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FIELD INSPECTION AND CLASSIFICATION OF PAVEMENT DISTRESSES OF ST JOHN'S CITY IN NEWFOUNDLAND CANADA

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Abstract: The City of St. John's (Newfoundland and Labrador, Canada) has a unique climate, with excessive precipitation year-round, moderate summers and extreme winters. The pavement foundation (subgrade) in this region consists mainly of strong metamorphic rocks. As the city is located on an island and has a small population size, roads of this city experience very low volume of heavy traffic. Despite having less traffic and strong foundation, most of the roads in St. John's suffer from serious structural and functional distresses. The distresses include but are not limited to deformation (structural, abrasion), moisture damages (pothole, ravelling), fatigue cracking (top down, bottom up), thermal cracking (longitudinal, transverse) etc. These distresses eventually lead to longer travel times, higher vehicular and pedestrian crashes and fatalities, excessive fuel consumption due to additional maneuvering actions as a result of poor road conditions, high CO_2 emissions and a sub-standard ride quality. To address these issues, a comprehensive understanding of these distresses under local conditions is necessary. As an initial effort, a small-scale field survey was conducted and the distresses were classified and ranked based on type and severity. In addition, summary of each distress mechanism has been presented, followed by some recommendations to mitigate and address these distresses in this region. It is expected that this study will not only contribute in enhancing the pavement service-life by developing an improved asphalt mixture design in future but also reduce deleterious emissions and improve traffic safety.

1 INTRODUCTION

More than 90% of the paved roads around the world are made from asphalt (EAPA 2015, WAPA 2010). Also known as flexible pavements, these roads generally consist of an asphalt surface course placed over the base course and subgrade of granular materials. Each layer plays a significant role in distributing the traffic loads received from the layer above and limiting the impact of environmental features such as freezing and thawing. Most of the distresses in pavements occur as a result of a large difference between high and low temperatures, water penetration and displacement in the subgrade, increase in traffic density, traffic loading, and inefficient compaction during construction. As a result, distresses in flexible pavements can be categorized as: (1) permanent deformation (at high service temperatures), (2) fatigue cracking (at intermediate service temperatures) and (3) thermal cracking (at low service temperatures).

St. John's has unique climatic conditions, i.e., a very high amount of precipitation throughout the year and temperate summers but extreme winter temperatures. With a population of just under a quarter million, the roads are exposed to a very low traffic volume. Nonetheless, the roads in St. John's show signs of serious deduction in structural as well as functional value. Instances of pavement deterioration due to traffic loads, tires, moisture, freezing and thawing, temperature variation, and other environmental factors are frequent in the city. These damages to the pavement not only require huge efforts in repair and maintenance activities but also result in general discomfort to the users if not taken care of in a timely manner. To address these issues, a field survey was conducted to identify the pavement distresses in St. John's. Also, an attempt has been made to classify the pavement distresses and to rank them based on their type and magnitude.

1.1 Literature Review

Researchers have classified pavement damages into three major categories: (1) crack type, (2) disintegration type dominated by potholes and (3) depression type (Sarie et al. 2015). Effects of traffic loads, materials and design parameters on pavement damage over time were also studied. It was revealed that pavement cracking is affected more by trucks with single and tandem axles than those with multiple axles (tridem and higher). Rutting (structural) occurs more due to heavier trucks with multiple axles than those with single and tandem axles (Salama et al. 2006). In addition, abrasion rutting (wearing of surface layer) occurs due to frictional impacts between tire studs and pavement surface that lead to loosening of mastic portion from pavement surface. Hicks (1999) provided a logical approach for determining the most effective preventive maintenance treatment for distresses in the flexible pavements at lower costs (Table 1). Te et al. (1995) developed a software program called "APDIS" which could evaluate pavement surface cracks using image processing algorithms.

Asphalt pavement materials play a vital role in determining the longevity of pavements. Aging of asphalt in the asphalt mix changes the structure, chemical composition and surface tension properties of asphalt. This causes the asphalt cement to become stiffer and more vulnerable to moisture damages (Hossain et al. 2018). Some other significant binder characteristics include: (1) temperature susceptibility, (2) adhesion/cohesion and (3) hardening and aging (VDOT 2012).

