Why Concrete Intersections Make Good Sense.

Mississauga's Courtney Park and Kennedy Rd. Intersection Case Study

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Abstract

In August 2012, the City of Mississauga was looking to repair a left hand turn lane at the intersection of Courtney Park Dr. and Kennedy Rd. The intersection had severe rutting and, reviewing the City's previous repairs, the flexible pavement wasn't standing up to road traffic. The City had fixed the intersection in 2007 and 2010 and planned to repair it again in 2012 with asphalt. The asphalt already had up to 100-mm (4-inches) of rutting in just 2 years. The relatively high traffic volume made it imperative to complete the repair in as short a time as possible. Given the City's specification for concrete pavement stating that concrete requires 72 hours prior to opening to traffic, the City had concerns with repairing it in concrete.

A life cycle cost assessment(LCCA) for asphalt and concrete pavement options that also considered the time required for the initial construction and all future maintenance activities was conducted. To address the total lane closure time, maturity methods were used to determine the strength of the concrete before opening.

The environmental impact of the maintenance cycles for the concrete and asphalt options was calculated using Athena Institute Life Cycle Impact Estimator for Highways, which evaluates the various materials and equipment used in the construction to calculate the total "cradle to grave" environmental impact of the pavement.

Following completion of these assessments, the intersection was repaired with concrete. Based on the success of this project, the City of Mississauga will now be considering concrete for other intersections.

Background

In late August of 2012, during a routine inspection of the Courtney Park Drive and Kennedy Road intersection in Mississauga, the city inspector noted severe rutting in the westbound left turn lane. Rutting depths of up to 100 mm were measured in the lane. The other lanes in the intersection only showed minor rutting, and the city decided to fix them with asphalt using conventional “shave and pave” techniques.

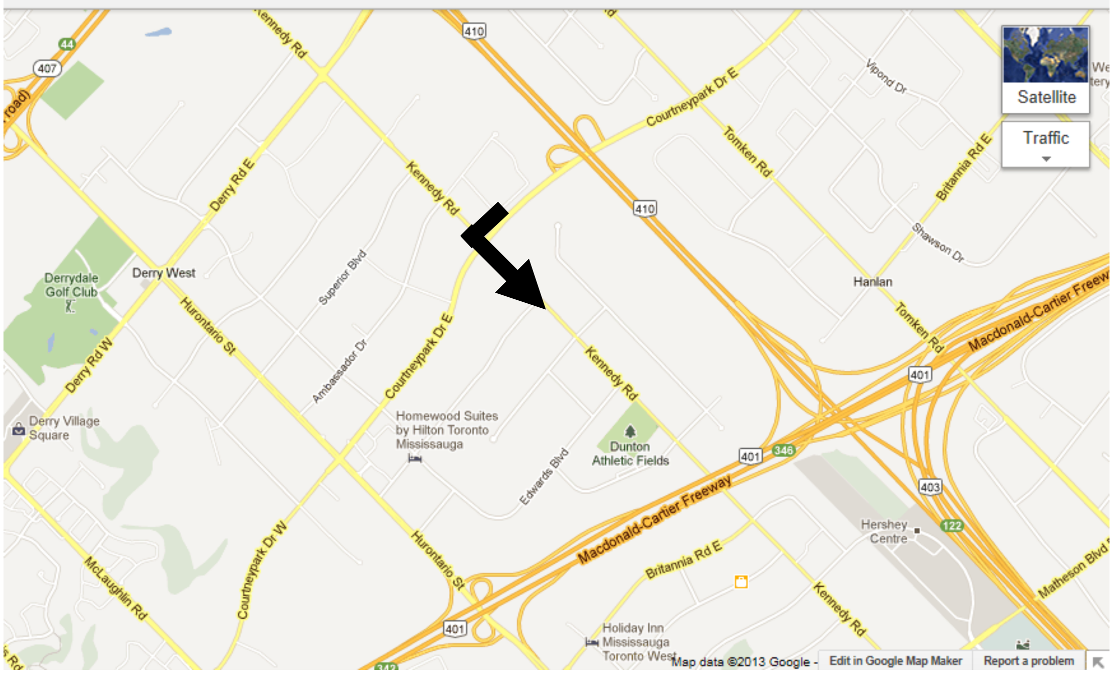


Figure 1: Intersection Map. Source:http://maps.google.ca

Due to the severity of the rutting, immediate action was required. The lane had been rehabilitated several times since 2007. That year, the entire intersection was milled 100 mm then overlaid with 60 mm of a Hot Laid-8 High Stability (HL-8HS) binder course and 40 mm of a Hot Laid-3 (HL-3) surface course. In 2010, the left lane had severe rutting and the shoved asphalt was milled off. Picture evidence suggests that an asphalt overlay was placed between August 2011 and August 2012 although there is no record of this repair in the database.

The City of Mississauga Public Works department was considering another asphalt repair in 2012, which would have comprised milling off 140 mm and replacing it with 100 mm of a high density binder course with 40 mm of Hot Laid-1 (HL-1) as the surface course.

Picture 1: Intersection in August 2011. Source:http://maps.google.ca

Picture 2: Intersection in August 2012 prior to repair. Source: RMCAO

Picture 3: Completed Project September 2012. Source: RMCAO

The City's policy is to limit all lane restriction time as much as possible. As a result, the "shave and pave" option was the only one it would normally consider. However, after discussions with the Ready Mixed Concrete Association of Ontario (RMCAO), the City decided to consider a concrete option. It did express concerns about repairing the lane in concrete since the traffic volume in the left turn lane is high – a total hours count (8 hours) completed in 2011 showed 1573 vehicles , 32% of which were truck/heavy vehicles, used the lane. The City of Mississauga's specifications for concrete wouldn't allow the lane to be opened to traffic for at least 72 hours, which would not be acceptable in this high traffic corridor. To accommodate the curing period, it was determined that the repair would start on Friday evening at 9 pm and the lane would be closed until Monday morning. Since traffic is relatively light over the weekend this was determined to be the best alternative.

The city had experience with concrete in their bus bays and had standard drawings with concrete cross-sections. Because of the urgency for the repair; the same drawings were used for the turn lane (225 mm thick), with a few adjustments.

Design Options and Specifications

Two options were presented:

1) Milling 140 mm, 100 mm High Density Base Course, 40 mm of HL1
2) Full depth asphalt removal (200-225mm thick), 225mm - 35MPa High early strength concrete

The concrete design was analysed using StreetPave 12 by The American Concrete Pavement Association (ACPA).

