ORTHOTROPIC DECK WEAR SURFACE SYSTEM SELECTION

LIONS GATE BRIDGE NORTH APPROACH VIADUCT, VANCOUVER BC

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Abstract: The paper presents the wear surface replacement options analysis methodology that was used to select the resurfacing system for the Lions Gate Bridge North Approach Viaduct in Vancouver British Columbia. The objective was to select the surfacing system that presents the best combination of performance and value. Lions Gate was opened to traffic in 1938. The bridge carries three traffic lanes, the centre lane is a counterflow (reversible) lane whereby two lanes are open to traffic in one direction at any given time, and a single lane is open in the opposite direction.

The original bridge deck of the North Viaduct was replaced in 1975 with an orthotropic steel deck. The orthotropic deck was first surfaced with epoxy asphalt concrete and has since been resurfaced several times with bituminous asphalt concrete, most recently in 2001.

A list was prepared of potential surfacing systems that have been used on orthotropic decks. The surfacing systems evaluated included: Bolidt ZOK; Epoxy Asphalt Concrete; Gussasphalt; Polyester Concrete; Polymer Modified Asphalt Concrete; Rosphalt 50; and Trinidad Lake Asphalt. An estimated construction cost and life cycle cost was prepared for each alternative wear surface system. Each system was then evaluated based on a number of weighted criteria.

The paper presents the ranking for each material, and then presents the outcome in terms of the highest ranking wear surface systems.

Key Words: *Orthotropic Bridge Deck; Life Cycle Cost; Bridge Wear Surface*

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INTRODUCTION

This paper presents an analysis framework prepared to select the optimum wear surface replacement system for an orthotropic steel bridge deck. The methodology was developed for the Lions Gate Bridge North Approach Viaduct in Vancouver, British Columba. The goal was to develop an analysis method that would allow selection of a reliable, long lasting and economical wear surface system for the bridge deck.

BACKGROUND

The Lions Gate Bridge is a key link in the British Columbia lower mainland road transportation network and is one of only two bridges connecting the City of Vancouver to the north shore of Burrard Inlet and communities beyond.

Lions Gate Bridge was opened to traffic in 1938. It is a three lane structure with one outer traffic lane in either direction and a central contraflow lane. The total length of the bridge is 1,516 m: 847 m for the main suspension bridge; and 669 m for the subject north approach viaduct. The north approach is 25 spans, and was re-decked in 1975 with the present orthotropic system. The orthotropic deck consists of a 12 mm thick steel deck plate, and longitudinal stiffeners at 305 mm centres (Figure 1).

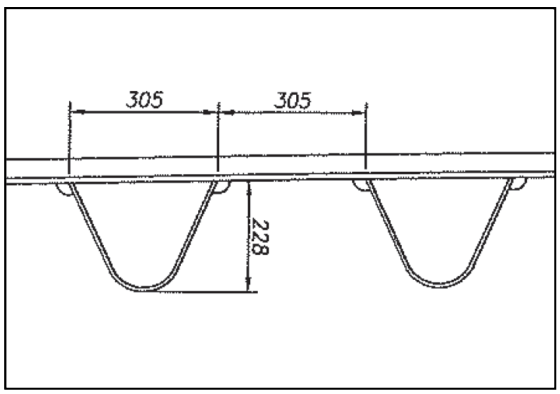


Figure 1 - Typical Transverse Section Showing Bridge Deck Stiffeners

In 1975, the then new orthotropic steel deck of the north approach viaduct was surfaced with a 38 mm thick layer of epoxy asphalt concrete. This system lasted 18 years (1993), at which time it was reported that the epoxy asphalt exhibited longitudinal cracking in wheelpaths, and rutting. At that time, the epoxy asphalt surface was milled partial depth and a layer of polymer modified asphalt concrete was placed. It was reported that this surface exhibited considerable distress with debonded patches in 1997-1998 (four or five years after placement). In 2001 the present asphalt concrete surface was placed. At that time, the previous surfacing materials were completely removed. This surface was then paved with asphalt concrete over a waterproofing membrane. The asphalt concrete had polymer modified asphalt binder and applied at an approximate thickness of 50 mm. This surface was reported to have performed well up to approximately 2008, at which time the surface began to exhibit “severe” longitudinal cracking in the wheelpaths and potholing.