Table 1: Appropriate maintenance strategies for various pavement distress types (Hicks et al. 1999)

Distress\Maintenance	Crack sealing	Fog seal	Micro surfacing	Slurry seal	Cape seal	Chip seal	Thin overlay	Mill or grind
Rutting			#	#	#		#	
Fatigue cracking								
Longitudinal cracking	#	#	#	#	#	#	#	
Transverse cracking	#	#	#	#	#	#	#	
Bleeding			#			#		#
Ravelling		#		#	#	#		

2 DISTRESS IDENTIFICATION

1.2 Area of Study

This study focuses on the identification of major distress types and factors responsible for causing pavement deterioration in St. John's. The data collection process was entirely based on visual inspection. Roads included in this study are a few major roads including Newfoundland Road, New Cove Road, Elizabeth Avenue, Portugal Cove Road, Torbay Road and roads located inside the Memorial University of Newfoundland (MUN). Figure 1 presents the major road network in St. John's.

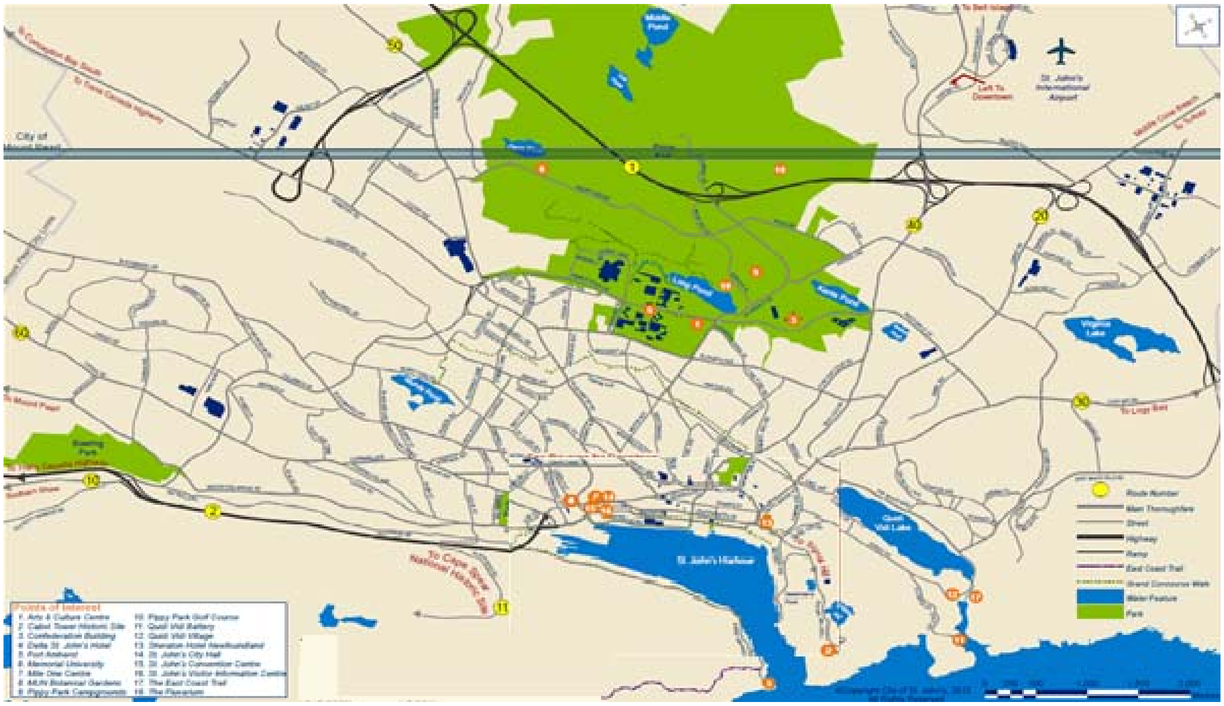


Figure 1: Map of the major road network of the City of St. John's (Map Viewer 2018)

1.3 Climate and Weather

Roads in St. John's are designed according to the historically available climate data. The average temperature in the city over the last 80 years ranged from -9.3 to 15.5 ºC. Air humidity is 79 to 83%, with an annual average of 81%. Average wind speed varies from 20 to 28 km/h.