INPUTS

Design Life: 25 Years

Reliability

Reliability: 90%

Percent of Slabs Cracked at End of Design Life: 10%

Traffic

Traffic Category: Major Arterial (Default from StreetPave: Average GLEF:3.68)

Direction Distribution: 100%

Design Lane Distribution: 100%

Trucks per day: 2000 (Conservatively Estimated)

Traffic Growth: 2% (Estimated)

Rigid ESAL's: 17,593,135

Design Details

Terminal Serviceability: 2.25

Reliability: 90%

% Slabs Cracked: 10%

Support Conditions

Composite Modulus of Subgrade Reaction: k=47.70 MPa/m (assumption based on existing asphalt granular layer composition)

Concrete Properties

28 Day Compressive Strength: 35 MPa

28 Day Flexural Strength: 4.76 MPa (Calculated)

Macrofibers: 18% Residual Strength

Modulus of Elasticity (E): 32,130 MPa (Calculated)

Design Features

Load Transfer Devices:
- 32 M Dowel Bars
- 15M Tie bars into curb

Edge Support: None (free edge between concrete and asphalt lane)

Design Outputs

Thickness as built: 225 mm

Theoretical Service Life: 113 Years

Erosion Potential Used: 22%

Fatigue Capacity Used: 2%

Reinforcement

For the transverse joints, dowel baskets were installed at each joint location. Dowels were 32M smooth bars at 300 mm spacing. Since the pavement was being tied to the curb without any isolation joint material, the joints were lined up with the saw cuts in the curb. The spacing of the cuts on the curb was six metres apart, which is too long for good practice with concrete pavements. To prevent any transfer of contraction joint cracks from the curb into the pavement, it was decided to install additional dowels at 3 m spacing and to cut additional saw cuts into the curb. The dowel baskets were aligned to have the dowels at the mid-depth of the slab. The baskets were tied down using steel pins with hooked ends to prevent the baskets from lifting during concrete placement.

For the joint between the curb and the concrete slab, 450 mm long 15M deformed bars were used. The bars were affixed into holes drilled into the curb using epoxy. All steel reinforcement was epoxy coated to reduce corrosion potential.

At the transition between the asphalt and concrete there was no reinforcement, which required the slab to be designed for a free edge condition.

Lastly, Tuf-strand Macro Synthetic fibres from Euclid Canada at a dosage of 2.0 kg/m3 of concrete were used to provide post-cracking control. The fibres provided a Residual Strength of 18% in the pavement design.

Construction

Construction was set to take place over a weekend, starting on the Friday evening. However, the day before the pour, the weather forecast called for rain on the Friday evening. It was decided to accelerate the schedule and start the pour after the Friday morning rush hour. However, a provincial highway southbound off-ramp lies less than one kilometre from the intersection and, since municipal staff cannot place signs on the provincial highway, traffic congestion would be a concern during afternoon rush hour.

At 10am on Friday, just after rush hour, the crews arrived and a CAT 420E backhoe was used to remove the asphalt. The asphalt thickness ranged from 200 to 225 mm, which made it easy to accommodate the 225 mm concrete design. In areas where the asphalt was only 200 mm, approximately 25mm of granular was removed in order to get a final concrete thickness of 225mm. The granular was then compacted using a steel roller vibrator.

The curb and the middle lane were used as the forms for the concrete. The first load of concrete arrived at 3 pm for a total of 55 m^3. The last truck was empty around 6 pm. The concrete ordered was 35 MPa High Early Strength with 5-8% air.

At the start of the repair, two of the three westbound lanes were blocked for the construction vehicles. Noticing that traffic was starting to back up, with the eastbound traffic being substantially less than the west bound traffic, the contractor determined it would be better for the dump trucks being filled with waste asphalt and the ready mix trucks to be in the second lane in the eastbound direction. This helped relieve traffic to approximately 1 km in length in the westbound lanes. The city did not receive any complaints for traffic congestion during this project.

Concrete Testing

The City requirement for opening the road to traffic is 72 hours with no provision for minimum concrete strength. Based on concrete compressive strength the lane can be opened much sooner. The concrete cylinders cast were to be broken at 3, 7 and 28 Days. At the recommendation of the Ready Mixed Concrete Association of Ontario, maturity testing was also carried out. While the mix was not calibrated prior to use, the results could be used for future work (Figure 2). At 24 hours, the mix reached 23 MPa and at 10 days, it reached the required strength of 32 MPa for durability. Based on the maturity probes in the pavement, 15 MPa was reached in less than 8 hours and 20 MPa was reached in 13 hours. Typically, the Ministry of Transportation of Ontario specifies 20 MPa for the fast track concrete prior to opening lanes on Highway 401 through Toronto.

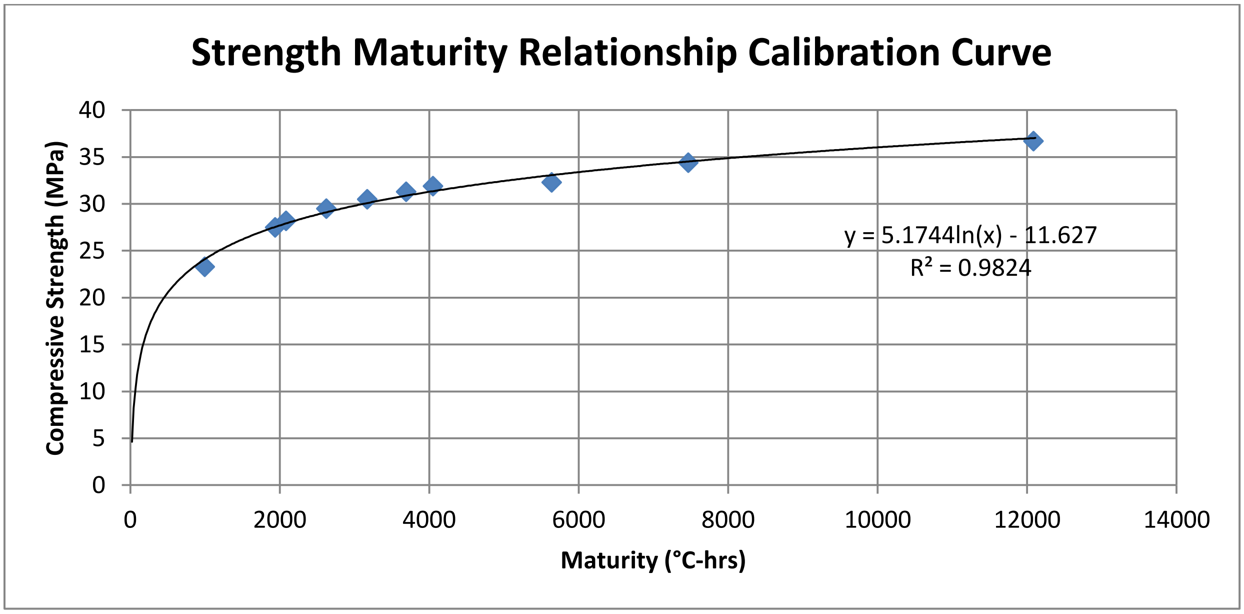


Figure 2: Maturity Calibration curve for 35 MPa High Early Strength Concrete

Fatigue Consumption

Opening the road prior to attaining the full design strength will induce additional fatigue damage and erosion of the pavement. Using Streetpave 12 software from the American

Concrete Pavement Association, the yearly fatigue damage was calculated using compressive strengths ranging from 15 MPa to 32 MPa (Table 1, Figures 3-8).

Table 1: Summary of Daily Fatigue and Erosion Damage

Design Strength	Years	Fatigue	Daily Fatigue	Erosion	Daily Erosion
35.0	25	2	0.000	22	0.002
32	1	0.28	0.001	0.79	0.002
30	1	0.7	0.002	0.87	0.002
25	1	7.35	0.020	1.15	0.003
20	1	73.15	0.200	1.59	0.004
15	1	794	2.175	2.39	0.007

The amount of fatigue and erosion damage can be calculated based on the maturity testing, using the strength data. This showed that if the lane was opened to traffic upon achieving 15 MPa, the damage to the pavement until 35 MPa was attained would be less than 1% for both fatigue and erosion (Table 2), with total damage at 25 years being 2.9% for fatigue and 22.0% for erosion.

