Bridge Corrosion

A Chloride Exposure Prediction Model for Bridges in Ontario

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The problem: chloride-induced corrosion

- Reinforced Concrete
- Deicing salts(NaCl)
  - Climate
    → snow
  - Traffic
    → dissolved chloride ions

Existing Paper & Collaboration

- Dr. Cancan Yang and Ph.D. candidate Mingsai Xu from the Department of Civil Engineering at McMaster University
- Hanmin Wang, Ravi Ranade & Pinar Okumus (2023) Estimating chloride exposure of reinforced concrete bridges using vehicle spray and splash mechanisms, Structure and Infrastructure Engineering, 19:11, 1676-1686, DOI: 10.1080/15732479.2022.2052910

Goal Statement

- This project should return a predictive model indicating corrosion trends based on location information.
- This project should ensure its applicability to all locations within Ontario.
- This project should provide trends for locations nearest to the input if exact data is unavailable.
- This project should extends the forecasted trend period to a minimum of five years
- This project should incorporates calculated data from previous years for comparison with real-world observations, verify the accuracy of the model.

Input & Output

Coordinate

- Locations inside Ontario
- (x,y) where x is longitude and y is latitude
- Float

Example:

- Input: 43.1, -79.3
- Output: [4.69, 4.92, 7.48, 6.00, 5.10]

Predictive model

- The likelihood of corrosion in bridges at the provided coordinates.
- Measured by the amount of chloride for every cubic meter
- A series of data

Assumption

- The deicing salt used is NaCl.
- The amount of deicing salts applied on the road is same for every snowfall.
- The melted water thickness is same for every snowfall.
- The speed for every vehicle reaches the highway speed limit.
- Bridges within the same classification has same annual average daily traffic

Procedures

1. Amount of deicing salts applied per day with snowfall
2. Thickness of melted water on the ground
3. Water sprayed and splashed by one truck
4. Chloride sprayed and splashed by one truck
5. Chloride sprayed and splashed by all vehicle
6. Chloride on the surface of bridge substructure

Theoretical Models - determining the amount of water sprayed and splashed by one truck

- Four primary mechanisms of vehicle spray and splash: capillary adhesion, tread pickup, bow wave, side wave. Total amount of water = sum of the four
- Computational fluid dynamics & regression analysis (Flintsch et al. (2014))
- $MR_w = V \cdot b \cdot WD \cdot \rho_{water}$

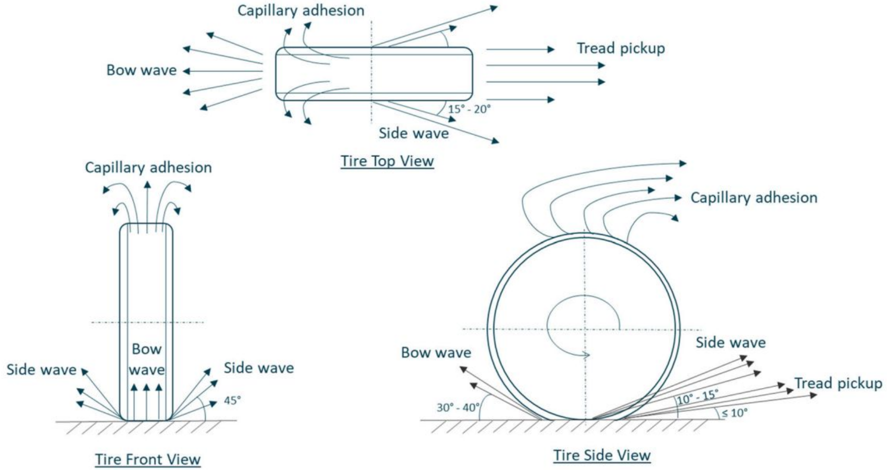

Figure 1. Mechanisms of vehicle spray and splash (adapted from Weir et al. (1978)).