The main suspension bridge was re-decked in 2002 and the new orthotropic deck was surfaced with epoxy asphalt concrete at that time. That material is performing well to date.

Average annual daily traffic at the bridge was 60,285 in 2012. The bridge is weight-restricted to light cars and trucks not exceeding 14.3 tonnes, and municipal and tour busses.

The surfacing history of the north approach viaduct shows the need for careful planning and selection of wear surfacing systems for orthotropic bridge decks. The surfacing is subject to environmental and load related demands that result in premature failure for surfacing materials like asphalt concrete.

PURPOSE AND METHODOLOGY

The purpose was to develop a framework to evaluate potential orthotropic deck surfacing systems in a rational manner to determine which systems offered the optimum combination of performance and value. The methodology was as follows:

- Develop a list of Key Performance Indicators which captures the desirable traits and characteristics of an ideal wear surface for the bridge.
- Develop a list of potential surfacing systems based on research and communication with other agencies, contractors and product suppliers.
- Prepare a preliminary plan for construction staging, and a schedule for each wear surface alternative so that the traffic delay for each alternative could be compared.
- Prepare preliminary construction and life cycle cost estimates for each wear surface alternative.
- Develop a weighting system for the Key Performance Indicators.
- Rank the potential systems based on the weighted Key Performance Indicators.
- The highest ranked alternative is selected as the preferred option.

The wear surface for an orthotropic bridge deck should provide a smooth surface for good riding comfort, good skid resistance, and protection of the underlying steel from corrosion. The surface should be durable and stable under imposed traffic and environmental demands over the selected design life. It must have a good bond to the steel substrate, and the bond must be durable over the design life. It should also be economical when both construction and life cycle costs are considered. The surfacing system should be one that can be installed and maintained by a trained local contractor. The thickness, density and stiffness of the surfacing system must be compatible with the underlying orthotropic steel deck design and act in a composite fashion to limit deformation of the system under traffic loading. The impact of lane closure for installation needs to be considered for each surfacing option. Environmental protection during construction also needs to be considered.

KEY PERFORMANCE INDICATORS

A list of Key Performance Indicators (KPIs) was prepared to allow ranking of the various alternative wear surface renewal systems. The KPIs were selected based on a review of desirable and undesirable traits and characteristics of wear surface systems and the Lions Gate North Approach Viaduct project specifics. The KPI list is intended to capture factors that must be checked for diligent wear surface selection, and factors considered to be critical to project success. The KPIs include both construction related and service related items. A list of the KPIs and a brief discussion of the reason for the KPIs selection are presented in the following table.

Table 1 - Key Performance Indicators

Construction Related KPIs		
1	Construction Duration	The Lions Gate Bridge is a key transportation route with only one alternative, the Iron Workers Memorial Bridge. Shorter duration is much better for reduced impact on the traveling public and commerce.
2	Construction Related Traffic Delay	Lower delay is better for reduced impact on the traveling public and commerce.
3	Low First Cost	Lower cost is better.
4	Low Life Cycle Cost	Lower life cycle cost is better.
5	Methods and Equipment for Application	Systems that can be placed with locally available workers and equipment are better.
6	Surfacing Thickness - Change in Joint Height	Systems with total thickness the same as the existing wear surface are better since joint height can be maintained.
7	Weather Risk	Systems that can be placed and cured in inclement weather are better since this would reduce construction related risk.
Service Related KPIs		
8	Bond to Substrate - 2 MPa minimum	Higher bond strength is better. Debonding of the wear surface would lead to a failure. A high bond strength is considered to be required due to the five percent longitudinal grade.
9	Design Life Expectancy - 15 Years Min.	Longer life systems are more desirable since user delay is minimized and lane availability maximized.
10	Environmental Impact	Lower environmental impact is better.
11	Future Maintenance Logistics	Systems that can be repaired and maintained by local forces with commonly available materials are better.
12	Improve Bridge Structural Performance	Systems that act in a composite fashion with the steel deck, reduce deck strains and reduce resultant fatigue are better.
13	Minimize Lane Closures for Maintenance	Systems that can be repaired and maintained quickly are better since this will maximize lane availability.
14	Protection of the underlying steel deck plate	Systems that protect the steel deck from corrosion and fatigue are better.
15	Resistance to Fatigue Cracking	Systems that are resistant to fatigue cracking are better.
16	Skid Resistance	Systems with good skid resistance are better for safety.
17	Track Record - Documented Years of Reliable Performance from Other Agencies	Systems with a documented record of good performance are better since this will reduce the overall risk of premature failure.
18	Track Record - on MOTI Recognized Products List	Systems preapproved by MOTI score higher.
19	Weight - compatible with existing structure	Systems with the same weight per unit area as the existing surfacing system are considered better.