Table 2: Weather in the City of St. John's (The Weather Network 2018)

Month	Average high temp (ºC)	Average low temp (ºC)	Record daily high with date (ºC)	Record daily low with date (ºC)	Wind speed (km/h)	Average precipitation (mm)	Humidity (%)
Jan	-0.9	-8.6	15.2 (Jan09/79)	-23.3 (Jan09/57)	28	150	82
Feb	-5.4	-9.3	16 (Feb4/96)	-23.8 (Feb18/90)	26	125	79
Mar	-2.5	-6.2	18.3 (Mar31/62)	-23.8 (Mar10/86)	26	131	82
Apr	1.6	-2	24.1 (Apr24/86)	-14.8 (Apr04/78)	22	122	83
May	6.2	1.5	25.6 (May30/72)	-6.7 (May05/64)	21	101	80
Jun	10.9	5.9	29.4 (Jun29/44)	-3.3 (Jun01/70)	21	102	79
Jul	15.4	10.5	31.5 (Jul 06/83)	-1.1 (Jul05/76)	21	89	79
Aug	15.5	11.1	31 (Aug07 /96)	0.5 (Aug24/83)	20	108	80
Sep	11.8	7.7	29.5 (Sep10/01)	-1.1 (Sep23/50)	21	131	81
Oct	6.9	3.3	24.6 (Oct04/87)	-5.6 (Oct31/46)	23	162	82
Nov	2.6	-0.7	19.4 (Nov06/50)	-13.4 (Nov25/83)	24	144	82
Dec	-2.2	-5.5	16.1 (Dec12/57)	-19.7 (Dec27/84)	27	149	83

3 DISTRESS IDENTIFICATION PROTOCOLS

Road maintenance is a critical step in the design of flexible pavements. In order to ensure the efficient functioning of pavements, maintenance procedures can be proposed based on the identification of pavement surface defects. Four steps are followed for this purpose: (1) Description: a short explanation of the substantial features of the distress together with some notes that might support if such a distress is identified; (2) Location: area of distress exposed to different loads and conditions is determined; (3) Causes of distress: factors causing the distress are identified; (4) Levels of severity: severity level is determined with respect to commonly defined qualitative judgement degrees (low, medium and high) and (5) Measurement and possible repairs.

1.4 **Types of Pavement Damage**

In this study, four major pavement distresses were identified, namely rutting, cracking (fatigue, block, longitudinal, transverse), potholes and delamination.

1.4.1 **Rutting**

Description: Rutting is normally defined as the vertical deformation of pavement materials that creates surface depression along the wheel path.

Location: Depressions can form over large areas of the road mostly along the wheel path. Figure 2 (a, b) shows examples of structural and abrasive rutting (due to studded tires) in the city of St. John’s.

Identifying distress causes: Rutting is a prominent distress type in the flexible pavement. Pavement shearing can happen along the sides of the rut rendering the top surface clearly damaged. This heavily affects the ride quality. Some major theories explaining rutting behaviour in the literature are:

1. One-dimensional densification or vertical compression: Deformation under the wheel path without an accompanying hump on either side of the deformation is caused by material densification. It is predominantly induced by excessive air voids or insufficient compaction. It might result in a low to moderate or high severity rutting (Kandhal et al. 2003, Miljkovic et al. 2011).

2. Lateral flow or plastic movement (Visco-plastic deformation): Asphalt mix with inadequate shear strength or higher percentage of air voids can result in lateral displacement of materials with an accompanying hump. Air void network in the asphalt mix act as a lubricant and under heavy and repeated traffic loading a high percentage of air voids can accelerate this type of rutting. The damage intensifies at high temperatures and mostly standing loads. It might be quite difficult to predict this form of rutting on field as well as experimentally on account of the anisotropic behavior of asphalt.

3. Mechanical deformation (Structural rutting): Lateral movement of unbound material in the lower layers (subgrade) results in wider ruts in the pavement structure. It generally occurs due to irregularities in elastic modulus of the asphalt mix (too stiff or high elastic modulus).

4. Abrasive rutting (Wearing): This is caused by the loss of mastic phase or fine grains of aggregate in surface layer from the impact of studded tires (Sarie et al. 2015). This phenomenon, in particular, is heavily observed in the city of St. John’s.

Levels of Severity: LOW (L): rut depth is ≥ 6mm and ≤ 12mm; MEDIUM (M): rut depth is ≥13mm and ≤ 25mm, HIGH (H): rut depth is ≥ 26mm (ODOT 2010).

