Baby It's Cold Outside (for Your Concrete Bridge)

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Figure 1. Concrete surface with severe salt scaling caused by use of deicers. All Figures and Photos: Kyle A. Riding.

You have likely seen the signs that say "Bridge ices before road" near bridges. These signs serve to warn drivers of the potential danger ahead caused by black ice that is difficult to see. Clear pavements can lull drivers into thinking the roadway is free of ice before they drive over the bridge and its hidden dangers. To help mitigate this unseen danger, bridges can be heavily salted with rock salt or, in recent years, with concentrated brines that keep the roads clear of ice.

Just as it does for drivers, cold, wet weather poses hidden dangers for bridge structures and their owners. Most civil engineers are aware of the danger of damage to concrete bridges caused by freezing and thawing, and know that air entrainment is used in concrete as a mitigation measure for this hazard. It is less well known, however, that deicing salts can exacerbate damage from freezing and thawing and can cause two other types of deterioration, namely, salt scaling and calcium oxychloride formation.

Salt Scaling

Deicing salt scaling causes progressive flaking of the concrete surface, leading to a rough ride. Mild salt scaling can resemble an exposed aggregate finish, whereas more severe scaling such as that shown in **Fig. 1** can be more problematic for bridge durability. Saltwater can pond in the scaled areas, leading to further scaling damage and increased chloride penetration. Deicing salt scaling can occur on bridge decks, vertical surfaces of parapet walls or columns where water with deicing chemicals is splashed, or on bent caps below leaky joints. Like sodium chloride and calcium chloride deicers, magnesium chloride deicers can contribute to deicing salt scaling. Magnesium chloride salts also react chemically with the glue holding the concrete together, the calcium silicate hydrate, resulting in rapid deterioration.

Preventing Salt Scaling

Salt scaling occurs in bridges where the concrete near the surface has low strength or a bad air-void system. Air entrainment should be used and measured during construction. Low water–cementitious material ratios (*w/cm*) below 0.45, curing with either curing compound or extended wet curing, and good finishing practices have been shown to improve salt scaling resistance by improving the concrete surface strength.[1–4] Retempering concrete by adding water on the jobsite has been associated with some cases of salt scaling damage and should be avoided.[5] There has been a concern that high dosages of supplementary cementitious materials (SCMs) increase salt scaling damage; however, field studies have shown that concrete containing SCMs can do well in the field if it is well cured and not overworked during finishing, and not finished while there is still bleed water on the surface.[3,4] Machine-finished concrete tends to do better than hand finished concrete because more-aggressive finishing with multiple passes with a float, which often occurs with hand finishing, tends to coalesce air bubbles at the surface, causing a bad air-void system.[4]

Calcium Oxychloride Formation

Calcium oxychloride formation causes joint deterioration in concrete pavements in cold regions of the United States; see **Fig. 2** for an example of a joint in the early stages of deterioration. Calcium oxychloride forms when chlorides from deicing salts react chemically with calcium hydroxide and water, which can result in large expansion, cracking, and deterioration.[6] Calcium oxychloride formation increases with salt concentration and as the temperature drops below 40°F.[7] Calcium chloride deicing salts are the most destructive, followed by magnesium chloride salts, with sodium chloride showing only a mild risk.[6] Many salt suppliers use impure salts or add calcium chloride or magnesium chloride to salt to lower the ice melting temperature below that of sodium chloride.[8]

Figure 2. A concrete joint in the early stages of joint deterioration. A straight edge is used to show the expansion in the concrete near the joint caused by calcium oxychloride formation.

Instances of joint deterioration have significantly increased in the past 15 years because agencies have started to apply concentrated liquid salt brines before storms as an anti-icing treatment, which allows the dry concrete to absorb the saltwater. Joints, areas near drains, and the cold joint between the parapet wall and the deck are especially vulnerable to problems because saltwater can pond in these locations and concentrate when the water evaporates. Salts that penetrate the concrete are also hygroscopic (that is, they tend to absorb moisture from their surroundings), which causes the joints to dry at a much slower rate. Because concrete cold-weather related deterioration involves moisture, these locations that stay wet longer experience more deterioration than areas that dry faster.