Some of these KPIs are redundant. For example a wear surface system with a long design life will result in lower lane closures. The influence of the overlapping KPIs on the final ranking is managed through selection of appropriate weighting factors.

POTENTIAL WEAR SURFACE SYSTEMS

Orthotropic steel bridge decks are relatively uncommon in Canada, and there are only a few wear surface systems that have been used with success. Research resulted in identification of seven wear surface systems that warranted consideration. A brief overview of each system is presented in the following subsections.

1. Bolidt ZOK

Bolidt ZOK is an asphalt concrete in which the binder consists of a two part polyurethane system. This system has been used on the Auckland Harbour Bridge in New Zealand.

2. Epoxy Asphalt Concrete

Epoxy Asphalt Concrete (EAC) consists of a mix of aggregate and epoxy asphalt binder. Epoxy asphalt binder is a mixture of special asphalt cement and a two part epoxy that, when cured, forms a dual phase, thermoset polymer. The binder and aggregate is mixed in a modified pug mill and placed and compacted on a wet epoxy bonding layer on the steel deck. EAC is considered a thermosetting material. EAC has been used with success on many orthotropic bridge decks. EAC was placed on the main span of the Lions Gate Bridge in 2002 and is performing very well to date. It was also used when the new orthotropic deck was constructed on the Lions Gate North Approach Viaduct in 1975.

3. Gussasphalt

The Gussasphalt system is mainly very dense, zero air void, mastic asphalt consisting of a prime coat and a wearing layer. It has been used on the Avonmouth Bridge in the United Kingdom.

4. Polyester Concrete

Polyester Concrete is a polyester based concrete overlay. The use of polyester concrete on orthotropic bridge decks appears to be in research stage only at this time with no known field application.

5. Polymer Modified Asphalt Concrete

Polymer Modified Asphalt Concrete is very similar to conventional asphalt concrete, with the exception that the binder is polymerized. Polymer modification is the most prevalent modification of asphalt binder to improve both the strength and the durability of hot mix asphalt concrete (HMAC). This is the system that is currently in place on the Lions Gate North Approach Viaduct.

6. Rosphalt 50

Rosphalt 50 is a concentrated thermoplastic polymeric dry mix additive that, when combined in an asphalt plant with hot mix asphalt (HMA) creates a low permeability asphalt mat, either interlayer or wear surface. In addition to the low permeability, the additive gives the resulting asphalt mix higher resistance to fatigue cracking and rutting compared to ordinary asphalt mix. Rosphalt has been used as the wear surface for several orthotropic steel bridge decks, including two bridges in New Brunswick, and notably the George Washington Bridge in New York.

7. Trinidad Lake Asphalt

Trinidad Lake Asphalt (TLA) is natural thermoplastic asphalt binder from an asphalt lake located in Trinidad in the West Indies. Usually the TLA asphalt mixes contain 25 to 40% TLA and 60 to 75% regular asphalt binder. TLA has been used on the Carquinez Bridge in San Francisco, and the third Tacoma Narrows Bridge near Seattle.