Symbols

symbol	unit	description
V_{speed}	km/h	heavy vehicle speed
V	$miles/h$	heavy vehicle speed
b	m	tire width
WD	m	water depth/thickness
K	m	ratio of the tire width that is not a groove to the tire width
h_{film}	m	depth of the water film picked up in each rotation
ρ_{water}	kg/m^3	density of water
h_{app}	m	daily water film thickness on the road
MR_{CA}	kg/s	amount of water displaced by a single tire due to capillary adhesion
MR_{TP}	kg/s	amount of water displaced by a single tire due to tread pickup
MR_{BW}	kg/s	amount of water displaced by a single tire due to bow
MR_{SW}	kg/s	amount of water displaced by a single tire due to side waves
SD_{CA}	kg/m^3	amount of water in 1 m^3 volume of air by a single tire due to capillary adhesion
SD_{TP}	kg/m^3	amount of water in 1 m^3 volume of air by a single tire due to tread pickup
SD_{BW}	kg/m^3	amount of water in 1 m^3 volume of air by a single tire due to bow
SD_{SW}	kg/m^3	amount of water in 1 m^3 volume of air by a single tire due to side waves
SD_{total}	kg/m^3	mass of water per unit air volume kicked up by each passing truck

Instance Models - Mass Flow Rate

Capillary adhesion: $MR_{CA} = V_{speed} \times b \times K \times h_{film} \times \rho_{water}$

Tread pickup: $MR_{TP} = V_{speed} \times b \times (1 - K) \times h_{app} \times \rho_{water}$

Bow and side waves:

$$MR_{BW} = MR_{SW} = 0.5 \times V_{speed} \times b \times \left(h_{app} - K \times h_{film} - (1 - K) \times h_{app}\right) \times \rho_{water}$$

Instance Models - Spray Density

Capillary adhesion: $SD_{CA} = (-2.69 \times 10^{-5} \times V + 2.43 \times 10^{-3}) \times MR_{CA}$

Tread pickup: $SD_{TP} = (1.16 \times 10^{-5} \times V - 5.25 \times 10^{-5})MR_{TP}$

Bow: $SD_{BW} = (2.67 \times 10^{-5} \times V - 4.71 \times 10^{-4})MR_{BW}$

Side waves: $SD_{SW} = (1.65 \times 10^{-5} \times V - 3.99 \times 10^{-4})MR_{SW}$

Instance Models

Mass of water per unit air volume kicked up by each passing truck:

$$SD_{total} = SD_{CA} + SD_{TP} + SD_{BW} + SD_{SW}$$

Other Model

- One truck → all vehicle over a year
- CanRCM4 regional climate model: https://climate-modelling.canada.ca/climatemodeldata/canrcm/CanRCM4/
- AASHTOWare Pavement ME Design Traffic Map: https://icorridor-mto-on-ca.hub.arcgis.com/apps/50798e771bd0440dbc96fd85d8fde9a5/explore

Stakeholders

- Governments
- Researchers
- Developers

Reference

- Du, Y. G., Clark, L. A., and Chan, A. H. C. 2005. “Effect of corrosion on ductility of reinforcing bars.” Magazine of Concrete Research, 57(7): 407-419.
- Guo, T., Sause, R., Frangopol, D. M., and Li, A. 2011. “Time-dependent reliability of PSC box girder bridge considering creep, shrinkage, and corrosion.” Journal of Bridge Engineering, 16(1): 29-43.
- Tang, L., and Utgenannt, P. 2007. Chloride ingress and reinforcement corrosion in concrete under de-icing highway environment-a study after 10 years’ field exposure. Sweden: SP Technical Research institute of Sweden.
- Lindvall, A. 2001. Environmental actions and response – Reinforced concrete structures exposed in road and marine environments (MSc Thesis). Chalmers University of Technology, Gothenburg, Sweden.
- Lindvall, A. 2003. Environmental actions on concrete exposed in marine and road environments and its response–Consequences for the initiation of chloride induced reinforcement corrosion (PhD dissertation). Chalmers University of Technology, Gothenburg, Sweden.
- Flintsch, G. W., Tang, L., Katicha, S. W., de Leon Izeppi, E., Viner, H., Dunford, A., ... Gibbons, R. B. (2014). Splash and spray assessment tool development program. Washington, D.C.: Federal Highway Administration.
- Weir, D. H., Strange, J. F., and Heffley, R. K. 1978. Reduction of adverse aerodynamic effects of large trucks, Volume I. Technical report (No. FHWA-RD-79-84). United States. Federal Highway Administration

Questions?