Reducing Calcium Oxychloride Damage

If temperatures are not too far below freezing, the best way to reduce joint deterioration on bridges is to not use deicing salts that contain calcium chloride or magnesium chloride. Calcium oxychloride formation requires the presence of a chloride-containing salt and calcium hydroxide. Good drainage, joint sealant maintenance, use of concrete sealers such as soy methyl ester polystyrene blends, low *w/cm*, and SCMs help keep salts out of the concrete.[9] SCMs reduce the amount of calcium hydroxide available to form calcium oxychloride through dilution of the portland cement and the pozzolanic reaction. Use of Class F fly ash (ASTM C618[10]), slag (ASTM C989[11]), or metakaolin (ASTM C618[10]) as cementitious materials with portland cement replacement rates of 35%, 35%, and 12%, respectively, is needed to minimize joint deterioration damage.[12] For hand-finished concrete where there is a concern about using more than 25% fly ash, a ternary blend could be used.[1]

Figure 3. Proposed signage **during** *concrete bridge construction. When proper materials are used along with proper construction practices, damage caused by freezing and thawing, salt scaling, and calcium oxychloride is mitigated.*

Summary

Concrete bridges in cold climates can be very resistant to damage caused by freezing and thawing, salt scaling, and calcium oxychloride formation when proper materials are used along with proper construction and maintenance practices. Recommended construction practices include avoiding retempering or overfinishing the concrete, as well as using air entrainment, a *w/cm* below 0.45, SCMs to reduce permeability and calcium hydroxide content in concrete, and sealers in areas of concern like joints and around drains. To remind everyone involved in bridge construction about material needs and practices to prevent damage, I think we should consider installing signs that state "Bridge ices before road," when construction projects begin, instead of at completion, and we should add the new sign proposed in **Fig. 3**.

References

1. American Concrete Institute (ACI) Committee 318. 2019. *Building Code Requirements for Structural Concrete* (ACI 318-19) *and Commentary* (ACI 318R-19). Farmington Hills, MI: ACI.
2. Bortz, B. S., and K. A. Riding. 2013. "Effects of Curing and Test Conditions on the Salt Scaling Durability of Fly Ash Concrete." *Advances in Civil Engineering Materials* 2 (1): 551–565.
3. Amini, K. 2018. "Toward Salt-Scaling Resistant Concrete." PhD dissertation. Ames: Iowa State University.
4. ACI Subcommittee 201. 2016. *Guide to Durable Concrete*. ACI 201.2-16. Farmington Hills, MI: ACI.
5. Schlorholtz, S., and R. D. Hooton. 2008. *Deicer Scaling Resistance of Concrete Pavements, Bridge Decks, and Other Structures Containing Slag Cement: Phase 1: Site Selection and Analysis of Field Cores*. Ames: National Concrete Pavement Technology Center, Iowa State University. https://intrans.iastate.edu/app/uploads/2018/03/schlorholtz_deicing_phase1.pdf
6. Suraneni, P., V. J. Azad, O. B. Isgor, and W. J. Weiss. 2016. "Calcium Oxychloride Formation in Pastes Containing Supplementary Cementitious Materials: Thoughts on the Role of Cement and Supplementary Cementitious Materials Reactivity." *RILEM Technical Letters* 1: 24–30.
7. Qiao, C., P. Suraneni, and J. Weiss. 2018. "Flexural Strength Reduction of Cement Pastes Exposed to $CaCl_2$ Solutions." *Cement and Concrete Composites* 86: 297–305.
8. Riding, K. A., J. Varner, and C. Armstrong. 2016. *Influence of Rock Salt Impurities on Limestone Aggregate Durability*. Report no. K-TRAN: KSU-12-6. Topeka: Kansas Department of Transportation. https://rosap.ntl.bts.gov/view/dot/31029
9. Wiese, A., Y. Farnam, W. Jones, P. Imbrock, B. Tao, and W. J. Weiss. 2015. *Evaluation of Sealers and Waterproofers for Extending the Life Cycle of Concrete*. Joint Transportation Research Program publication no. FHWA/IN/JTRP-2015/17. West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316002
10. ASTM International. 2019. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. ASTM C618-19. West Conshohocken, PA: ASTM International.
11. ASTM International. 2018. *Standard Specification for Slag Cement for Use in Concrete and Mortars*. ASTM C989-18a. West Conshohocken, PA: ASTM International.
12. Suraneni, P., V. J. Azad, O. B. Isgor, and J. Weiss. 2018. "Role of Supplementary Cementitious Material Type in the Mitigation of Calcium Oxychloride Formation in Cementitious Pastes." *Journal of Materials in Civil Engineering* 30 (10): 1–10.

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