CONSTRUCTION STAGING AND SCHEDULE

A preliminary construction staging and closure plan was prepared for each alternative to allow scoring of the construction duration related KPIs. The general construction staging plan is as follows:

- Bridge joint repair and/or replacement will take place during partial night-time closures and this work will be complete well in advance of resurfacing.

- A Test Strip of the wear surface system will be placed in June of the construction year (tentatively 2014). This would be conducted in a convenient off-bridge location in order to train crews, demonstrate use of equipment, and test the constructed product for specified performance properties. The Test Strip allows the contractor to fully demonstrate that they can execute the mixing, transportation, and placement/compaction before the bridge is closed. This reduces the risk of additional lane closures for replacement of non-conforming bridge deck paving.

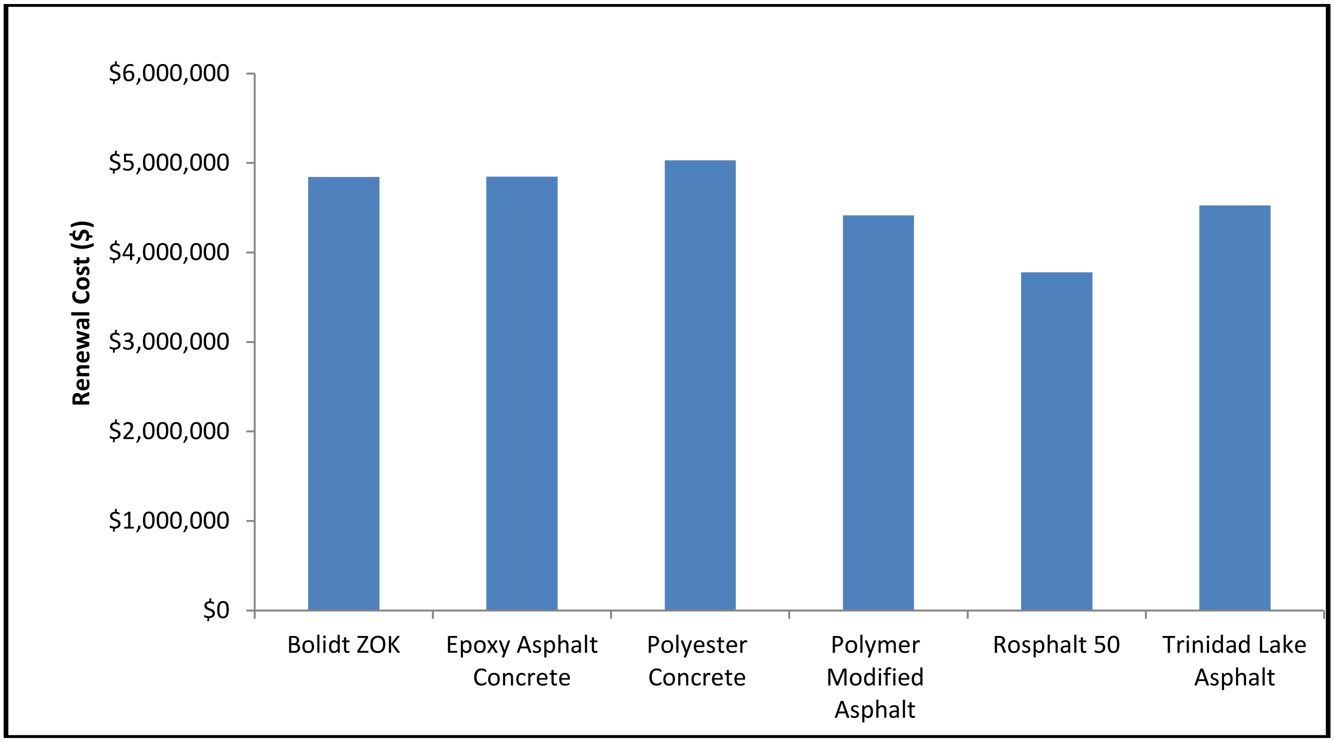
- Removal of the existing wear surface, deck preparation, and placement of the new wear surface would take place over three partial weekend closures in July of the construction year. The work will predominantly be completed within two lane night-time closures with the third lane available to emergency traffic. Closure of a single lane only is allowed during the daytime. The closures would be used to fully remove the existing wear surface, prepare the steel deck, and place the new wear surface for one complete lane per weekend closure. Some of the systems have more layers than others and so the duration of the closures for wear surface placement varies between the alternatives. An allowance will be made for backup weekend closures in August in case of weather or construction problems in July. July was chosen for wear surface placement since July and August typically have the highest temperatures and lowest precipitation of the year which decreases the weather risk.

