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IMPACT OF FLOODING ON CONCRETE PAVEMENT PERFORMANCE

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Abstract: Pavement infrastructures have become vulnerable to damage as they were not designed to withstand the aggressions of extreme weather events such as flooding, induced by climate change. In Ontario, flooding tops the list of climate change hazards having a consequential impact on pavement performance. Rigid pavements are recorded to provide resilience to flood hazard in literature but knowledge about its behaviour and response to flood impact is currently scarce. The objective of this study is to investigate the impact of flood hazards on the performance of concrete pavement examining a case study of Jointed Plain Concrete Pavement (JPCP) road classes in Ontario. Subsequent to this, the Mechanistic-Empirical Pavement Design Guide (MEPDG) was employed to simulate JPCP performance under climate change using a conservative Representative Concentration Pathways (RCP) of 4.5W/m^2. Flood depth, duration and event cycles were used to define flood loading. Typical designs of JPCP collector and arterial road classes in the province were chosen and modelled. The result indicated lower damage ratios and loss of pavement life based on changes in faulting and International Roughness Index (IRI). Increases in flood frequency resulted in additional damages and loss of pavement performance and analysis showed that arterial pavement was more resilient to flood damage than collector pavements. The inference is that concrete pavements may not have their life shortened at lower cycles of extreme precipitation. However, at higher frequencies of extreme precipitation, damage may increase and resilience to flood hazards in JPCP pavement altered.

1 INTRODUCTION

Based on historical studies, climate is changing due to anthropogenic activities (IPCC 2013) thereby increasing the frequent occurrence of natural hazards. A number of infrastructural systems are being threatened by these hazards as they were not designed to cater for the extreme conditions brought about by climate change. Road, a critical infrastructure pivotal to socio-economic growth, is not exempted from this threat and has been declared susceptible to the impact of the changing climate (Schweikert *et al.* 2014). Therefore, given its importance, potential climate change impacts need to be addressed (Tighe 2015).

Natural hazards classified into hydrological, meteorological, geological, and biological hazards have increased over the years. In Ontario, hydrological hazards such as flooding is more pronounced as it tops the list of natural hazards in the province for over a century. Public Safety Canada and Environment Canada reported a total of 160 disasters occurring between the year 1900 to 2013, out of which flood hazard occurred 56 times amidst 12 other climate disasters recorded. (Nirupamaa N. and Sheybanib 2014, PSC 2014). This portrays flooding as a major threat and investigation into its possible impact on road infrastructure is pertinent.

Following the July 8, 2013 extreme precipitation of over 126 mm of rainfall which flooded major parts of the Toronto city, the Insurance Bureau of Canada evaluated socio-economic damages to be in the tune of $1 billion, describing the event as the most expensive natural disaster in the history of Toronto and Ontario (Environment Canada 2014). Similarly, a previous event washed out a portion of Finch Avenue in the same city on August 19, 2005. According to publication by Clean Air Partnership, predictions indicates increases in the frequency of these kind of events over the next 50 years (CAP 2006).

For pavement infrastructure, increased frequency in rainfalls may lead to pavement flooding and higher groundwater levels, causing soil erosion, slope instability, reduced pavement strength, and lowering of pavement's load bearing capacity. Furthermore, flooding and freezing rain are liable to cause safety hazards for the transportation sector, and potentially loss of pavement infrastructure. (Tighe 2015). Sequel to the vulnerability of pavements to flooding, interests have grown in the study of the impact of flood on road pavements especially flexible pavements, being cosmopolitan. Chen and Zhang (2014) assessed the performance of submerged pavements during the 2005 Hurricane Katrina and Rita in Louisiana, using before and after flood pavement management system data. Their study primarily reported slight increases in road roughness in both flexible and rigid surfaces as a result of the flood event. This increase was further intensified by debris-carrying heavy trucks traversing the submerged roadways immediately after the hurricane event. The inundation of the pavement weakened subgrade strength and could not sustain heavy vehicle load. Evaluation of pavements structural performance in terms of Deflection at the plate (D1), Effective Structural Number (SN_{eff}) and subgrade Resilient Modulus M_r of inundated pavements was done months after the same flood event to estimate structural damages. Loss of structural strength was recorded in both flexible and concrete pavements with AC suffering more damage and concrete pavements recording a diminutive loss in SN_{eff} strength and Mr after the hurricane event. (Gaspard *et al*. 2006).