Measurement and Possible Repairs: Special recording devices such as a profilometer or straightedge can be used to record rut depths. A Data Collection Vehicle (DCV) can also be employed to measure the extent of pavement rutting (ODOT 2010). Minor surface ruts can be filled and deeper ruts can be covered with an overlay. If surface asphalt is unstable, recycling can be performed. In the case of subgrade inconsistencies, reclamation or reconstruction is the best option (Adlinge et al. 2009).

(a) Structural rutting (b) Abrasive rutting

Figure 2: Rutting in the city of St. John’s

1.4.2 **Cracking**

Four major types of cracking were identified as discussed in this section.

1.4.2.1 Fatigue Cracking (Alligator Cracking)

Description: Fatigue cracking comprises single crack or a series of interconnected cracks creating small, irregular regions on the pavement. Pavement deterioration due to fatigue mainly depends on the repetitive application of traffic loads, temperature of pavement and vehicle speed. According to Olard et al. (2005), it is possible to determine the fatigue behaviour of asphalt mixes by taking into account the level of strain imposed and the number of associated stress cycles. At low strain amplitudes ($<10^{-4}$), if the number of cycles imposed is greater than ten thousand, then the material damages due to fatigue (Perraton et al. 2003).

Location: Fatigue failure occurs in areas of the road subjected to repeated traffic loading (wheel paths) or wander within the lane.

Identifying distress causes: Failure of the surface layer or base due to repeated traffic loading results from the loss of mechanical properties (such as bearing capacity and stiffness modulus) of the pavement structure (Valdés et al. 2011) and consequently causes fatigue cracking. Other factors that contribute to fatigue cracking are low pavement thickness, aging pavement, poor quality of constituent materials and inadequate stiffness of the asphalt mix used in pavement (Adhikari et al. 2009).

Levels of Severity: LOW (L): area with none or only a few interconnecting cracks and the cracks are not sealed or spalled, average crack width is 6 mm and the crack pattern is no more apart than 32.8 mm (Figure 3a) (FHWA 2009, Salvatore et al. 2006, Scott et al. 2012); MEDIUM (M): interconnected cracks forming a complete pattern with slight spalling and sealing, average crack width is 6 to 19 mm and crack pattern is no more apart than 150 mm (Figure 3b) (Scott et al. 2012); HIGH (H): severely spalled interconnected cracks and average crack width is 19 mm (Figure 3c) (FHWA 2009).

Measurement and Possible Repairs: Linear distance of the affected wheel path or area of fatigue cracking in square meters is measured. Any zone is classified according to the level of severity. If fatigue cracking and rutting occur in the same zone, each distress should be treated separately (FHWA 2009). Changes in drainage pattern, base materials can be made. A full depth patch or spray patching can be performed for temporary repair (Ningyuan et al. 2001).

(a) Low Severity

(b) Medium Severity

(c) High Severity

FIGURE 3: Severity levels for fatigue (alligator) cracking

1.4.2.2 Block Cracking

Description: Interconnected cracks over an area not subjected to traffic load that divide the pavement into rectangular blocks ranging in size from approximately 30x30 cm to 300x300 cm (FHWA 2009, FDOT 2015).

Location: Block cracking occurs throughout the pavement width and not just in the wheel paths. They usually extend only a short distance on the hot-mix asphalt (HMA) surface. Figure 4 shows an example of block cracking in the city.

Identifying distress causes: This type of cracking can be caused by inadequate compaction, shrinkage and hardening of the asphalt mix (FHWA 2009, FDOT 2015).

Levels of Severity: LOW (L): tights cracks with negligible spalling, average width is 6 mm or less (Hall et al. 1993) and the width of sealed cracks can’t be determined; MEDIUM (M): crack width is between 6 mm and 12 mm; HIGH (H): cracks with a mean width greater than 12 mm, severe spalling and moderate or serious random parallel cracking at the intersection of the cracks or near the crack exists (Hall et al. 1993).

Measurement and Possible Repairs: Affected area in square meters or the length of pavement at each severity level is measured. Thin wearing course can be constructed to repair a low severity block cracking. For more severe situations, overlays and recycling can be performed. For base problems, the reclamation and reconstruction of the pavement can be proposed (Adlinge et al. 2013).