Table 2 - Comparison of Construction Steps

Construction Sequence	Bolidt	Epoxy Asphalt Concrete	Gussasphalt over Eliminator	Kwik Bond	Polymer Modified Asphalt over Eliminator	Rosphalt	Trinidad Lake Asphalt over Eliminator
Joint Repair or Replacement	same for all options						
Surface Preparation	same for all options						
Application of Primer	same for all options						
Water Proofing Membrane	✓(2 layers)	✗	✓	✗	✓	✗	✓
Tack (Bond) Coat	✓	✓	✓	✗	✓	✓	✓
Wear Surface	✓	✓	✓	✓	✓	✓	✓
Additional Layer in the System	✓ (anti-skid layer over tack coat)	✗	✓ (broadcast aggregate over bond coat)	✗	✗	✗	✗

RENEWAL AND LIFE CYCLE COST COMPARISON

The preliminary estimate of construction costs for each alternative wear surface system was prepared based on recent bid prices where available, and discussions with agency and contractor representatives. A comparison of these costs is presented in Figure 2.



Note: no renewal cost available for Gusasphalt

Figure 2 - Renewal Cost Comparison

The life cycle costs include a user cost equal to 20 minutes per vehicle for traffic that needs to detour to the Iron Workers' Memorial Bridge during the weekend closures. A comparison of life cycle costs is presented in Figure 3.

