CHAPTER I.

INTRODUCTION

1.1 Background

There is a national need to develop asphalt wearing surfaces for modern timber bridges that are not only skid resistant, but also limit the transport of moisture to the underlying wooden bridge deck and substructure. According to Ritter (1990), bare treated timber decks tend to have very poor skid resistance characteristics, especially when wet, and are quite susceptible to abrasive damage caused by vehicular traffic. Without a sacrificial wearing surface, a bare wood deck will deteriorate rapidly and incur an accompanying loss in structural capacity. A wearing surface that impedes the flow of water will tend to reduce the magnitude and rate of dimensional change of the wood in the bridge deck and reduce the probability of glue line failure I glue laminated elements throughout the entire bridge. In addition, keeping bridge components below the fiber saturation point will decrease the likelihood of attack from biotic deterioration agents thereby prolonging the functional service life of the structure.

Timber bridge decks offer several advantages compared to conventional form-in-place concrete bridge decks. Some advantages include: the rapid deployment of new or replacement structures since no form work or concrete curing is required once the abutments are completed; the use of lighter duty erection equipment due to lower dead weight of structural components as compared to similar steel or reinforced concrete elements; and the elimination of problems associated with the corrosion of reinforcing steel caused by the use of deicing salts since no reinforcing steel is required in the deck. Other positive characteristics associated with timber bridges include the use of well established manufacturing practices (i.e., glulam and preservative treatment) and the efficient use of readily available natural resource through the use of rapid growth species and manufacturing techniques such as finger jointing.

Unfortunately, several field trials of timber bridges employing transverse glulam bridge decks have brought to light the potential for cracking in the asphalt concrete surfacing at joints between adjacent deck panels. In addition, while some performance criteria exist for bond and watertightness of waterproof asphalt wearing surfaces applied to concrete bridge decks, there appears to be very limited knowledge of component interactions when these systems are applied to timber bridge decks; more specifically, the effects of oilborne preservative treatments on waterproofing membranes and asphalt concrete overlays.

1.2.1 Literature Review - Background

In a 1994 report for the National Highway Research Program entitled, "Waterproofing Membranes for Bridge Decks", Manning examined the use of waterproofing systems on concrete bridge decks since they were first used in the 1960's. The initial use of waterproofing systems began as a response to severe premature deterioration caused by corrosion of embedded reinforcing steel by chloride based deicing salts. While many state agencies took steps to increase concrete cover depth over reinforcement, waterproofing membranes with a bituminous wearing surface were widely used as secondary protection.

Membranes have been in use in the northeastern United States for decades, but their use in the rest of the country has been sporadic. The 1972 Federal Highway Administration (FHWA) requirement for secondary protection on federal-aid bridges left many states with little experience in specifying membranes to cope with a rapidly expanding membrane market, often with varying field results. Membranes were the preferred method of protection because of their wide availability and relatively low cost coupled with the need for immediate implementation.

Starting in the 1960's, liquid membrane systems made with hot-applied rubberized asphalt came into use, and are still relied upon today, though more so in Canada than in the U.S. A slightly more sophisticated approach, the built-up membrane, uses several layers of glass fabric mopped with alternate coats of coal tar pitch emulsion. The glass fabric acts as a tensile reinforcement for the membrane system. The use of this method has fallen out of popularity because it is labor intensive and requires curing time between each layer. Additionally, follow-up condition surveys have shown evidence of rotting in the glass fabric. Liquid membranes based on polymer resins are also commonly used in Europe, but have had limited acceptance in the U.S.

In the 1970's, preformed membranes requiring a separately applied adhesive came into use, but were not without their own inherent problems. Large membrane sheets were very difficult to handle in windy conditions and system integrity was highly dependent upon quality of workmanship. The self-adhesive membranes in use today were developed to overcome the problems of the first generation systems.