Figure 4: Block cracking

1.4.2.3 Longitudinal Cracking

Description: Long cracks that are parallel to the pavement centerline. However, cracks that are located exactly in the center of the lane are classified as center-of-lane cracking.

Location: Longitudinal cracks can exist anywhere between the centreline to the outer edge of the outer wheel path (Figure 5 (a, b)). Their position within the lane (wheel path or non-wheel path) is more critical.

Identifying distress causes: Longitudinal cracks can be caused by frost heaving or construction failures (low compaction or poor construction technique) between the construction lanes. They can also be load-induced. Other reasons include low temperatures causing surface shrinkage in the asphalt mix and creation and propagation of cracks beneath the surface course (Scott et al. 2012).

Levels of Severity: LOW (L): non-wheel path cracks with negligible spalling, mean crack width is 6 mm or less; sealed crack width is difficult to determine (FHWA 2009); MEDIUM (M): moderate spalling with filled cracks of a mean width less than 6 mm and non-filled cracks of a mean width greater than 6 mm but less than 19 mm (Miller et al. 2003); HIGH (H): mean crack width greater than 19 mm.

Measurement and Possible Repairs: The linear distance in meters of the affected area is measured at each severity level. Crack treatment or spray patching can be performed to repair the damage.

(a) (b)

Figure 5: Longitudinal cracking

1.4.2.4 Transverse Cracking

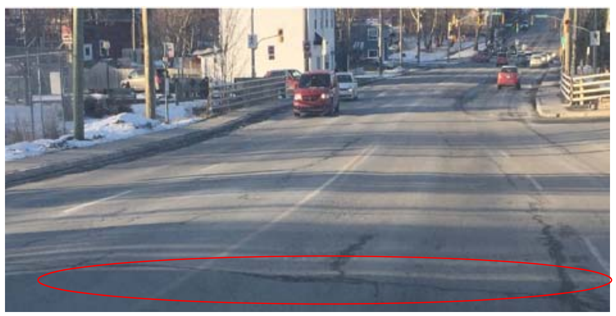
Description: Cracks that forms perpendicular to the centerline of the roadway. They are regularly spaced and start as thin, hairline cracks that widen later (Miller et al. 2003).

Location: Transverse cracks develop anywhere on the surface and propagate deeper with time.

Identifying distress causes: Transverse cracks are normally caused by shrinkage of the surface due to low temperatures, reflective cracks induced by the cracks beneath the surface, and a poorly constructed paving lane joint (Hall et al. 1993).

Levels of Severity: LOW (L): tight cracks with average width of 6 mm and slightly spalled or sealed cracks with a width that is difficult to determine; MEDIUM (M): cracks with average width between 6 to 19 mm, cracks less than 19 mm average width and low severity random cracking (FHWA 2009); HIGH (H): cracks with average width greater than 19 mm and cracks with average width less than 19 mm and medium to high severity random cracking (Miller et al. 2003). Severe spalling can also be noticed. Figure 6 (a, b) illustrates some examples of transverse cracking.

Measurement and Possible Repairs: Number and length in meters of cracks at each severity level are measured. Sealing can be performed for low severity cracks and an overlay can be placed for high severity cracks.



(a)

(b)

