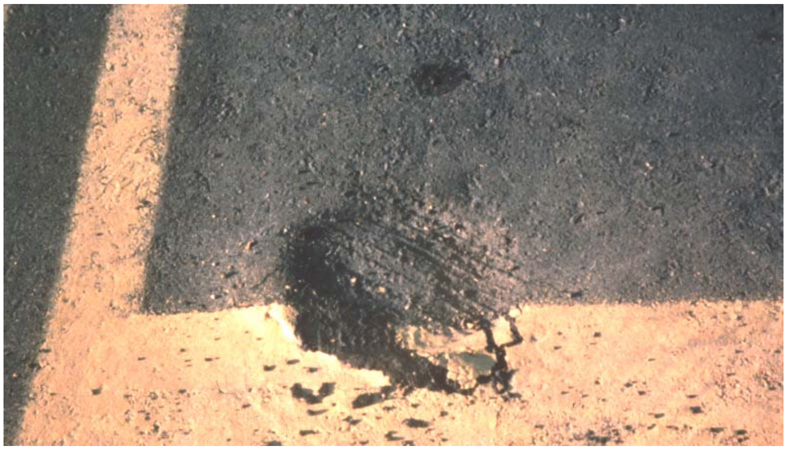
14. Micro-Surfacing of Manhattan Bridge Tee Deck 1996 Rehabilitation with Liquid Polymer Membrane, New York, 1998. Micro-Surfacing was Being Considered for Temporary Repair of the Severely Deteriorated Lions' Gate Bridge Deck, Vancouver 1998.

B.4 TYPICAL PROTECTION SYSTEM DISTRESSES

The Most Probable Cause of the Asphalt Concrete Cracking, Potholing, Shoving, and Tearing Distresses was: a Lack of Adequate Basal Shear Resistance at the Membrane-Asphalt Concrete Interface; Water Trapped Under the Asphalt Concrete (Deck Drains not Installed); and Hot-Mix Asphalt too Thin and/or Not Adequate in Stability.

15. Asphalt Concrete Distress Area of Oak Street Bridge 1995 Deck Rehabilitation (Photograph 1) Sheet Membrane Waterproofing System, Vancouver, 1998.

16. Close-up of Typical Asphalt Concrete Patch, Cracking, Blistering and Potholing of the Asphalt Concrete for the Oak Street Deck Rehabilitation (Photograph 15) Due to Performance Problems with the Sheet Membrane Waterproofing System, Vancouver, 1998.