By 1992, there were as many as 22 different proprietary waterproofing products in the U.S. Most were preformed and three have dominated the market for twenty years. A 1994 NCHRP survey showed that 14 states named preformed membranes as their preferred system compared to four which have approved liquid systems, and only one which designated a built-up membrane. The use of liquid applied membrane systems has been more pronounced in other countries.

The absence of a quantitative definition of performance requirements, realistic pre-qualification test procedures, and accurate quality assurance tests have hampered the development of system specifications. In addition, further developments in waterproofing systems have been slowed by inadequate research, the low bid process, and the absence of life cycle cost analysis.

1.2.2 Membrane Classification

Membranes can be classified into several different categories, the broadest being preformed sheets versus applied in place liquid systems. Typical characteristics of each are listed in Table-1.1. As part of Price's 1990 UK publication, "Laboratory Tests on Waterproofing Systems for Concrete Bridge Decks", published by the Transport and Road Research Laboratory, systems were further categorized based on material composition as follows.

Sheet systems were separated into four types as presented in Figure-1.1. They include: asphalt impregnated fabrics made of polyester fleece, glass cloth, or woven polypropylene; polymeric sheets extruded from either bituminised, laminated, or chlorosulfonated polyethylene, ethylene propylene, ethylene vinyl acetate, or polymer plasticised polyvinylchloride; elastomeric sheets made of calendared and vulcanized butyl rubber with an asphalt saturated felt underlayment, polyisoprene rubber, polychloroprene, ethylene propylene diene monomer, or butyl and hypalon rubbers; and asphalt-laminated boards made from a core of finely crushed aggregate saturated with asphalt placed between layers of asphalt saturated felt.

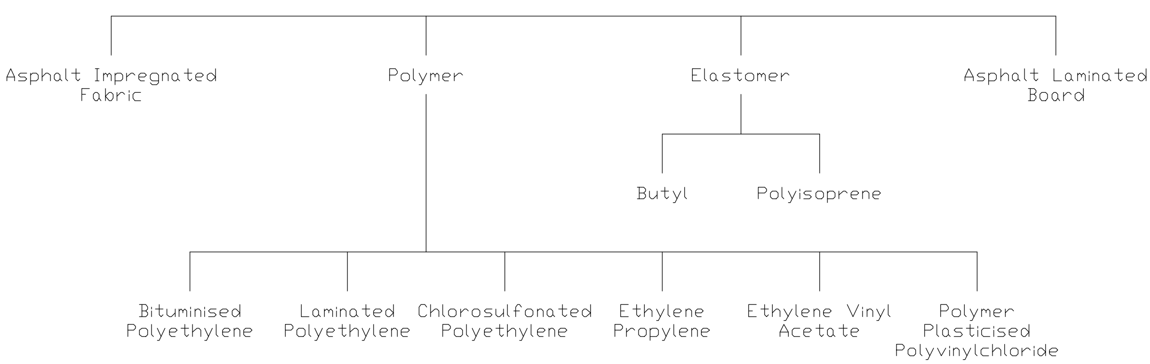

Figure-1.1: Sheet Waterproofing Systems (Price, 1990)

Liquid systems were divided into two basic types as presented in Figure-1.2: bituminous and resinous systems. Bituminous systems were further subdivided into mastics, which are refined natural or elastomer modified asphalts, both requiring heat to be converted into liquid state, and bituminous one part solutions in hydrocarbon solvents or two part polymer modified compositions.