Figure 6: Transverse cracking

1.4.3 **Potholes**

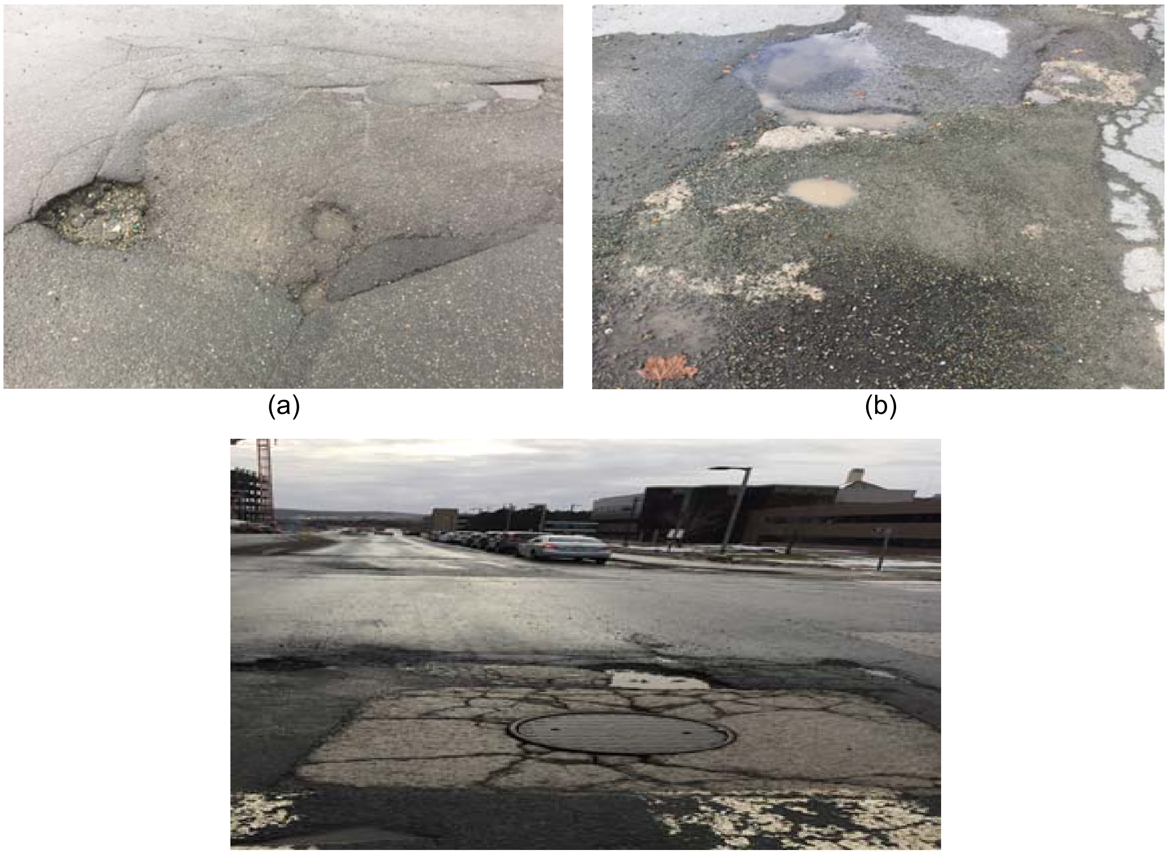
Description: Potholes are localized distresses in the form of bowl-shaped holes of varying sizes.

Location: Potholes often form in the areas of poor drainage and high traffic of slow-moving vehicles. Figure 7 (a, b, c) shows some examples of potholes filled with water.

Identifying distress causes: Depressions are formed when pavement progressively deteriorates due to fatigue cracking or inadequate strength in one or more layers of the pavement structure. Small fragments of the pavement are removed and the distress then gradually propagates in the lower layers.

Levels of Severity: LOW (L): 25 mm deep; MEDIUM (M): 25 – 50 mm deep; HIGH (H): 50 mm deep

Measurement and Possible Repairs: Number of potholes and the affected area in square meters are measured for each severity level. They can be repaired by patching or excavation and rebuilding. Patching is a very common technique used to cover up the potholes on a regular basis. However, when done incorrectly patches can result in uneven roads causing discomfort to the drivers.



(a) (b) (c)