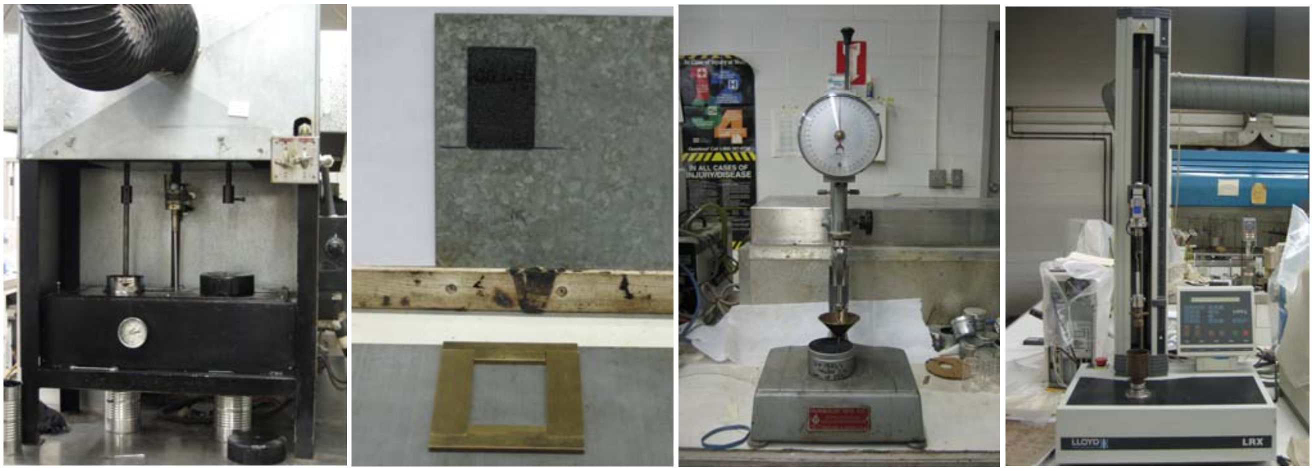


Development of Depressions and Shearing (Slippage) of Asphalt Concrete for Exposed Parking Structure Decks with Hot-Applied Rubberized Asphalt Membrane Waterproofing Systems Has Been Quite Common. Overall In-Place Shearing Deformation Resistance (Stability) Must be Provided Through an Adequate Hot-Mix Asphalt Thickness (Minimum 65 mm) and Stability, Particularly at High Ambient Temperatures.

17. Typical Early Car Tire Shearing Damage to an Exposed Parking Structure Deck Hot-Applied Rubberized Asphalt Membrane System with Basal Slip, Toronto, 1996.

18. Asphalt Concrete Distress Area With Shoving, Cracking and Potholing of the Verrazano-Narrows Bridge Deck Waterproofing System, New York, 1998.

B.5 TESTING HOT-APPLIED RUBBERIZED ASPHALT WATERPROOFING SYSTEM COMPONENTS



19. Laboratory Melting and Mixing Kettle, Flow Testing, Cone Penetration Testing, and Toughness Testing of Rubberized Asphalt Waterproofing Material (OPSS 1213).

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APPENDIX C PROTECTION SYSTEMS MINI QUESTIONNAIRE

STRUCTURAL CONCRETE DECK PROTECTION SYSTEMS
BEST PRACTICES GUIDE
PROTECTION SYSTEMS MINI QUESTIONNAIRE JEGEL FOR TAC

RESPONDING AGENCY INFORMATION

PLEASE COMPLETE THE FOLLOWING REQUEST FOR INFORMATION TO AID IN PROCESSING THIS QUESTIONNAIRE:

AGENCY: ______________________________

ADDRESS: ______________________________

CITY: __________ PROVINCE: __________ POSTAL CODE: __________

PRIMARY PERSON COMPLETING QUESTIONNAIRE: ______________________________

CURRENT POSITION/TITLE: ______________________________

DATE: ______ EMAIL: __________ FAX: ______ PHONE: __________

AGENCY CONTACT (IF DIFFERENT FROM ABOVE): ______________________________

EMAIL: ______________________________ FAX: ______ PHONE: __________

INSTRUCTIONS

BECAUSE SOME QUESTIONS ARE OPEN-ENDED, FOLLOW-UP TELEPHONE INTERVIEWS MAY BE NECESSARY TO CONFIRM OR ENHANCE OUR UNDERSTANDING OF THE RESPONSE. PLEASE BE SURE TO PROVIDE A CONTACT PERSON FOR EACH QUESTIONNAIRE.

WHEN THE ANSWER TO A QUESTION IS “OTHER”, PLEASE PROVIDE DETAILS.

PLEASE PROVIDE A COPY (WORD OR PDF FILES PREFERRED) OR WEB ADDRESS OF YOUR DESIGN AND CONSTRUCTION SPECIFICATIONS FOR BRIDGE DECKS. PLEASE PROVIDE ANY OTHER INFORMATION THAT IS RELEVANT TO THE ANSWERS PROVIDED IN THE QUESTIONNAIRE, INCLUDING APPLICABLE PROCEDURES, POLICIES, OR OTHER INFORMATION MIGHT BE OF ASSISTANCE TO THE PROJECT.

PLEASE COMPLETE THIS FORM ONLINE, OR DOWNLOAD A PDF COPY TO RETURN BY FAX OR MAIL TO JEGEL BY OCTOBER 16, 2006
www.jegel.com/TACSCDPS

TO: JOHN EMERY
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PLEASE CONTACT JOHN EMERY WITH ANY QUESTIONS

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PROTECTIVE SYSTEMS

1. WHICH OF THE FOLLOWING OVERLAY SYSTEMS HAS YOUR AGENCY USED IN THE PAST AND WHICH DOES YOUR AGENCY CURRENTLY USE? FOR EACH OVERLAY SYSTEM THAT OUR AGENCY HAS USED, PLEASE RATE ITS PERFORMANCE ON A SCALE OF 1 TO 5, WHERE 1= EXCELLENT AND 5 = POOR.