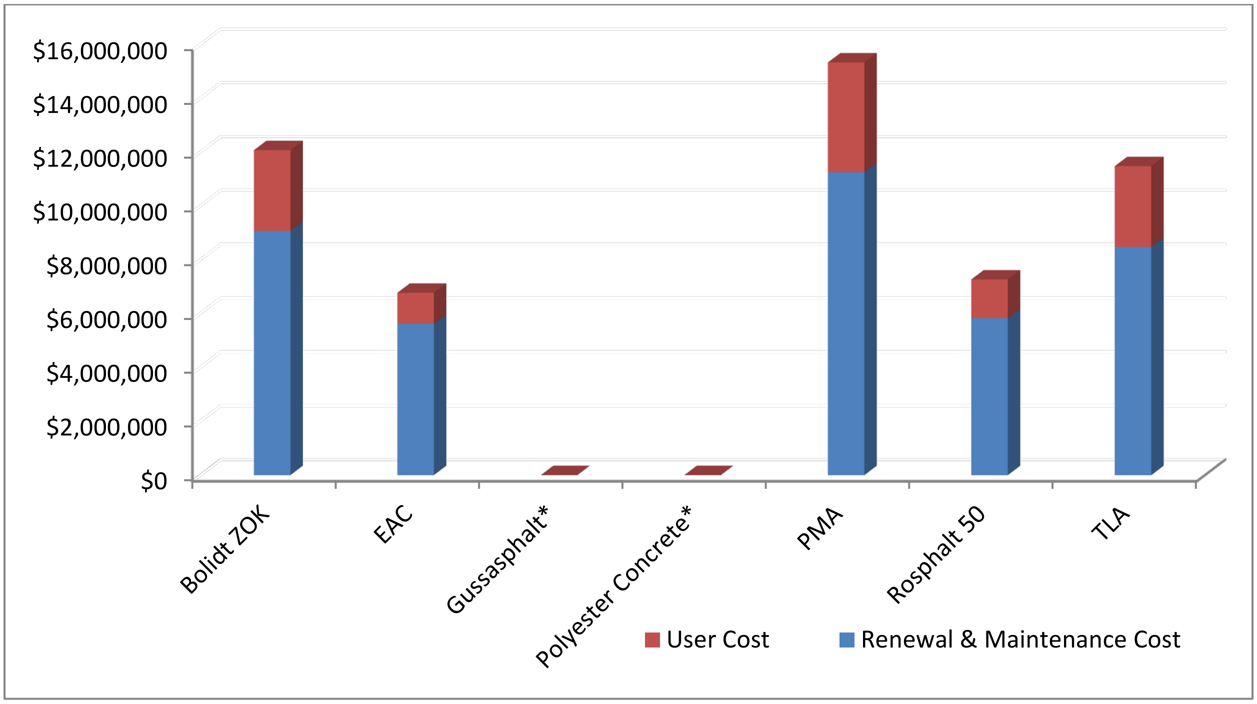


Figure 3 - Life Cycle Cost Comparison

*The life cycle costs for Gussasphalt and Polyester Concrete have not been calculated due to lack of information about their renewal cost and life expectancy.

WEAR SURFACE REPLACEMENT OPTIONS ANALYSIS

The methodology developed for scoring each system based on the Key Performance Indicators included:

- assigning a weighting factor to each KPI,
- scoring each alternative wear surface system, and,
- adding up the weighted scores to determine the overall score for each of the wear surface systems.

Weighting factors were assigned to each KPI based on the individual KPIs influence on the overall success of the project. Critical KPIs received a higher weighting. The sum of the weighting factors equals 100. The critical KPIs were typically those that dealt with user delay, risk, service life, and life cycle cost. Scoring criteria are presented in Table 3. The wear surface system ranking table is presented in Table 4.

Table 3 - Scoring Criteria

Construction Duration	Pro-rated from 0 for the system with the longest construction duration to 10 for the system with the shortest duration.
Construction Related Traffic Delay	Systems which can be placed with shorter cumulative lane closure duration score higher.
Low First Cost	Low initial cost scores higher.
Low Life Cycle Cost	Low life cycle cost scores higher; pro-rated from 0 for highest to 10 for lowest.
Methods and Equipment for Application	Systems that can be applied by a trained local contractor with locally available equipment score higher.
Surfacing Thickness - Change in Joint Height	Systems that provide a surface elevation equal to the existing score highest; lower than existing score 1/2; higher than existing score 0.
Weather Risk	Systems that can be applied and cured in inclement weather score higher.
Bond to Substrate	Bond must be equal to or greater than the specified minimum, then higher bond receives higher score pro-rated from 0 for meeting the minimum, to 10 for the product with the highest bond.
Design Life Expectancy	Long lasting systems score higher: pro-rated from 0 for the shortest life (15 years) to 10 for the longest life
Environmental Impact	Systems which have lower Greenhouse Gas emissions and generate less waste score higher.
Future Maintenance Logistics	Systems that can be repaired using local forces and equipment score higher.
Improve Bridge Structural Performance	Systems that strengthen the existing bridge deck score higher.
Minimize Lane Closures for Maintenance	Reliable, low-maintenance systems score higher.
Protection of the underlying steel deck plate	Systems that prevent ingress of chlorides score higher. Systems with no documented evidence of protection of chloride intrusion score 0, systems with proven, effective protection over the design life score 10. Score pro-rated in between.
Resistance to Fatigue Cracking	Systems with proven resistance to fatigue score higher: pro-rated from 0 for 15 years equivalent fatigue cycles, to 10 for the system with the longest documented fatigue resistance. Systems with < 15 years equivalent fatigue resistance do not qualify.
Skid Resistance	Systems with high and long lasting skid resistance score higher. Score will vary from 0 for systems with skid resistance equal to the minimum allowable; to 10 for systems with proven skid resistance much higher than the minimum. Score is pro-rated in between.
Track Record - Years of Reliable Performance	Systems with proven long life score higher. Score varies from 0 for systems with proven life = 15 years, to 10 for systems with proven life = 35 years.
Track Record - on MoTI Recognized Products List	Systems listed on MOTI Recognized Product List score 10, otherwise score 0.
Weight	Systems with net weight equal to or less than maximum allowable score higher. Systems meeting this criteria are pro-rated based on actual % relative to max allowable; systems that do not meet the criteria score 0.