Figure 7: Potholes

1.4.4 Delamination

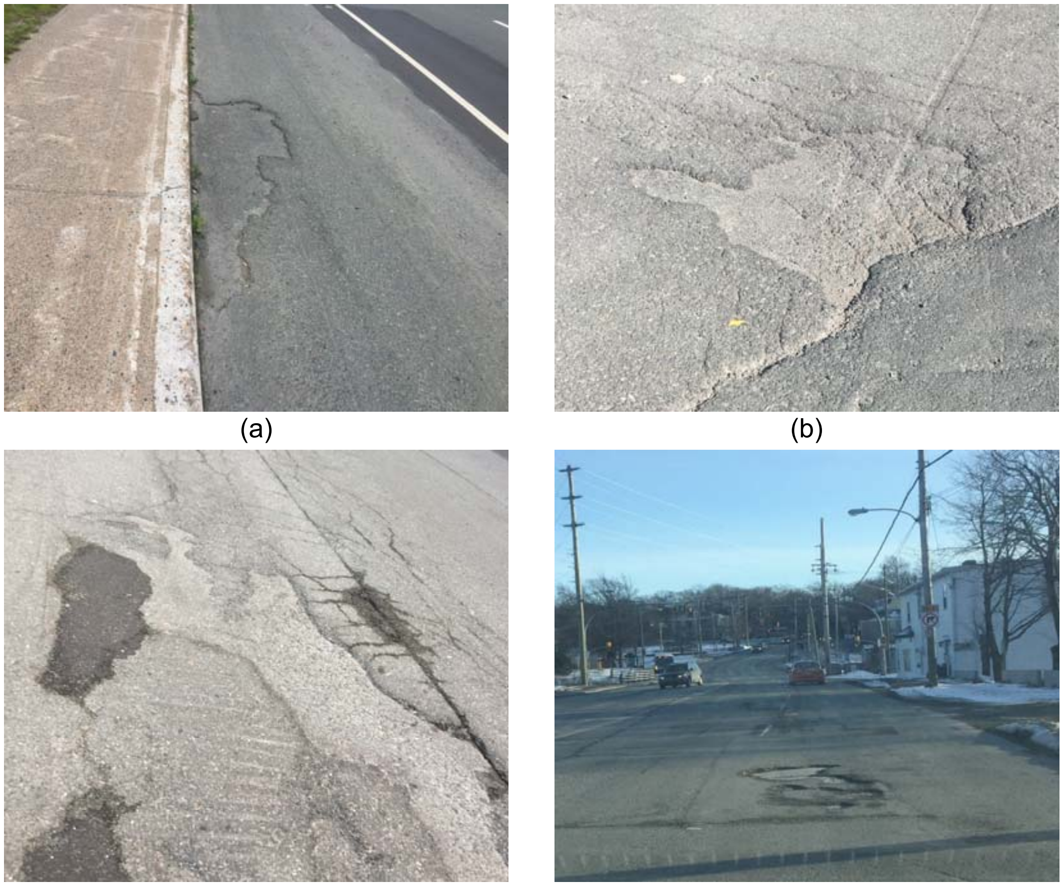
Description: Delamination is the gradual removal of an area of asphalt surface due to poor bonding with the underlying HMA layer. It reduces the serviceability of the pavement by causing subsequent slippage, cracking in the wheel paths, peeling and distortion in the layers.

Location: Mostly happens on the wheel path or shoulders of the pavement (Figure 8 (a, b, c, d)).

Identifying distress causes: Poor interfacial bonding between different layers, water percolation and heavy traffic loads are the major causes of delamination.

Levels of Severity: Delamination can extend from 30 square centimeters to tens of square meters. Even though it is undesirable at any depth, delamination deeper than the top two layers can cause surface distress during high traffic.

Measurement and Possible Repairs: Non-destructive test methods such as Ground Penetrating Radar or strain gages can be used to identify surface or subsurface delamination effectively. It can be treated by milling off the surface layer, replacing the wearing course or placing a thin asphalt overlay (Celaya et al. 2011).



(a) (b) (c) (d)

Figure 8: Delamination

1.5 Summary of Distress Survey

A distress survey was conducted on 19 randomly selected road sections (without considering traffic volume and construction history) in St. John’s city to identify different types of pavement distresses and document the level of severity for each distress type. Each road section of approximately 50 meters long was used for inspection and distress investigation. Major distresses such as rutting, fatigue cracking, block cracking, longitudinal cracking, transverse cracking, potholes, delamination and unevenness due to patching (patching related issues) were considered. Three levels of severity (low, moderate, high) were recorded to quantify the degree of distresses. If none of the distresses were found on the pavement, level of severity was indicated as “NO”.

Tables 3 to 5 present the severity levels of each distress for different roads in the city. In the case of presence of more than one level of severity of distress, the highest severity was taken into account. The severity levels are designated as “LOW” for low severity, “MOD” for moderate severity and “HIGH” for high severity.