Table-1.1: Characteristics of Sheet and Liquid Membrane Systems (Manning, 1994)

Preformed Systems	**Liquid Systems**
Tend to perform well in laboratory evaluations.	Tend to perform less well in laboratory evaluations.
Quality of material controlled under factory conditions.	Difficult to ensure consistent quality of materials.
Thickness and integrity controlled at the factory.	Difficult to control thickness of membrane and detect presence of pinholes.
Labor intensive installation, especially if non-self adhesive.	Usually applied in one application by spray or squeegee. Built up systems are labor intensive.
Laps required.	Laps not required.
Difficult to install on curved or rough decks.	Application independent of deck geometry. Thin membranes require a smooth deck.
Vulcanized sheets may be difficult to bond to substrate, protection layer, and at laps.	Bonding not usually a problem if substrate prepared properly. Self adhesive.
Vulnerable to quality of work at critical locations such as curbs, expansion joints, and deck drains	Less vulnerable at critical locations.
Blisters must be repaired by puncturing and patching.	Blisters and blowholes easily repaired in self-sealing materials, but not in thermosetting materials.
Tend to be more expensive	Tend to be less expensive.

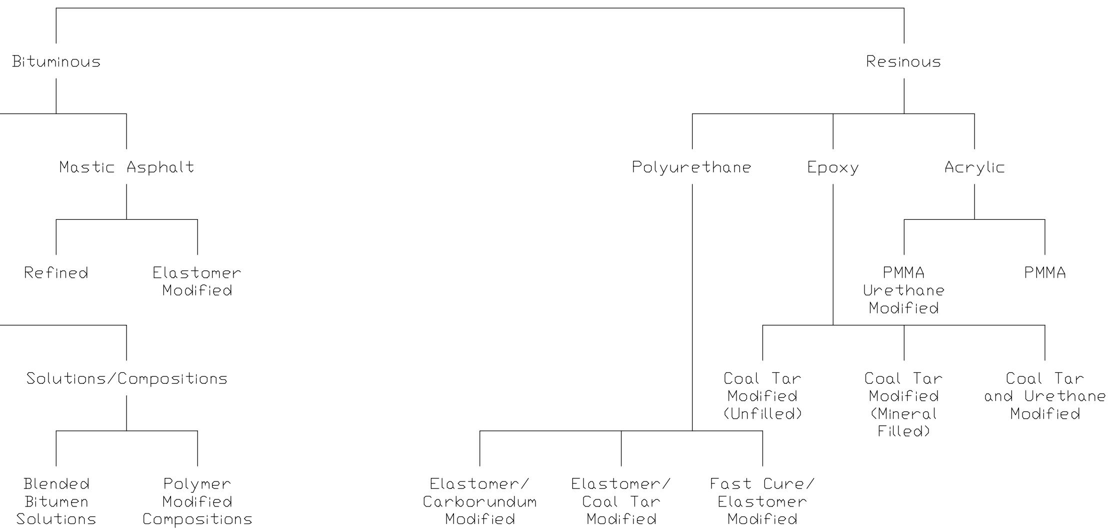

Figure-1.2: Liquid Waterproofing Systems (Price, 1990)

Resinous systems using either one or two part moisture curing or two part chemical curing can be classified as either urethane, epoxy, or acrylic based. Urethane systems are usually made from polymer modified polyurethane and also include fast curing elastomer/polymer modified polyurethane and the family referred to as pitch urethanes which are further modified with carborundum or coal tar. Most urethane based membranes require a chemically similar primer.

Epoxy resin systems, referred to as pitch epoxies, are modified with coal tar and may also be mineral filled. One system is also modified with polyurethane and reinforced with a polyester fleece. The epoxy systems reported did not require a primer to be applied to the concrete deck.

Acrylic systems are largely based on polymethylmethacrylate (PMMA), may be modified with urethane, and generally require a chemically similar primer.

1.2.3 Waterproofing System Components

Waterproofing membranes are only one component in an overall waterproofing system which can include primers, adhesives, ventilation layers, protection board, tack coats, and asphalt concrete surfacing. Waterproofing integrity is determined not only by the amount of damage to the membrane, but by its bond to the deck. Even a damaged membrane will slow the flow of water if it remains well bonded. Bond to the deck is also important for good performance of asphalt surfacing since a loss of bond is often a precursor to cracking, slippage, or break-up of the asphalt concrete surfacing.