Table 2: Fatigue and Erosion Consumption at various Compressive Strengths

						Total Consumption	
Maturity Info	Maturity	Time (hrs)	Delta Time (hrs)	Opening		Fatigue	Erosion
15 MPa	175	6	7	7	Hrs	0.634	0.002
20 MPa	450	13	27	1.1	Days	0.200	0.004
25 MPa	1200	40	77	3.2	Days	0.060	0.009
30 MPa	3100	117	53	2.2	Days	0.004	0.005
32 MPa	4500	170	156	6.5	Days	0.005	0.014
35 MPa	8200	326		25	Years	2	22
					Total	2.90	22.0 %

Since the design was extremely conservative, the additional damage from opening the lanes early would be insignificant. In this case, the City of Mississauga requirement for 72 hours prior to opening was overly conservative and would have led to unnecessary complaints. If maturity testing was specified in the contract and 15 MPa specified as the strength required prior to opening the entire lane, the closure would be only 16 hours. The use of maturity testing can significantly reduce the total lane closure time.

In comparison, the time required for the hot mix asphalt repair was estimated at 15 hours (Table 3). The range of values varied significantly from 8 hours up to 2 days. For the eight hour case, it was expected that the asphalt binder course would be rapidly cooled with cold water to reduce the temperature prior to placement of the surface course. For the two day case, the asphalt would have been milled and the binder course placed on the first day. The traffic would then have been allowed on the pavement until the surface course was placed the following day. Total lane closure time would have been approximately 15 hours over the 48 hour period. In the other cases, the asphalt would have been milled and the binder and surface courses placed within the same day. Estimates varied on the length of time required to sufficiently cool the 100 mm of binder course prior to the surface course being placed. It was ultimately determined that 15 hours was the best estimate.

Table 3: Estimated Asphalt Cost and Construction Times for 2012 Repair.

Asphalt Costs 2012		
Reference	Cost Estimate	Time Estimate
Contractor 1	18400	14 hours
Consultant 1		12-15 hours
Consultant 2	22000	1 day
Municipality 1		2 days
Municipality 2		8 hours

Life Cycle Cost Estimates

The entire intersection was milled and resurfaced with HL8- High stability base course and HL3 surface course in 2007. Based on the cost for the total intersection repair, the proportional cost of the repair for the 4 m by 55 m lane would have been $8000. This would have been a low estimate since mobilization and traffic control costs would not be proportional. Therefore, it was estimated that the cost for the 2007 repair, if only the turn lane was reconstructed, would have been approximately $12,000.

The lane was then milled in 2010 at a cost of $2000.

Based on picture evidence, part of the lane was rout, sealed and overlaid between August 2011 and August 2012. These repairs are not in the database and there are no estimates accounting for them.

In 2012, the pavement was to be milled down 140 mm then resurfaced with a high density base course and 40 mm of HL1. Various estimates were provided from municipalities, consultants and contractors. The low end estimate was approximately $18,000. (Table 3)

To be conservative with its estimate, the City of Mississauga's Public Works Department assumed total repair cost of $32,000 over the five year span.

If this cycle of milling every second year and asphalt overlay every fifth year were to continue for the next 20 years (Table 4), the costs using the 2012 repair costs as a baseline would be over $100,000, excluding any inflation costs of material and labour.

The cost for the concrete repair in 2012 was less than $30,000. Because of the significant over-design of the concrete, it is likely that the only repair required would be diamond grinding to improve skid resistance. Since this is a turn lane with low speed traffic, this repair would likely occur at year 20. The life cycle cost of the concrete pavement option at year 20 is estimated at $32,000, which is only slightly higher than the original cost of the concrete.

Table 4: Life Cycle Cost of Asphalt and Concrete Options over 20 year Analysis Period

Initial Construction					
Year	Asphalt Repair	Cost	Year	Concrete Repair	Cost
2007	Asphalt Repair - 100mm thick	12000	2012	Concrete	30000
2010	Milling	2000			
2012	Proposed Repair - 140 mm thick	18000			
	Total	32000		Total	30000
Maintenance and Rehabilitation					
2015	Milling	2000	2032	Diamond Grinding	2000
2017	Repair	18000			
2020	Milling	2000			
2022	Repair	18000			
2025	Milling	2000			
2027	Repair	18000			
2029	Milling	2000			
2032	Repair	18000			
	Total	80000		Total	2000
	Total over 20 years (Asphalt)	112000	Total over 20 Years (Concrete)		32000

Lane Closure Estimates

Traffic congestion and user costs are two significant impacts of lane closures. While they are difficult to calculate, it is well known that there are associated costs such as fuel, time, late delivery, and so on. The schedule of repairs was calculated over a twenty year period for both the asphalt option and the concrete option (Table 5).

Table 5: Total Lane Closure Time over 20 year Analysis Period						
Initial9h Construction						
Year	**Asphalt Repair**	**Time (h)**		**Year**	**Concrete Repair**	**Time (h)**
2007	Asphalt Repair	12		2012	Concrete	16
2010	Milling	2				
2012	Proposed Repair	15				
	Total	29			Total	16
Maintenance and Rehabilitation						
2015	Milling	2		2032	Diamond Grinding	2
2017	Repair	15				
2020	Milling	2				
2022	Repair	15				
2025	Milling	2				
2027	Repair	15				
	Total	51			Total	2
	Total over 20 years (Asphalt)	80		Total over 20 Years (Concrete)		18

The asphalt option had approximately 80 hours of lane closures over the 20 year analysis period. Most of the repairs would have been completed during night work operations but some of the repairs would have impacted rush hour traffic. For the concrete option, the estimated lane closure time is 18 hours, 16 hours of which being for the original repair, when one afternoon rush hour period was affected. The remaining two hours of lane closure would have occurred around year twenty for the diamond grinding operation to improve skid resistance.

Sustainability

Every time a pavement is repaired there is an impact on the environment. The use of large equipment, removal of material, heating and placement of asphalt, cement production – all create green house gases, consume fossil fuels, and so on. Limiting the number of repairs over a pavement's service life can dramatically reduce its impact on the environment.

The environmental impact of the repairs over a twenty year life cycle was assessed using the Athena Sustainable Materials Institute Impact Estimator for Highways' 1.0 beta software (Table 6 and 7).

The Athena Institute describes the Estimator as peer-reviewed software that utilizes ISO 14000 principles to [1]:

- provide a cradle-to-grave life cycle inventory profile for a given area of paved roadway. The inventory results comprise the flow from and to nature: energy and raw material plus emissions to air, water and land.
- report footprint data for the following environmental impact measures consistent with the US EPA TRACI methodology(1): global warming potential, acidification potential, human health criteria, ozone depletion potential, smog potential, and eutrophication potential. The Impact Estimator additionally reports fossil fuel consumption.
- take into account the environmental impacts of the following life cycle stages: material manufacturing, including resource extraction and recycled content and related transportation; on-site construction; and maintenance and replacement effects; annual and total operating energy effect. Pavement Vehicle Interaction effects, demolition and disposal are not addressed, as highways typically have very long service lives. (Athena, 2013)