PAST	CURRENT	PERFORMANCE	
☐	☐	[ ]	NONE
☐	☐	[ ]	ASPHALT
☐	☐	[ ]	LOW-SLUMP DENSE CONCRETE
☐	☐	[ ]	LATEX-MODIFIED CONCRETE
☐	☐	[ ]	FLY ASH CONCRETE
☐	☐	[ ]	SILICA FUME CONCRETE
☐	☐	[ ]	EPOXY
☐	☐	[ ]	POLYESTER
☐	☐	[ ]	OTHERS: ______________

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2. WHICH OF THE FOLLOWING WATERPROOFING MEMBRANE SYSTEM HAS YOUR AGENCY USED IN THE PAST AND WHICH DOES YOUR AGENCY CURRENTLY USE? FOR EACH WATERPROOFING MEMBRANE SYSTEM THAT YOUR AGENCY HAS USED, PLEASE RATE ITS PERFORMANCE ON A SCALE OF 1 TO 5, WHERE 1 = EXCELLENT AND 5 = POOR.

PAST	CURRENT	PERFORMANCE	
PREFORMED SHEET SYSTEMS			
☐	☐	[ ]	NONE
☐	☐	[ ]	ASPHALT-IMPREGNATED FABRIC
☐	☐	[ ]	POLYMER
☐	☐	[ ]	ELASTOMER
☐	☐	[ ]	ASPHALT-LAMINATED BOARD
☐	☐	[ ]	OTHERS: ______________
LIQUID SYSTEMS			
☐	☐	[ ]	BITUMINOUS
☐	☐	[ ]	RESINOUS
☐	☐	[ ]	OTHERS: ______________

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3. WHICH OF THE FOLLOWING SEALERS HAS YOUR AGENCY USED IN THE PAST AND WHICH DOES YOUR AGENCY CURRENTLY USE. FOR EACH SEALER THAT YOUR AGENCY HAS USED, PLEASE RATE ITS PERFORMANCE ON A SCALE OF 1 TO 5, WHERE 1 = EXCELLENT AND 5 = POOR.

PAST	CURRENT	PERFORMANCE	
☐	☐	[ ]	NONE
☐	☐	[ ]	SILANES, SILOXANES, AND SILICONATES
☐	☐	[ ]	EXPOXIES
☐	☐	[ ]	GUM RESINS AND MINERAL SPIRITS
☐	☐	[ ]	LINSEED OIL
☐	☐	[ ]	STEARATES
☐	☐	[ ]	ACRYLICS
☐	☐	[ ]	SILICATES AND FLUOROSILICATES
☐	☐	[ ]	URETHANES AND POLYURETHANES
☐	☐	[ ]	POLYESTERS
☐	☐	[ ]	CHLORINATED RUBBER
☐	☐	[ ]	SILICONES
☐	☐	[ ]	VINYLS
☐	☐	[ ]	OTHERS: ______________

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4. IF YOUR AGENCY HAS USED CATHODIC PROTECTION SYSTEMS IN THE PAST, PLEASE PROVIDE THE NAME OF THE SYSTEM(S) AND DESCRIBE HOW SUCCESSFUL IT WAS:

____
____
____
____
____

5. DESCRIBE YOUR AGENCY'S EXPERIENCE WITH PROTECTIVE SYSTEMS:

____
____
____
____
____

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6. ANY OTHER COMMENTS OR SUGGESTIONS:

____
____
____
____
____

COMPLETED BY: ______________________________

E-MAIL: ______________________________

PHONE: ______________________________

FAX: ______________________________

THANK YOU FOR YOUR HELP AND COOPERATION WITH THE TAC STRUCTURAL CONCRETE DECK PROTECTION SYSTEM PROJECT

JOHN EMERY
jemery@jegel.com