By coating and penetrating the deck surface, primers improve the adhesion of a waterproofing membrane. The primers used currently are usually bituminous emulsions, but in the past, bitumen dissolved in an organic solvent was often used. This change of practice has been forced by greater concern for safety and the environment. Synthetic rubber, sometimes combined with a resin and dissolved in a solvent, is used as a primer with some proprietary sheet membranes. Resinous primers of similar chemical make up to their resinous membrane counterparts are used in these instances.

Many of the proprietary sheet membranes employ a self-adhesive, pressure sensitive bituminous backing, but others require separately applied adhesive to bond the membrane to the deck. The most commonly used adhesive is oxidized bitumen which is sometimes modified by the addition of polymers.

In situations where blistering caused by vaporization of water or primer beneath the membrane after application is anticipated, a ventilation layer may be used. To dissipate this vapor pressure, the ventilating layer might consist of a perforated sheet of prefabricated non-woven fabric such as felt and a thin lift of sand asphalt up to 0.5 inches thick. One advantage of using sand asphalt is its ability to serve as a leveling course on rough deck surfaces. Ventilating layers have been used more often in Europe than in North America, however, they are not recommended since they reduce the bond of the membrane to the bridge deck.

Protection board, similar in configuration to ventilating layer, is sometimes used between a membrane and the overlying bituminous surfacing. Though its primary purpose is to prevent damage to the membrane from construction activities and equipment, it also serves to protect against penetration by large aggregate particles under normal traffic loading once the deck is open to traffic. Protection board is used almost exclusively with liquid membrane waterproofing systems.

Since the binder content of bituminous surfacing is usually too low to "wet" the contact surface of the membrane or protection board, a tack coat may be used to improve adhesion. Asphalt emulsions have always been used to improve adhesion because most membranes are easily damaged by organic solvents.

Any asphalt concrete overlay should be a dense-graded mixture to help inhibit transmission of water through the pavement that will collect above the membrane. Though many agencies use a single layer of bituminous concrete over membranes, the use of two separate layers (a base and a surface/wearing course) is also quite common. In the U.K and Illinois, an additional layer of sand asphalt is used to protect the membrane from damage during application of the base course. A configuration not yet reported on for concrete decks would place the waterproofing membrane between a base course and wearing coarse of asphalt concrete. A sloped (crowned) base course could be provided before membrane installation that would provide improved deck drainage directly above the membrane and at the pavement surface. An added advantage of this system is that the membrane could be milled off along with the surface wearing course after it has exceeded its design life or starts to show signs of debonding or leaking.

1.2.4 Waterproofing System Performance on Concrete Bridge Decks

According to Manning, a waterproofing system should be watertight after installation and throughout its anticipated service life. Other system requirements, both during installation and in service are listed in Table-1.2. Because acceptance is often based on the testing of only one component, usually the membrane, it is difficult to predict the performance of the overall waterproofing system. A system performance approach needs to be undertaken so that membranes develop enough bond between layers and to ensure that materials are compatible. This type of approach is difficult, however, because of the large number of different materials involved whose useful lives are still unknown, the fact that service conditions are difficult to define and simulate in the laboratory, and the lack of good correlation between acceptance tests for components and their real field performance.

Table-1.2: Requirements for Waterproofing Systems (Manning, 1994)

During Installation	In Service
Tolerant of variable surface roughness and cleanliness.	Unaffected by service temperature, which could be -40 to 140°F (-40 to 60°C).
Tolerant of changes in temperature and humidity.	Remains watertight and bonded to deck and surfacing during anticipated service life (typically 15 to 30 years).
Easy to install, independent of deck geometry.	Resists puncture by aggregates in surfacing as a result of traffic loads.
Bonds well to deck, especially at edges.	Resists shear stresses from traffic loading, including braking and turning stresses.
Resists damage by loose particles, fuel spillage, foot traffic, and dropped objects prior to surfacing.	Bridges cracks in the deck slab.
Not damaged by paving equipment.	Unaffected by salt and water, including traffic induced hydraulic pressures.
Not damaged by asphalt application temperatures up to 365°F (180°C) .	Surfacing can be replaced without replacing membrane.
Bonds well to surfacing	