Table 6: Environmental Impact of Asphalt Option over 20 year Analysis Period

Life Cycle Stage	**Asphalt**			
	Manufacturing	Construction	Maintenance	Totals
Fossil Fuel Consumption (MJ)	497,000	747,000	2,560,000	3,800,000
Global Warming Potential (kg CO_2 eq)	7,060	58,200	482,000	547,000
Acidification Potential (moles of H^+ eq)	3,560	18,000	154,000	175,000
HH Criteria (kg PM10 eq)	17.5	25.4	280	323
Eutrophication Potential (kg N eq)	2.85	18.6	145	167
Ozone Depletion Potential (kg CFC-11 eq)	1.53 x 10^-7	2.24*10^-6	1.75*10^-5	1.98*10^-5
Smog Potential (kg O_3 eq)	733	9,070	68,600	78,400

Table 7: Environmental Impact of Concrete Option over 20 year Analysis Period				
Life Cycle Stage	**Concrete**			
	Manufacturing	Construction	Maintenance	Totals
Fossil Fuel Consumption (MJ)	36,000	153,000	6,110	195,000
Global Warming Potential (kg CO_2 eq)	4,070	11,900	470	16,400
Acidification Potential (moles of H^+ eq)	879	3,670	144	4,700
HH Criteria (kg PM10 eq)	7	5	0	13
Eutrophication Potential (kg N eq)	2	4	0	6
Ozone Depletion Potential (kg CFC-11 eq)	2.88*10^-5	4.58*10^-7	1.87*10^-8	2.93*10^-5
Smog Potential (kg O_3 eq)	142	1,860	77	2,080

The pavement vehicle interaction (PVI) effects were not considered in this assessment since the road section was only 55 metres in length.

Fossil fuel consumption consists of all the energy, direct and indirect, used to transform or transport raw materials into products and roadways. This includes the inherent energy contained in the feedstock materials that are commonly used as an energy source. For the asphalt option, the manufacturing and construction stage consumed 1,244,000 MJ of fossil fuel and the maintenance phase consumed an additional 2,560,000 MJ. For the concrete option, the total fossil fuel use was 197,000 MJ.

The most commonly referenced measure for “Global Warming Potential” is the release of green house gases (GHG) typically expressed as kg CO_2 equivalent. While the production of cement releases some 707 kg of CO_2 for every 1000 kg of cement produced [2], cement typically comprises only 7% to 9% of a concrete mix. For this project, the cement and concrete production contributed less than 4070 kg CO_2. The total GHG potential for the concrete over the 20 year analysis period is 16,400 kg CO_2 eq. In comparison, the asphalt option is 547,000 kg CO_2 eq. The most significant contribution to GHG potential was during the HMA maintenance phase because of the unique repair schedule on this project.

Overall, the impact of the concrete pavement for six of the seven life cycle stages was at least an order of magnitude less than that of the comparable asphalt section over the 20 year life analysed. Most of the impact occurred during the maintenance phase since the asphalt was repaired every 2-3 years versus the concrete only requiring the diamond grinding around year 20.

Conclusions

Even though the asphalt pavement outside of an intersection may last 15 years or more, the exceptional conditions at intersections may significantly reduce service life. Because of their unique purpose, intersections have increased maintenance activities due to the stopping and starting forces of large trucks. Depending on the situation, the HMA pavements may exhibit rutting much sooner than expected, which would increase repair schedules. Traditionally, the easiest repair for rutting is to mill the asphalt and replace it with new material. While this may be a quick option, it is not always the best option and alternatives may prove to be more advantageous than initially thought.

Using maturity methods for concrete not only can provide much information to the agency, it can also reduce the opening time to very reasonable amounts. In this case, the concrete option only delayed the lane opening by one hour more than the asphalt option. At 20 years, the concrete option will have required only 18 hours of lane closure while asphalt would have required approximately 80 hours. From a safety standpoint, the more time crews are on the roads repairing them, the greater the risk of an accident. Also, the more time the lanes are closed, the more traffic congestion there will be, leading to higher societal costs due to pollution from idling vehicles, additional fuel costs and potentially overtime costs for late deliveries.

From a life cycle cost perspective, in this case, the concrete option was higher at initial cost because a “shave and pave” repair was compared to a full depth replacement. However, the increased frequency of repair for the asphalt quickly balanced out the cost. At the five year mark, the cost of the concrete option will be equal to that of the asphalt option. At the twenty year mark, the concrete option could potentially be $82,000 than the asphalt option.

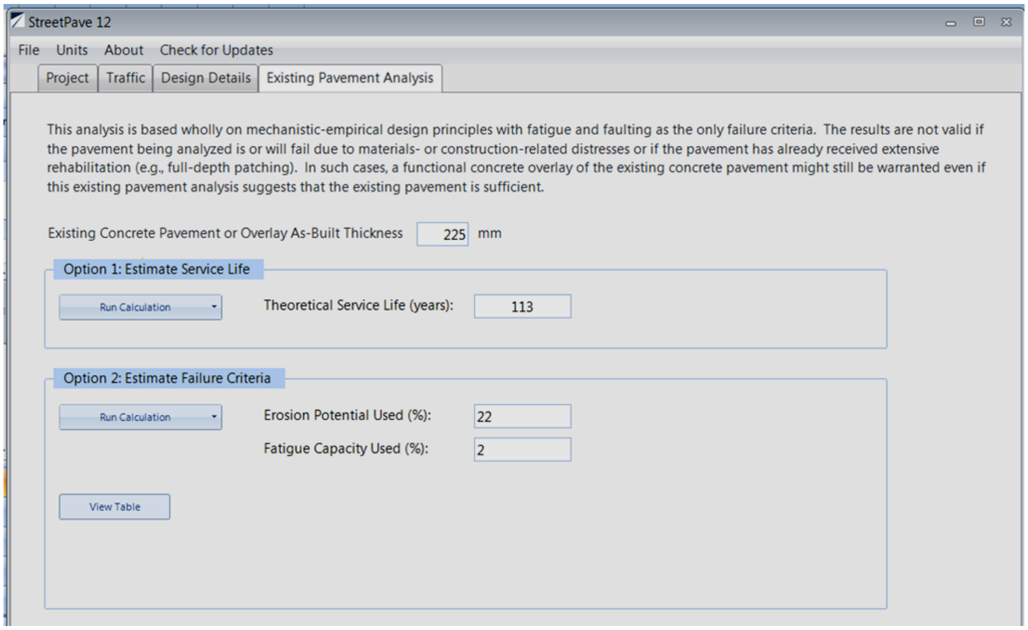
Lastly, from an environmental sustainability perspective, the impact of the asphalt option on fossil fuels, global warming potential and other key measures was an order of magnitude higher than the concrete repair. The exception was Ozone Depletion Potential where both options were similar at 20 years. The large differences in environmental sustainability were due to asphalt’s frequent repair requirements.

Due to the exceptional requirements of intersections, the use of asphalt pavement is not always effective. Asphalt requires repair every 2-3 years in these situations whereas concrete requires a minor diamond-grinding at year 20. The continual repair of asphalt increases the cost of use overall for the municipality. This repair also carries a significant environmental cost as well as a societal cost. In this situation, concrete proves to be a more viable option.

References

1. Athena Institute (2013) Impact Estimator for Highways User Guide,1- 7, http://www.athenasmi.org/wp-content/uploads/2012/01/ImpactEstimatorForHighways_UserGuide.pdf
2. Cement Association of Canada (2013). 2012 Environmental Performance Report, 5, http://www.rediscoverconcrete.ca/assets/files/sustainability/Environmental%20Performace%20Report%20-%20English.pdf

Figures



This analysis is based wholly on mechanistic-empirical design principles with fatigue and faulting as the only failure criteria. The results are not valid if the pavement being analyzed is or will fail due to materials- or construction-related distresses or if the pavement has already received extensive rehabilitation (e.g., full-depth patching). In such cases, a functional concrete overlay of the existing concrete pavement might still be warranted even if this existing pavement analysis suggests that the existing pavement is sufficient.