With more emphasis on functional performance, Khan *et al.* (2014, 2017) explored the changes in International Roughness Index (IRI) of 34,000 km of Queensland roads inundated in the 2011 extreme flood event in Australia. Using before-flood and after-flood performance data to develop a new roughness and rutting-based road deterioration model, he reported that high strength rigid pavements provided the highest resilience to flooding and further proposed concrete pavement to be employed as a preflood strategy. This resiliency of concrete pavements can be further justified considering the response of Continuously Reinforced Concrete Pavement (CRCP) roads to flooding in the 2017 hurricane Harvey event (an over 1000mm storm which lasted for over four (4) days) in South East Texas and South West Louisiana. After the event, no major maintenance of CRCP roads was advised. The road pavement was open to traffic immediately after the water receded (Powell 2018). However, to properly articulate if there were damages, a damage evaluation is currently being executed to estimate after-flood pavement strength of all the roads submerged in the extreme event (TRB 2018).

The resiliency of concrete pavement to flood hazard is receiving attention amid the need for flood adaptation measures. Therefore, an intensive study to provide insight on its response to flood hazard is desired. In 2017, a Research Need Statement (RNS) was issued by the Transportation Research Board (TRB), under its Committee for Design and Rehabilitation of Concrete Pavements AFD50, on the impact of flooding and inundation on concrete pavement performance and an assessment of any modifications that could improve the resiliency of concrete pavements (Mack 2017).

This paper investigates the impact of flood hazards on concrete pavements performance using the AASHTOWare Mechanistic-Empirical Pavement Design Guide (MEPDG) modelling program. This modelling technique uses an Enhanced Integrated Climate Model (EICM) in its simulation of pavement performance and has been employed in previous studies relating to climate change hazards on flexible pavements. (Tighe *et al.* 2008, Mills *et al.* 2007, Meagher *et al.* 2012, Qiao 2015, Gudipudi *et al*. 2017, Lu *et al*. 2018a, Lu *et al*. 2018b). Therefore, specific analysis on the impact of flood hazard on rigid pavements using MEPDG simulation should be carried out, and this is presented in this paper. Typical arterial and collector Jointed Plain Concrete Pavement (JPCP) designs common to the province of Ontario were selected as case study.

2 OBJECTIVE

The aim of this study is to investigate the impact of flood hazard on concrete pavements performance. A case study, engaging the use of the Mechanistic-Empirical Pavement Design Guide (MEPDG), was further conducted to model the influence of extreme precipitation events on the performance of concrete pavement.

3 FLOODING OF CONCRETE PAVEMENT STRUCTURE

To properly evaluate flood impact on the concrete pavements, this paper takes the approach shown in Figure 1:

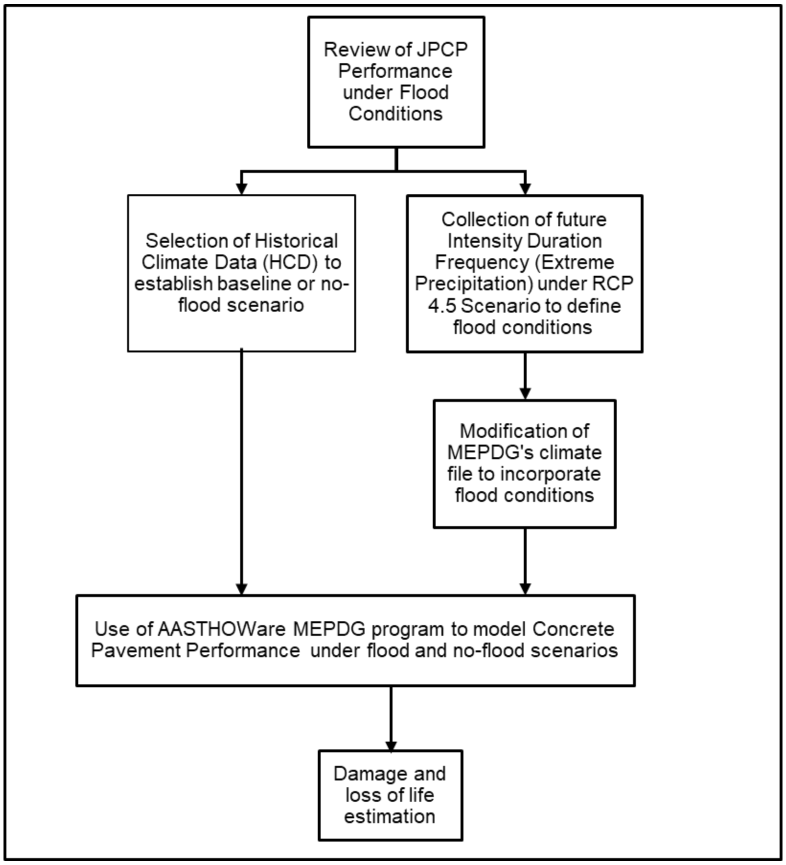


Figure 1: Methodological approach of evaluating flood impact on JPCP.

Concrete pavements can provide improved resistance to damage in the presence of excessive water due to the rigid nature of the structure. In his study, Zhang *et al.* (2008) reported that AC pavements had a Mr loss of subgrade and deflection of 20% and 46%, while concrete pavements had 1% Mr loss of subgrade and 9% deflection following Hurricane Katrina event. (Kahn *et al*. 2017). This reveals Portland Cement Concrete (PCC) pavement as being resilient to flooding, and a choice to be considered in flood plain areas. The resistance to flood damage in a dowelled and non-dowelled JPCP may have different magnitude. Resistance can be less, when compared to non-jointed PCC such as CRCP due to the presence of joints in JPCP, as concrete pavement structural failures can occur at the joints. Thus, result in the development of different failure patterns. Lu *et al.* (2018b) proposed four different pavement flood damage patterns namely delayed effect, jump effect, jump and delayed effect, and direct failure effect to describe the possible effect of flood impact. Flooded concrete can potentially experience pavement failure patterns depending on its level of resilience which is a function of traffic, pavement age, existing distresses, PCC pavement type, sub-layer support and structural strength. The MEPDG practically helps to integrate all these design variables for performance prediction hence the reason why it is employed to model flood performance in this paper. With regards to pavement type, CRCP is not as common as

JPCP in Ontario and as there are no MEPDG typical inputs for CRCP, it is difficult to estimate its flood resilience. Nevertheless, future research should be conducted to compare the flood performance of these two rigid pavement types.

Generally, the detrimental impact of flooding in pavement is more pronounced in the sublayers. Studies have shown that inundated roads experience 15 times more damage compared to a well-drained soil. (Yuan and Nazarian 2008) causing more deformation and loss of strength. Unbound sublayer soils tend to be at their weakest state during and after a flood event and heavy traffic loading such as those imposed by debris carrying trucks may permanently damage the pavement. Although the sublayer soils under the rigid pavement offers no structural strength, it may lose its ability to provide a uniform foundation to the PCC slab under flood conditions. Floods of high velocity can entirely erode the base and subgrade layer of the PCC leaving no sublayer support. In some cases, flood may carry large boulders, rocks and other heavy matter known as flood debris to collide with PCC pavements at high speeds, leading to collapse, large spalls, massive edge breaks and in some cases, entire damage of the concrete pavement. It could be difficult to quantify the extent of these loadings due to the dynamic nature of flooding which can be characterized by flood velocity, flood debris and hydrogeological conditions. Inundation is typically considered when evaluating flood impact, as it basically describes flood depth and duration. Flood loading types are further highlighted under the flood modelling section of this paper.

4 FLOOD INDUCED DISTRESSES IN JPCP

4.1 Pumping and joint faulting

Unbound underlying soils are not uncommon to JPCP and inundation of these layers combined with the action of fast moving traffic may increase the hydraulic pressure under the JPCP slab, pushing underlying fine materials into PCC joints or underneath the adjacent slab at the joint in a process referred to as pumping. Soil depletion under the slab may initiate large voids and lead to the depression of one adjacent PCC slab to another, initiating the development of faulting distresses. Joint faulting is described as the difference in elevation between adjacent joints at a transverse joint (ARA 2004b). As flooding surges moisture in the unbound underlying layer, difference in joint elevation would likely increase due to traffic loading, hence the reduction in JPCP performance. .