In 1989, the UK based Transport and Road Research Laboratory published, "A Field Trial of Waterproofing Systems for Concrete Bridge Decks", by Price in which a comprehensive study of 47 different types of proprietary bridge deck waterproofing systems was discussed. The author found that although performance is a complex combination of system components, the most serious damage to system integrity is caused by the placement of hot mix base course asphalt directly onto an unprotected membrane. The high temperatures involved can cause softening of bitumen and polymer based membranes and leads to embrittlement in some epoxy based systems. In addition, the hot aggregate used in the asphalt concrete can embed into and even rupture many membrane systems. The problem is further compounded by the forces applied during bituminous pavement compaction activities. Sheet systems less than 2.5 mm thick and liquid systems less than 2.0 mm thick are particularly vulnerable to aggregate penetration. Though protection board is quite effective in reducing the damage caused by paving operations, the tradeoff is loss of bond strength which is unacceptable. Further, bituminous mineral dressed protection sheets and bitumen laminated boards are not effective at preventing the penetration of hot aggregate because of their low softening point. Limiting the rolling temperature of the base course asphalt concrete will considerably reduce the risk of damage caused by exceeding the membranes softening point.

1.2.5 Wooden Bridge Decks

There are several differences between wood and concrete decks which will affect the performance of waterproof asphalt wearing surfaces. According to Ritter in "Timber Bridges: Design, Construction, and Maintenance", the presence of preservative treatment on the deck surface may have negative effects on the successful bond of the waterproof membrane or base course asphalt to the deck. Since most bridge timber is treated with oilborne chemicals that offer added protection against checking and splitting by inhibiting fluctuations in moisture content, proper care must be taken to ensure that excess preservative be eliminated from the surface of the bridge deck before application of any waterproofing system component. This can be accomplished by using the empty-cell pressure treatment method which yields much deeper penetration accompanied by lower net retention of preservative than the full-cell process. Because of the lower retention, less preservative will exude from the wood following treatment. This should be followed by steam cleaning and sufficient time to allow any remaining preservative to bleed and evaporate from the surface. This is usually 30-45 days after treatment if the material is placed so that it is surrounded by free circulating air.

Another consideration which will affect the bond of waterproofing system components to the deck is whether or not the glulam deck panels are planed on the side that will receive the waterproof asphalt wearing surface. If a membrane is to be placed on the wooden deck surface, it is advisable to have the deck planed when it is manufactured. However, by placing a base course asphalt mixture on the deck first followed by a membrane and then a surface course, the wooden deck would not have to be planed.

The final and possibly most important difference between wood and concrete decks lies in the far greater structural flexibility of timber as compared to concrete. This flexibility can lead to a magnitude of global and localized deflections that bituminous concrete cannot dissipate without cracking. This cracking can lead to the loss of a smooth riding surface and the eventual failure of the waterproofing envelope. Deflections must be limited by design to values that asphalt concrete pavements can cope with.

1.3 Objective and Scope

The objective of this research was to evaluate the bond and watertightness characteristics of traditional and proposed waterproof asphalt concrete wearing surfaces for timber bridge decks and develop performance criteria which will:

- limit the magnitude and rate of dimensional change in the wood deck by keeping the moisture content in the deck below fiber saturation point;
- be compatible with oilborne wood preservative treatments used to protect the deck from fungal decay;
- eliminate abrasive traffic wear of the structural wood deck;
- provide a more skid resistant surface as compared to a bare wood deck;
- maintain a similar appearance and riding surface between the bridge deck and adjacent roadway;
- prevent cracking between adjacent transverse glulam deck panels.

The research reported here was limited to transverse glulam bridge deck panel configurations using pre-formed waterproof membrane sheets overlaid with an asphalt concrete wearing surface.