Existing Concrete Pavement or Overlay As-Built Thickness: 225 mm

Option 1: Estimate Service Life

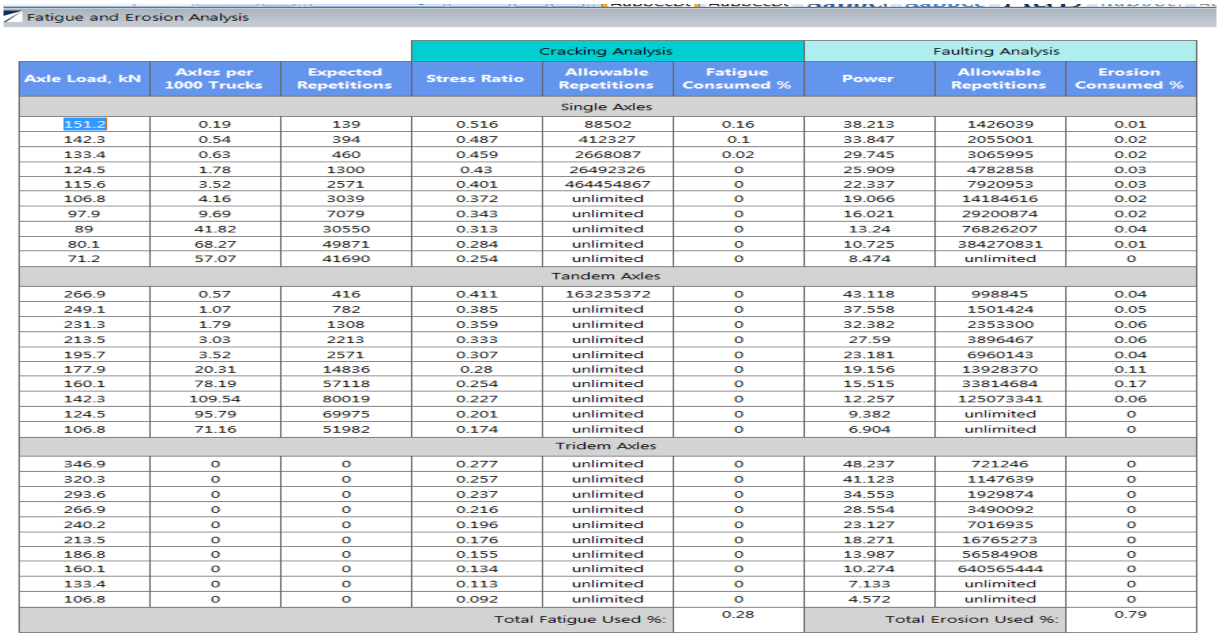
Theoretical Service Life (years): 113

Option 2: Estimate Failure Criteria

Erosion Potential Used (%): 22

Fatigue Capacity Used (%): 2

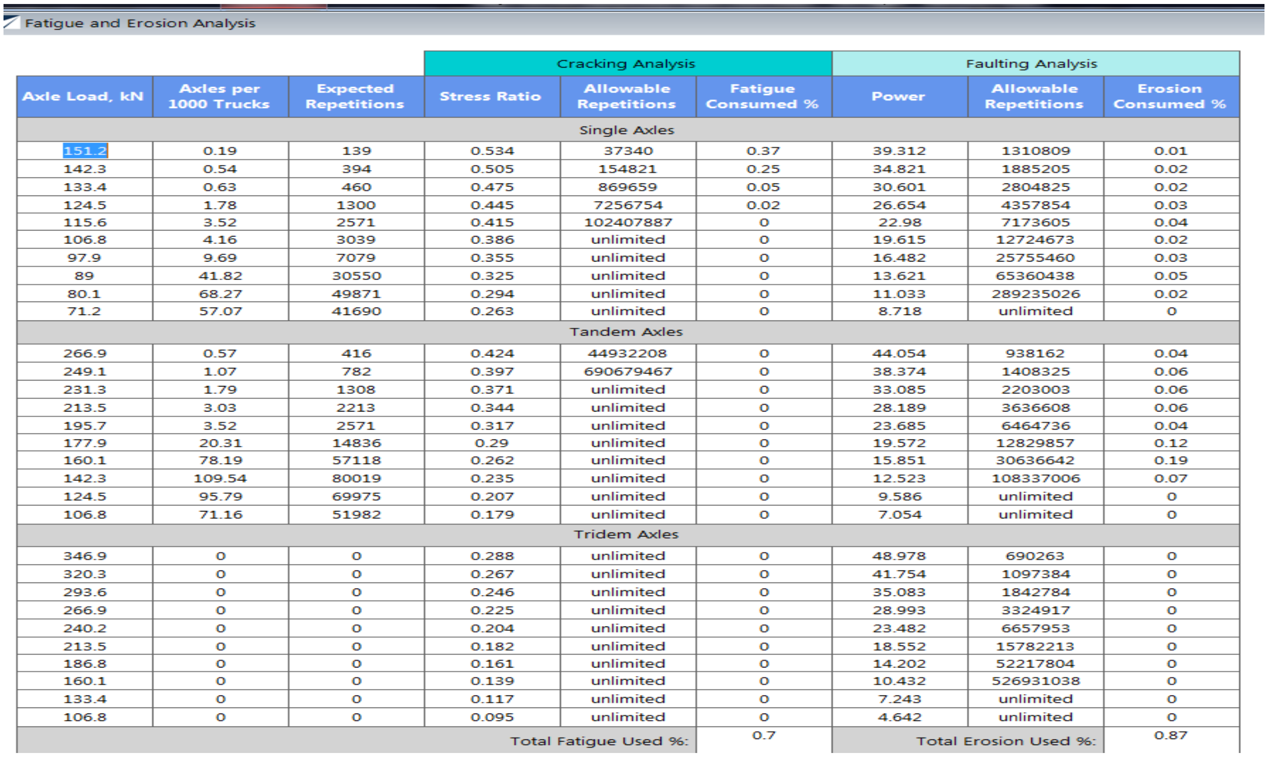
Figure 3 – Fatigue/Erosion for 35 MPa using StreetPave 12 Software from American Concrete Pavement Association