4.2 Warping

After an extreme precipitation event and water is allowed to drain, a moisture gradient will most likely develop in the slab, increasing from top to bottom. Concrete pavements are sensitive to volumetric changes in the presence of moisture and temperature. Therefore, tensile stresses develop in a PCC slab with moisture gradient, causing movements that deflect the slab along its edges compared to the middle in a distress known as warping. As shown in Figure 2, downward curvature and upward curvature or warping is as a result of negative and positive moisture gradient respectively (FHWA Techbrief 2015). Increased frequency of flood event may potentiallty worsen this situation by instigating higher groundwater tables and longer drainage days (Daniel *et al.* 2014). Hence, limit the service life and smoothness of the PCC pavement. This is indicative based on a seventeen (17) year study of the LTPP SPS-2 site. Analysis of the study revealed that long-term increases in slab curvature is more associated with moisture-induced warping as it independently increased IRI by an average of 0.58m/km with no other distress observed. (Karamihas and Senn 2012). Therefore, one could infer that increases in flood events, which potentially heightens water table, may in the long-term increase roughness and reduce pavement functional performance

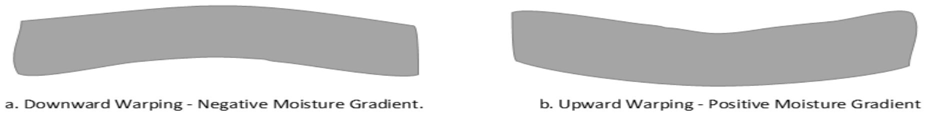

a. Downward Warping - Negative Moisture Gradient.
b. Upward Warping - Positive Moisture Gradient

Figure 2: Moisture warping in JPCP

5 FLOOD PERFORMANCE MODELLING FOR JPCP

The Based on the types of flood load considered, performance modelling of pavement under flood conditions could be complex. Flood loads such as flood depth, flood duration, flood velocity, flood debris and contaminants (van de Lindt *et al*. 2009) all have a damaging impact on pavement, but a modelling method to integrate all these stressors is yet to exist. However, extreme precipitation in the form of flood depth could be used to properly describe flood potential (Lu *et al*. 2018a). Certain modelling programs have tried to incorporate hydrological conditions in rigid pavement design. An instance is the ACPA PerviousPave program strictly for pervious concrete pavements. (ACPA 2010).

To model extreme precipitation on conventional concrete pavement, the use of the MEPDG which combines the Enhanced Integrated Climate Model (EICM) and other design parameters to predict performance indicators such as faulting, fatigue cracking, spalling and roughness under extreme precipitation is reasonable. The MEPDG can assess the impact of pavement structure, material characteristics, traffic loads and change in incremental and terminal pavement deterioration and performance (ARA 2004a cited Tighe 2015). EICM in MEPDG consists of Temperature, Relative Humidity, Precipitation, Wind, and Sunshine. Thus, to incorporate flooding, precipitation data could be modified to account for extreme precipitation scenarios. The AASHTOWare ME Design version 2.5.3. was employed to model these flood scenarios and event frequency on typical arterial and collector JPCP roads in the province of Ontario.

6 CLIMATE DATA

6.1 Historical data

Hourly Climate Data (HCD) files of the North American Regional Reanalysis (NARR) data were accessed via the open-source AASTHO M-E design database (AASHTOWare Pavement ME Design Climatic Data) for two climate stations in Toronto. These two stations were then synchronized to create a virtual station as shown in Table 1, interpolating climate data for the area under consideration. This interpolated climate data was harnessed in the MEPDG program for pavement performance prediction. With the recent calibration of the MEPDG to use the Modern-Era Retrospective Analysis for Research and Applications (MERRA) climate data, developed by the National Aeronautics and Space Administration (NASA) in its flexible pavement analysis (ARA 2018), an upgrade from NARR to MERRA for rigid pavements will be evident in the nearest future. Translating to better performance predictions from historical climate data. NARR's historical data was integrated into the program to establish a base-case or no-flooding scenario.