Table 3: Severity levels for Newfoundland road and Elizabeth Avenue road

Sl. No.	Type of distress	Newfoundland road				Elizabeth Avenue road			
		Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4
1	Rutting	LOW	MOD	MOD	MOD	HIGH	HIGH	LOW	LOW
2	Block cracking	NO	NO	HIGH	MOD	LOW	NO	NO	NO
3	Fatigue cracking	MOD	LOW	MOD	MOD	MOD	MOD	NO	NO
4	Longitudinal cracking	LOW	NO	MOD	MOD	MOD	LOW	NO	NO
5	Transverse cracking	MOD	NO	NO	NO	NO	NO	NO	NO
7	Delamination	NO	YES	NO	NO	NO	NO	NO	NO
8	Potholes	NO	LOW	MOD	NO	LOW	MOD	NO	NO
9	Patching related issues	HIGH	HIGH	HIGH	HIGH	MOD	HIGH	NO	NO

Table 4: Severity levels for New cove road, Portugal road and Internal road at MUN

Sl. No.	Type of distress	New Cove road		Portugal road		Internal road at MUN		
		Section 1	Section 2	Section 1	Section 2	Section 1	Section 2	Section 3
1	Rutting	LOW	HIGH	LOW	LOW	LOW	MOD	LOW
2	Block cracking	NO	NO	MOD	NO	HIGH	MOD	MOD
3	Fatigue cracking	LOW	LOW	MOD	LOW	NO	MOD	LOW
4	Longitudinal cracking	LOW	MOD	LOW	NO	NO	LOW	NO
5	Transverse cracking	NO	NO	NO	NO	NO	NO	NO
7	Delamination	NO	NO	YES	YES	NO	NO	NO
8	Potholes	NO	NO	LOW	NO	HIGH	MOD	MOD
9	Patching related issues	HIGH	HIGH	MOD	HIGH	MOD	LOW	LOW

Table 5: Severity levels for Torbay road

Sl. No.	Type of distress	Torbay road			
		Section 1	Section 2	Section 3	Section 4
1	Rutting	MOD	MOD	HIGH	MOD
2	Block cracking	LOW	MOD	MOD	LOW
3	Fatigue cracking	LOW	NO	MOD	LOW
4	Longitudinal cracking	LOW	LOW	LOW	MOD
5	Transverse cracking	NO	NO	NO	NO
7	Delamination	NO	NO	NO	NO
8	Potholes	LOW	NO	NO	MOD
9	Patching related issues	HIGH	MOD	LOW	HIGH

4 DISCUSSION

Table 6 shows the dominant distress types in the selected roads of St. John's. The first two sections on Elizabeth Avenue were taken between Freshwater Road intersection and Portugal Cove Road intersection and the other sections were considered between Portugal Road intersection and the north-east end of Elizabeth Avenue.

Table 6: High severity distress types in different roads of St. John's city

Sl. No.	Distress type	Road
1	Rutting	Elizabeth Avenue & Torbay roads
2	Block cracking	Newfoundland road & MUN roads
3	Fatigue cracking	Newfoundland & Elizabeth Avenue roads
4	Longitudinal cracking	Newfoundland road
5	Transverse cracking	Not noticed
7	Delamination	Present only in Newfoundland and Portugal roads
8	Potholes	Internal road at MUN
9	Patching related issues (e.g., unevenness, crack formation)	Everywhere

It is evident from Table 6 that Elizabeth Avenue is highly damaged from Freshwater Road intersection to Portugal Cove Road intersection where both rutting and fatigue related cracking can frequently be observed. After Portugal Cove Road intersection, the road is in quite a good condition without any damage. Delamination was observed on Portugal Cove Road which might have occurred mainly due to longitudinal gradient and loss of adhesion between the HMA and base layers. Delamination was also noticed in the second section of the Newfoundland Road. Potholes were mainly observed in the internal roads of Memorial University. Primary reason for potholes is the high traffic loads due to the ongoing construction. On Newfoundland Road, 9 to 14-meter-long longitudinal cracks were observed. Transverse cracking was not noticed anywhere.

5 CONCLUSIONS

Every year pavement failures increase the cost of operation of roads and vehicle maintenance. In addition, drivers and passengers face major discomfort due to the poor condition of roads.

In this study, 19 sections, each 50 m in length, were surveyed for the purpose of determining the various distress types on the roads of St. John's city. On the basis of visual survey and measurements conducted, major distresses noticed are rutting, fatigue cracking, longitudinal cracking, transverse cracking, potholes and delamination. Rutting and patching are the primary causes of unevenness on the roads. In general, other distress types are also frequently observed during the survey. The intent of this phase of survey was to obtain a preliminary understanding of the conditions of roads in St. John's. Results from this study will be utilized to design a more systematic survey with an advanced data collection system.

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