Fatigue and Erosion Analysis

			Cracking Analysis			Faulting Analysis		
Axle Load, kN	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed %	Power	Allowable Repetitions	Erosion Consumed %
Single Axles								
151.2	0.19	139	0.516	88502	0.16	38.213	1426039	0.01
142.3	0.54	394	0.487	412327	0.1	33.847	2055001	0.02
133.4	0.63	460	0.459	2668087	0.02	29.745	3065995	0.02
124.5	1.78	1300	0.43	26492326	0	25.909	4782858	0.03
115.6	3.52	2571	0.401	464454867	0	22.337	7920953	0.03
106.8	4.16	3039	0.372	unlimited	0	19.066	14184616	0.02
97.9	9.69	7079	0.343	unlimited	0	16.021	29200874	0.02
89	41.82	30550	0.313	unlimited	0	13.24	76826207	0.04
80.1	68.27	49871	0.284	unlimited	0	10.725	384270831	0.01
71.2	57.07	41690	0.254	unlimited	0	8.474	unlimited	0
Tandem Axles								
266.9	0.57	416	0.411	163235372	0	43.118	998845	0.04
249.1	1.07	782	0.385	unlimited	0	37.558	1501424	0.05
231.3	1.79	1308	0.359	unlimited	0	32.382	2353300	0.06
213.5	3.03	2213	0.333	unlimited	0	27.59	3896467	0.06
195.7	3.52	2571	0.307	unlimited	0	23.181	6960143	0.04
177.9	20.31	14836	0.28	unlimited	0	19.156	13928370	0.11
160.1	78.19	57118	0.254	unlimited	0	15.515	33814684	0.17
142.3	109.54	80019	0.227	unlimited	0	12.257	125073341	0.06
124.5	95.79	69975	0.201	unlimited	0	9.382	unlimited	0
106.8	71.16	51982	0.174	unlimited	0	6.904	unlimited	0
Tridem Axles								
346.9	0	0	0.277	unlimited	0	48.237	721246	0
320.3	0	0	0.257	unlimited	0	41.123	1147639	0
293.6	0	0	0.237	unlimited	0	34.553	1929874	0
266.9	0	0	0.216	unlimited	0	28.554	3490092	0
240.2	0	0	0.196	unlimited	0	23.127	7016935	0
213.5	0	0	0.176	unlimited	0	18.271	16765273	0
186.8	0	0	0.155	unlimited	0	13.987	56584908	0
160.1	0	0	0.134	unlimited	0	10.274	640565444	0
133.4	0	0	0.113	unlimited	0	7.133	unlimited	0
106.8	0	0	0.092	unlimited	0	4.572	unlimited	0
				Total Fatigue Used %:	0.28		Total Erosion Used %:	0.79

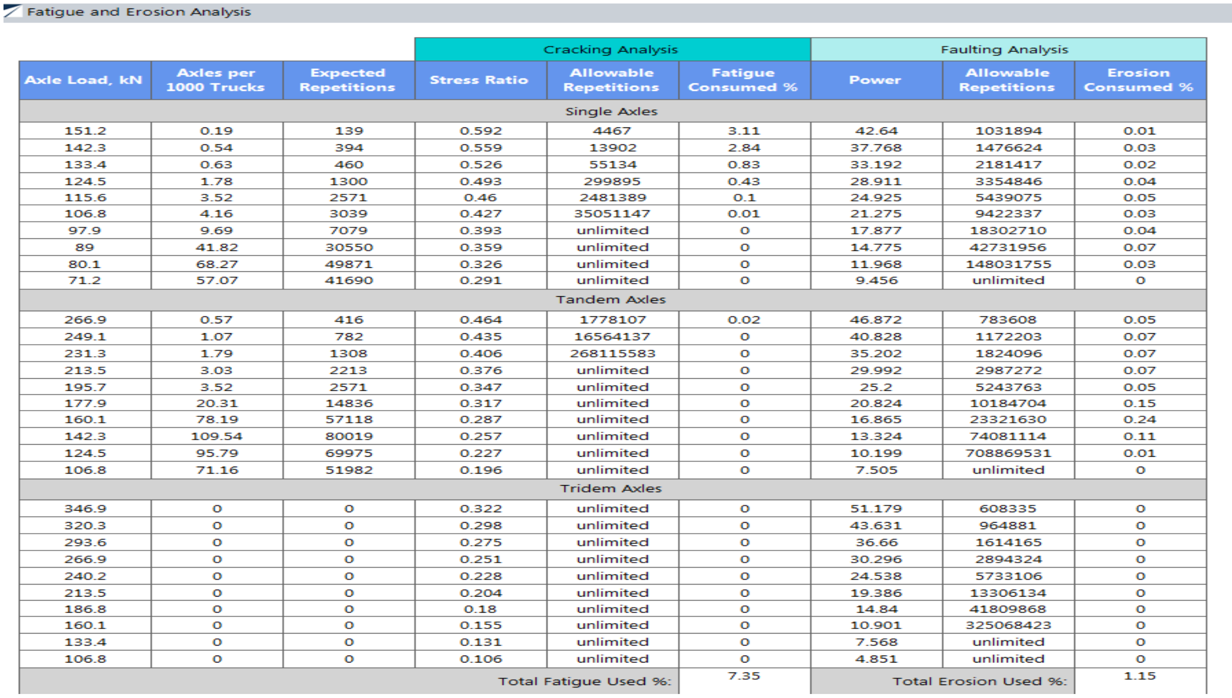
Figure 4– Fatigue/Erosion for 32 MPa using StreetPave 12 Software from American Concrete Pavement Association



Fatigue and Erosion Analysis

			Cracking Analysis			Faulting Analysis		
Axle Load, kN	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed %	Power	Allowable Repetitions	Erosion Consumed %
Single Axles								
151.2	0.19	139	0.534	37340	0.37	39.312	1310809	0.01
142.3	0.54	394	0.505	154821	0.25	34.821	1885205	0.02
133.4	0.63	460	0.475	869659	0.05	30.601	2804825	0.02
124.5	1.78	1300	0.445	7256754	0.02	26.654	4357854	0.03
115.6	3.52	2571	0.415	102407887	0	22.98	7173605	0.04
106.8	4.16	3039	0.386	unlimited	0	19.615	12724673	0.02
97.9	9.69	7079	0.355	unlimited	0	16.482	25755460	0.03
89	41.82	30550	0.325	unlimited	0	13.621	65360438	0.05
80.1	68.27	49871	0.294	unlimited	0	11.033	289235026	0.02
71.2	57.07	41690	0.263	unlimited	0	8.718	unlimited	0
Tandem Axles								
266.9	0.57	416	0.424	44932208	0	44.054	938162	0.04
249.1	1.07	782	0.397	690679467	0	38.374	1408325	0.06
231.3	1.79	1308	0.371	unlimited	0	33.085	2203003	0.06
213.5	3.03	2213	0.344	unlimited	0	28.189	3636608	0.06
195.7	3.52	2571	0.317	unlimited	0	23.685	6464736	0.04
177.9	20.31	14836	0.29	unlimited	0	19.572	12829857	0.12
160.1	78.19	57118	0.262	unlimited	0	15.851	30636642	0.19
142.3	109.54	80019	0.235	unlimited	0	12.523	108337006	0.07
124.5	95.79	69975	0.207	unlimited	0	9.586	unlimited	0
106.8	71.16	51982	0.179	unlimited	0	7.054	unlimited	0
Tridem Axles								
346.9	0	0	0.288	unlimited	0	48.978	690263	0
320.3	0	0	0.267	unlimited	0	41.754	1097384	0
293.6	0	0	0.246	unlimited	0	35.083	1842784	0
266.9	0	0	0.225	unlimited	0	28.993	3324917	0
240.2	0	0	0.204	unlimited	0	23.482	6657953	0
213.5	0	0	0.182	unlimited	0	18.552	15782213	0
186.8	0	0	0.161	unlimited	0	14.202	52217804	0
160.1	0	0	0.139	unlimited	0	10.432	526931038	0
133.4	0	0	0.117	unlimited	0	7.243	unlimited	0
106.8	0	0	0.095	unlimited	0	4.642	unlimited	0
				Total Fatigue Used %:	0.7		Total Erosion Used %:	0.87