Table 1: Climate data input for collector and arterial pavement

	Climate station	Latitude	Longitude	Elevation
Collector	Virtual station: Toronto_NARR_GRID(94791); Toronto_NARR_GRID (54753)	43.67	-79.63	173.43
Major Arterial		43.86	-79.37	198.12

6.2 Future Climate Data

Future climate models were employed to evaluate future flood cases as a result of climate change under a Representative Concentration Pathways (RCP) with a radiative forcing of 4.5 watts per metre square (W/m^2). Radiative forcing is the additional energy absorbed by the earth due to increases in the effect of greenhouse gases, while RCPs are time and space dependent trajectories of greenhouse gas concentration resulting from anthropogenic activities. There are other radiative forcing values associated with possible RCP scenarios such as RCP 2.6 W/m^2, RCP 6.0 W/m^2 and RCP 8.5 W/m^2. However, RCP 4.5 scenario is assumed to be more realistic and conservative considering that greenhouse gas concentrations will peak in the year 2040 and afterwards decline (Meinshausen *et al.* 2011) following the intensity of greenhouse gas mitigation and policy changes embarked upon by concerned stakeholders and government institutions in Canada. Also, knowing that the design life of the JPCP pavement classes used as case study ends by year 2043, the extremities of RCP 4.5 climate scenario which may likely peak in

2040 would therefore reflect in the pavement analysis. In all, it should be noted that the purpose of using this scenario is not to predict the future, but to explore scientific and real-world implications of different plausible futures. (Bjørnæs 2013)

The precipitation scenario under RCP 4.5 scenario was obtained using the Intensity Duration Frequency Climate Change Tool (IDF_CC Tool 3.0). The IDF_CC tool is an open source information which estimates precipitation accumulation depths for a variety of return periods (2, 5, 10, 25, 50 and 100 years) and durations (5, 10, 15 and 30 minutes and 1, 2, 6, 12 and 24 hours) for the Canadian environment. The tool engages 24 Global Circulation Models (GCMs) and 9 downscaled GCMs using rigorous downscaling method such as spatial and temporal downscaling, statistical analysis and optimization to update pre-estimated IDF from historical precipitation data (Simonovic et al., 2016) to IDF under RCP scenarios. The idea is to identify future local extreme precipitation data for a specific location from repositories of Global Circulation Models (GCM) and Regional Circulation Models (RCM) using climate forcing scenarios as inputs.

By means of these models, mean future extreme precipitation values of the distribution of results produced by each of the GCMs were obtained for future return floods of 50-years and 100-years under RCP 4.5 scenario. Precipitation values obtained were 151.94 mm and 168.84 mm respectively as shown in Table 2 for the future return years. Considering the flood event of July 8th, 2013 in Toronto, MEPDG's integrated climate file was modified to include future return floods under RCP 4.5 starting on this date. A 7-day flood duration was assumed based on a previous study by Gaspard *et al.* (2006) who reported that flooding durations beyond seven (7) days did not cause additional damage on inundated pavements during the Hurricane Katrina event. Whereas, a recent study has identified increases in damage of Asphalt Concrete (AC) pavements due to increase in extreme precipitation cycles (Lu. *et al.* 2018b). Hence, considerations were both given to flood duration and event cycle (one, two and three) alongside precipitation depth to properly define flood scenario. Datasets of other climate parameters such as temperature, wind, relative density and sunshine were sourced from the historical data of the virtual climate station for the year 2012/2013.

Table 2: Return flood under RCP 4.5 climate change scenario

Location (Lat, Long)	Duration	RCP 4.5 50-year	RCP 4.5 100-year
(43.81174, -79.41639)	24hr	151.94mm	168.84mm

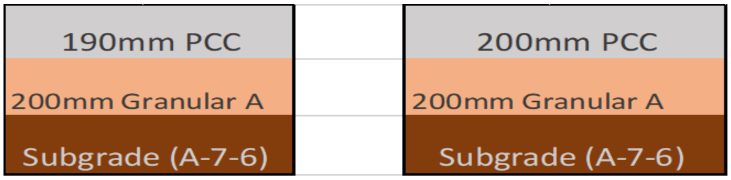
7 CONCRETE PAVEMENT DESIGN

Typical arterial and collector JPCP road designs and MEPDG inputs common to Ontario were obtained from the Ontario Pavement Structural Design Matrix for Municipal Roadways document prepared by Applied Research Associates (ARA 2011a, ARA 2011b). Table 3 shows JPCP design inputs and Figure 3, the cross-section of the pavement classes. Pavement performance is then predicted using historical, and future climate data under RCP 4.5.