Table 4 - Wear Surface System Evaluation Ranking Table

Key Indicator		Weighting Σ=100%	Score (10 highest, 0 lowest)						
			Bolidt	Epoxy Asphalt Concrete	Gussasphalt over Eliminator	Polyester Concrete	Polymer Modified Asphalt over Eliminator	Rosphalt	TLA over Eliminator
Construction Related									
1	Construction Duration	13	2	10	2	6	2	6	2
2	Construction Related Traffic Delay	13	2	10	2	6	2	6	2
3	Low Renewal Cost	4	2	4	*	0	8	10	6
4	Low Life Cycle Cost	10	2	10	*	*	0	8	4
5	Application Methods and Equipment	2	10	2	2	6	10	8	8
6	Surfacing Thickness	2	0	10	10	10	10	10	10
7	Weather Risk	2	0	10	10	10	10	10	10
Service Related									
8	Bond to Substrate - 2 MPa Min.	4	*	10	*	10	0	5	0
9	Life Expectancy - 15 Years Min.	13	0	10	*	*	0	7	2
10	Environmental Impact	3	10	10	*	8	6	10	10
11	Future Maintenance Logistics	2	0	2	0	0	10	10	6
12	Improve Bridge Structural	4	0	0	0	0	0	0	0
13	Min. Maintenance Lane Closures	2	0	10	*	*	0	7	4
14	Protection of underlying deck plate	3	10	10	10	10	10	10	10
15	Resistance to Fatigue Cracking	7	0	10	*	*	0	7	0
16	Skid Resistance	3	10	10	*	10	10	10	10
17	Track Record - Other Agencies	8	0	10	0	0	0	7	4
18	Track Record - MOTI Recognized	3	0	0	0	0	10	10	0
19	Weight - compatible with structure	2	*	10	*	10	10	10	10
Total		100							
Σ (Weighting x Score)			190	874	126	352	292	722	360
Rank			6	1	7	4	5	2	3
Variance From Highest Rank (%)			78	0	86	60	67	17	59

*no data

The wear surface systems that scored the highest in the analysis are Epoxy Asphalt Concrete and Rosphalt. Key factors that set these systems apart from the rest include:

- These systems have proven track records for use on orthotropic bridge decks and therefore present less risk. The Lions Gate Bridge is a key link in the lower mainland transportation network with only one alternate bridge as an option so this low risk is very attractive for this project.

- Because of the relatively long service life of these systems they both have lower life cycle costs and lower user delay.

The Epoxy Asphalt Concrete has a history of local Vancouver use from the Lions Gate main span in 2002 and North Approach Viaduct in 1975, and it also has a longer track record than Rosphalt. These factors result in a higher score for Epoxy Asphalt Concrete.

Some of the systems scored poorly because information on some key performance indicators was not available (Bolidt, Gussasphalt). These systems do not appear to be distributed in North America. The polyester concrete scored poorly because there is no track record.

CONCLUSIONS

Epoxy Asphalt Concrete is the highest scoring wear surface system evaluated, and it's score is some 17% greater than the next closest system (Rosphalt). This spread is high enough to conclude that EAC is the clear choice for Lions Gate North Approach Viaduct when all Key Performance Indicators are considered.

Production and application of Epoxy Asphalt Concrete is a specialized process. Contractor experience is an important factor in project success. The local BC lower mainland contracting community does have past experience with Epoxy Asphalt Concrete and there is a demonstrated track record of performance.

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REFERENCES

(1) Harvey, David and Niroumand, Saeed J. (2013) "Fatigue Damage Assessment of The Lions Gate Bridge North Viaduct Deck" *Proceedings of the 3rd Orthotropic Bridge Conference*, American Society of Civil Engineers, Sacramento Section, June 26-28, 2013, Sacramento, California, USA.