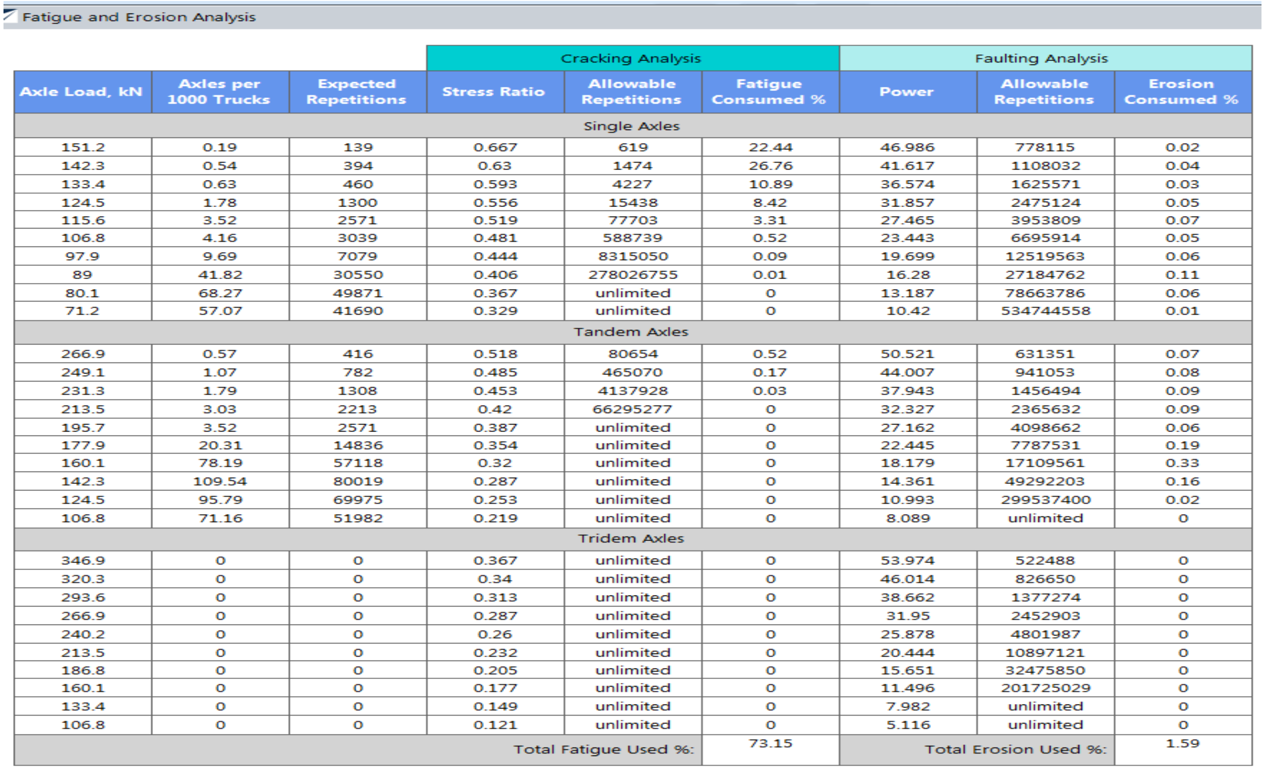
Figure 5 – Fatigue/Erosion for 30 MPa using StreetPave 12 Software from American Concrete Pavement Association



Fatigue and Erosion Analysis

			Cracking Analysis			Faulting Analysis		
Axle Load, kN	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed %	Power	Allowable Repetitions	Erosion Consumed %
Single Axles								
151.2	0.19	139	0.592	4467	3.11	42.64	1031894	0.01
142.3	0.54	394	0.559	13902	2.84	37.768	1476624	0.03
133.4	0.63	460	0.526	55134	0.83	33.192	2181417	0.02
124.5	1.78	1300	0.493	299895	0.43	28.911	3354846	0.04
115.6	3.52	2571	0.46	2481389	0.1	24.925	5439075	0.05
106.8	4.16	3039	0.427	35051147	0.01	21.275	9422337	0.03
97.9	9.69	7079	0.393	unlimited	0	17.877	18302710	0.04
89	41.82	30550	0.359	unlimited	0	14.775	42731956	0.07
80.1	68.27	49871	0.326	unlimited	0	11.968	148031755	0.03
71.2	57.07	41690	0.291	unlimited	0	9.456	unlimited	0
Tandem Axles								
266.9	0.57	416	0.464	1778107	0.02	46.872	783608	0.05
249.1	1.07	782	0.435	16564137	0	40.828	1172203	0.07
231.3	1.79	1308	0.406	268115583	0	35.202	1824096	0.07
213.5	3.03	2213	0.376	unlimited	0	29.992	2987272	0.07
195.7	3.52	2571	0.347	unlimited	0	25.2	5243763	0.05
177.9	20.31	14836	0.317	unlimited	0	20.824	10184704	0.15
160.1	78.19	57118	0.287	unlimited	0	16.865	23321630	0.24
142.3	109.54	80019	0.257	unlimited	0	13.324	74081114	0.11
124.5	95.79	69975	0.227	unlimited	0	10.199	708869531	0.01
106.8	71.16	51982	0.196	unlimited	0	7.505	unlimited	0
Tridem Axles								
346.9	0	0	0.322	unlimited	0	51.179	608335	0
320.3	0	0	0.298	unlimited	0	43.631	964881	0
293.6	0	0	0.275	unlimited	0	36.66	1614165	0
266.9	0	0	0.251	unlimited	0	30.296	2894324	0
240.2	0	0	0.228	unlimited	0	24.538	5733106	0
213.5	0	0	0.204	unlimited	0	19.386	13306134	0
186.8	0	0	0.18	unlimited	0	14.84	41809868	0
160.1	0	0	0.155	unlimited	0	10.901	325068423	0
133.4	0	0	0.131	unlimited	0	7.568	unlimited	0
106.8	0	0	0.106	unlimited	0	4.851	unlimited	0
				Total Fatigue Used %:	7.35		Total Erosion Used %:	1.15