Table 3: Typical Ontario JPCP pavement design inputs (ARA 2011a, ARA 2011b)

	Design Parameters	Collector	Arterial
Traffic inputs	Two-way AADTT	500	5000
	Truck traffic in design lane	90%	90%
	No. of lanes in design direction	2	2
	% of trucks in design direction	50%	50%
	Reliability	75%	90%

Concrete slab properties	Dowel diameter(mm)	**No Dowel**	**Dowelled** (32mm)
	Slab length	4.0m	4.5m
	Tied shoulder/curb	Tied	Tied
	Load transfer efficiency	70%	70%
Performance trigger values	International Roughness Index (IRI)	2.70m/km	2.70m/km
	Mean joint faulting	3.00mm	3.00mm
	JPCP traverse cracking	20%	10%
	Design life	25years	25years



(a) Collector Design (b) Arterial Design

Figure 3: Typical collector and arterial JPCP pavement design in Ontario

8 CASE STUDY - FLOOD IMPACT ON ARTERIAL AND COLLECTOR ROADS IN ONTARIO

Analysis of performance under flooding conditions indicated changes in faulting and IRI values. IRI change is more preferred in describing damage as it is a function of faulting distresses. Nevertheless, damage was calculated for both performance indicators to show how each responded to flood impact in form of damage ratio. Damage ratio is the percentage (%) change in terminal IRI of a flooded pavement, and a non-flooded pavement divided by the non-flooded pavement terminal IRI or for a given design life.

Table 4. Damage ratios under RCP 4.5 respect to IRI

		Damage ratios under RCP 4.5 due to IRI change	
Pavement	Event	50-year Flood	100-year Flood
Collector	1-cycle	2.22%	2.22%
	2-cycle	2.22%	2.22%
	3-cycle	2.50%	5.56%
Arterial	1-cycle	1.06%	1.86%
	2-cycle	1.59%	2.39%
	3-cycle	2.92%	2.92%

As shown in Table 4, a 7-day extreme event was regarded as one-cycle EP event for each 50-year and 100-year return flood under RCP 4.5. This event was further repeated to make second and third cycles. At one-event cycle, damage ratio of 2.22% was the same across return floods of 50 and 100 years for collector pavement. This demonstrates that a higher return period of 100-year EP may have the same damage effect as a 50-year event in a JPCP at lower cycles of EP. The opposite is the case for arterial JPCP as there was an increase in damage ratio from 1.06 % to 1.86%. Still, the magnitude of damage was less, when compared to a collector JPCP at one-event cycle of extreme precipitation. Lesser damage in arterial pavement may be due to the presence of dowels at its joints compared to a no-dowel collector pavement design. Also, there was a 9.2% damage to faulting in collector pavements and this was same across return periods as shown in Table 5.

Table 5: Damage ratios under RCP 4.5 respect to faulting

Pavement type	Event	Damage ratios due to change in joint faulting 50 -year	 100-year
Collector	1-cycle	9.20%	9.20%
	2-cycle	9.70%	9.70%
	3-cycle	9.95%	30.60%
Arterial	1-cycle	5.39%	4.17%
	2-cycle	4.90%	4.41%
	3-cycle	7.11%	4.41%

At two-cycle event, damage ratios in collector pavements remained the same as a one-cycle event, no further damage beyond 2.22% was estimated for both 50 and 100-year EP event as shown in Figure 4. Increase in cycle event did not cause any increase in damages. Even though Arterial JPCP experienced a lower damage magnitude compared to collector JPCP, there was an increase in damage across return periods that is from 1.59% to 2.39% for 50 and 100 years respectively as shown in Figure 5. Collector faulting damage also increased from 9.2% to 9.7% and remained same across return flood years (50 &100).