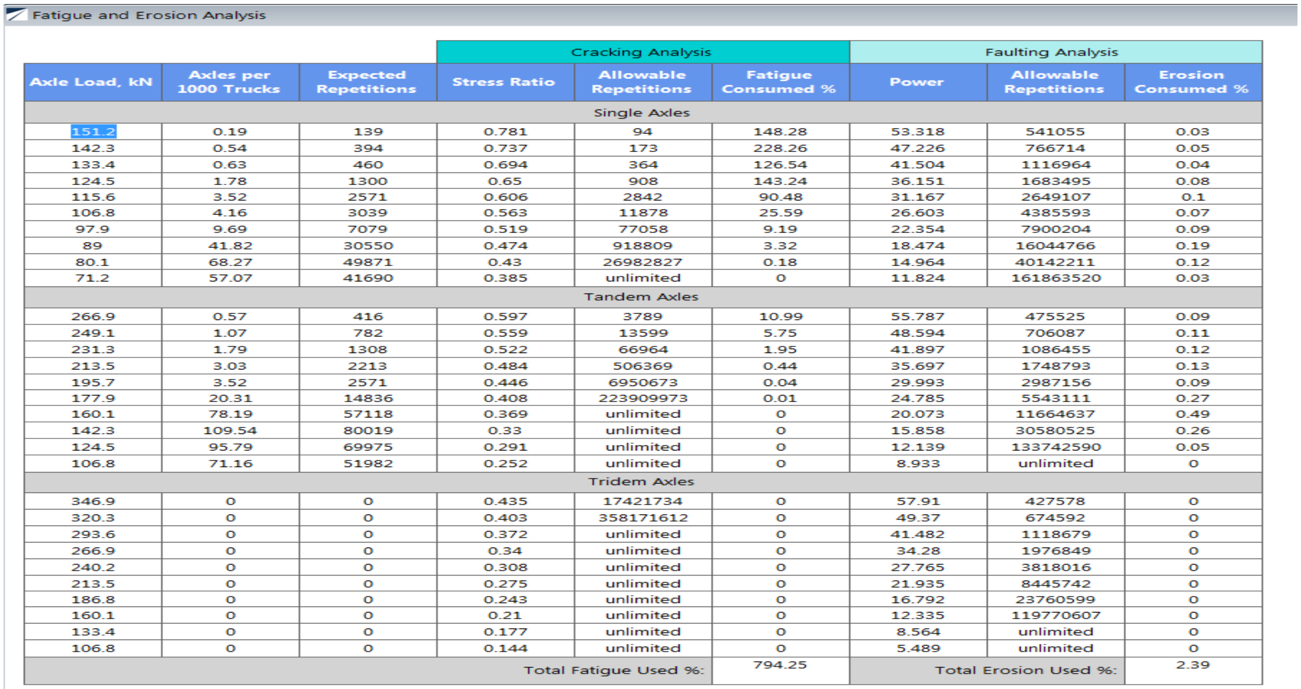
Figure 6 – Fatigue/Erosion for 25 MPa using StreetPave 12 Software from American Concrete Pavement Association



Fatigue and Erosion Analysis

			Cracking Analysis			Faulting Analysis		
Axle Load, kN	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed %	Power	Allowable Repetitions	Erosion Consumed %
Single Axles								
151.2	0.19	139	0.667	619	22.44	46.986	778115	0.02
142.3	0.54	394	0.63	1474	26.76	41.617	1108032	0.04
133.4	0.63	460	0.593	4227	10.89	36.574	1625571	0.03
124.5	1.78	1300	0.556	15438	8.42	31.857	2475124	0.05
115.6	3.52	2571	0.519	77703	3.31	27.465	3953809	0.07
106.8	4.16	3039	0.481	588739	0.52	23.443	6695914	0.05
97.9	9.69	7079	0.444	8315050	0.09	19.699	12519563	0.06
89	41.82	30550	0.406	278026755	0.01	16.28	27184762	0.11
80.1	68.27	49871	0.367	unlimited	0	13.187	78663786	0.06
71.2	57.07	41690	0.329	unlimited	0	10.42	534744558	0.01
Tandem Axles								
266.9	0.57	416	0.518	80654	0.52	50.521	631351	0.07
249.1	1.07	782	0.485	465070	0.17	44.007	941053	0.08
231.3	1.79	1308	0.453	4137928	0.03	37.943	1456494	0.09
213.5	3.03	2213	0.42	66295277	0	32.327	2365632	0.09
195.7	3.52	2571	0.387	unlimited	0	27.162	4098662	0.06
177.9	20.31	14836	0.354	unlimited	0	22.445	7787531	0.19
160.1	78.19	57118	0.32	unlimited	0	18.179	17109561	0.33
142.3	109.54	80019	0.287	unlimited	0	14.361	49292203	0.16
124.5	95.79	69975	0.253	unlimited	0	10.993	299537400	0.02
106.8	71.16	51982	0.219	unlimited	0	8.089	unlimited	0
Tridem Axles								
346.9	0	0	0.367	unlimited	0	53.974	522488	0
320.3	0	0	0.34	unlimited	0	46.014	826650	0
293.6	0	0	0.313	unlimited	0	38.662	1377274	0
266.9	0	0	0.287	unlimited	0	31.95	2452903	0
240.2	0	0	0.26	unlimited	0	25.878	4801987	0
213.5	0	0	0.232	unlimited	0	20.444	10897121	0
186.8	0	0	0.205	unlimited	0	15.651	32475850	0
160.1	0	0	0.177	unlimited	0	11.496	201725029	0
133.4	0	0	0.149	unlimited	0	7.982	unlimited	0
106.8	0	0	0.121	unlimited	0	5.116	unlimited	0
Total Fatigue Used %:					73.15	Total Erosion Used %:		1.59

Figure 7 – Fatigue/Erosion for 20 MPa using StreetPave 12 Software from American Concrete Pavement Association



Fatigue and Erosion Analysis

			Cracking Analysis			Faulting Analysis		
Axle Load, kN	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed %	Power	Allowable Repetitions	Erosion Consumed %
Single Axles								
151.2	0.19	139	0.781	94	148.28	53.318	541055	0.03
142.3	0.54	394	0.737	173	228.26	47.226	766714	0.05
133.4	0.63	460	0.694	364	126.54	41.504	1116964	0.04
124.5	1.78	1300	0.65	908	143.24	36.151	1683495	0.08
115.6	3.52	2571	0.606	2842	90.48	31.167	2649107	0.1
106.8	4.16	3039	0.563	11878	25.59	26.603	4385593	0.07
97.9	9.69	7079	0.519	77058	9.19	22.354	7900204	0.09
89	41.82	30550	0.474	918809	3.32	18.474	16044766	0.19
80.1	68.27	49871	0.43	26982827	0.18	14.964	40142211	0.12
71.2	57.07	41690	0.385	unlimited	0	11.824	161863520	0.03
Tandem Axles								
266.9	0.57	416	0.597	3789	10.99	55.787	475525	0.09
249.1	1.07	782	0.559	13599	5.75	48.594	706087	0.11
231.3	1.79	1308	0.522	66964	1.95	41.897	1086455	0.12
213.5	3.03	2213	0.484	506369	0.44	35.697	1748793	0.13
195.7	3.52	2571	0.446	6950673	0.04	29.993	2987156	0.09
177.9	20.31	14836	0.408	223909973	0.01	24.785	5543111	0.27
160.1	78.19	57118	0.369	unlimited	0	20.073	11664637	0.49
142.3	109.54	80019	0.33	unlimited	0	15.858	30580525	0.26
124.5	95.79	69975	0.291	unlimited	0	12.139	133742590	0.05
106.8	71.16	51982	0.252	unlimited	0	8.933	unlimited	0
Tridem Axles								
346.9	0	0	0.435	17421734	0	57.91	427578	0
320.3	0	0	0.403	358171612	0	49.37	674592	0
293.6	0	0	0.372	unlimited	0	41.482	1118679	0
266.9	0	0	0.34	unlimited	0	34.28	1976849	0
240.2	0	0	0.308	unlimited	0	27.765	3818016	0
213.5	0	0	0.275	unlimited	0	21.935	8445742	0
186.8	0	0	0.243	unlimited	0	16.792	23760599	0
160.1	0	0	0.21	unlimited	0	12.335	119770607	0
133.4	0	0	0.177	unlimited	0	8.564	unlimited	0
106.8	0	0	0.144	unlimited	0	5.489	unlimited	0
Total Fatigue Used %:					794.25	Total Erosion Used %:		2.39

Figure 8 – Fatigue/Erosion for 15 MPa using StreetPave 12 Software from American Concrete Pavement Association