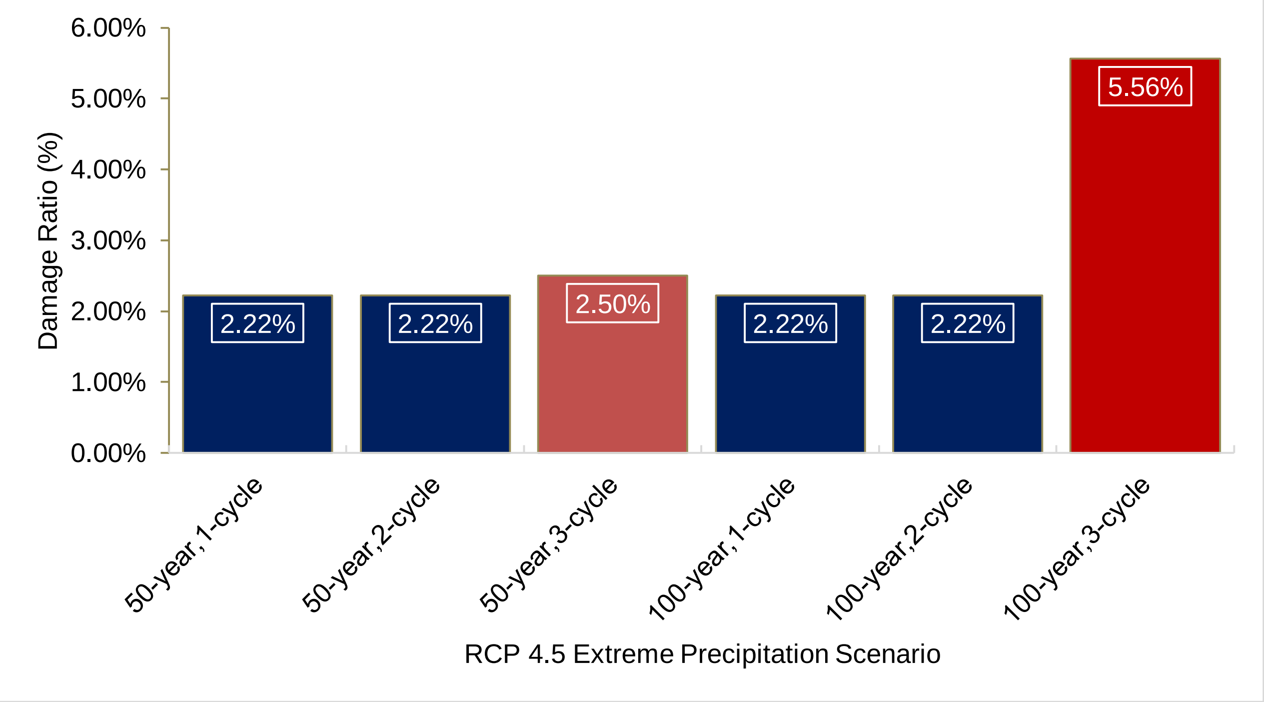


Figure 4: Damage ratio (%) against return flood (years) of JPCP Collector pavement under RCP 4.5 climate change scenario

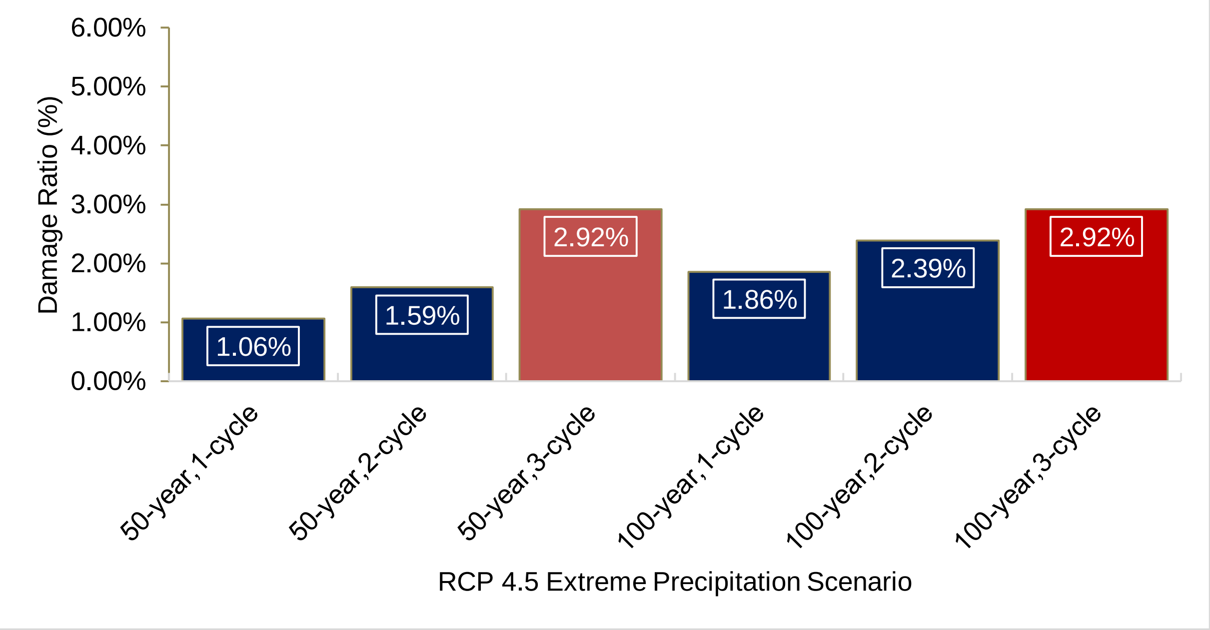


Figure 5: Damage ratio (%) against return flood (years) of JPCP Arterial pavement under RCP 4.5 climate change scenario

At three-event cycle, an increase in damage ratio was noted across RCP return floods in the collector pavement. Increase in the number of cycles (two-cycle to three-cycle) resulted into slight increase for the 50-year flood (from 2.22% to 2.5%) and larger increases for the 100-year EP (2.22% to 5.56%) as shown in Figure 4. This sharp augment in damages was due to the faulting damages at three-cycle which increased from 9.70% to 30.60% as shown in Table 5. This holistically shows the influence of flooding on inducing faulting failure in non-dowelled JPCP pavements. Also, at three-cycle, arterial pavement damage increased from 1.59% to 2.92% and 2.39% to 2.92% under a 50-year EP and 100-year EP event respectively.

9 REDUCTION IN PAVEMENT LIFE

In reference to damage sustained by the Ontario JPCP road classes, loss of pavement life was estimated by comparing terminal IRI of the road classes at base-case or no-flood scenario with RCP 4.5 IDF extreme precipitation or flood scenarios. Table 6 shows the pavement life loss in days. Considering the 25 years design life, pavement life loss is higher in collector compared to arterial pavements, peaking at 507 days to 266 days respectively after three-cycle extreme precipitation. Increase in the event cycles resulted in more loss of pavement life in the pavement classes.

Table 6: Reduction in design life under RCP 4.5

		(Design life of 25 years)	
JPCP Pavement	Event Cycle	50-year Return Period (days)	100-year Return Period (days)
Collector	1	203	203
	2	203	203
	3	228	507
Arterial	1	97	169
	2	145	218
	3	266	266

10 CONCLUSION

In this study, a review of flood impact on pavement and analysis of flood-induced distresses on JPCP pavements were conducted. The performance of Ontario JPCP concrete pavement classes was then assessed under flooded and no-flooding conditions using the AASTHO Ware MEPDG 2.5.3 tool. Extreme precipitation values of predicted Intensity Duration Frequency (IDF) obtained under RCP 4.5 climate change scenarios were used to modify the MEPDG climate file to evaluate performance under flood condition, while historical climate data estimated performance for no-flood conditions also regarded as base-case scenario. Extreme precipitation depth, event cycles, and flood duration were variables used in the analysis. MEPDG representative JPCP collector and arterial pavement designs for Ontario were selected for a case study and extreme cases of traffic and environmental loading, in terms of precipitation, were modelled on these pavements. Overall, a total of 48 simulations was completed and changes in IRI and faulting performance values were utilized to estimate damage ratios (%). Below are conclusions drawn from pavement performance under base-case and RCP 4.5 precipitation scenario:

- JPCP pavement may provide high resilience to flood impact at lower cycles of extreme precipitation but its resilience could reduce at higher cycles of extreme precipitation under RCP 4.5.
- Extreme Precipitation (EP) under RCP 4.5 scenario slightly reduced pavement performance in both collector and arterial pavements.
- Increase in extreme precipitation cycles under RCP 4.5 caused additional damage and loss of pavement life, but magnitude varied depending on pavement classes.
- Inundation contributed to damage in both dowelled (arterial) and non-dowelled (collector) JPCP pavement but loss of pavement life was lesser in doweled than non-dowelled JPCP

Improvement is needed to develop programs that model flood velocity and flood debris as the impact of these stressors could be more catastrophic that the ones considered in this analysis. Similarly, intentions to upgrade from the use of NARR to MERRA historical climate data for rigid pavement analysis may result in more accurate estimation of pavement performance. This paper recognizes that there are uncertainties in climate projections and has conducted this research to provide insight into implications of flood hazards on concrete pavement due to climate change.

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