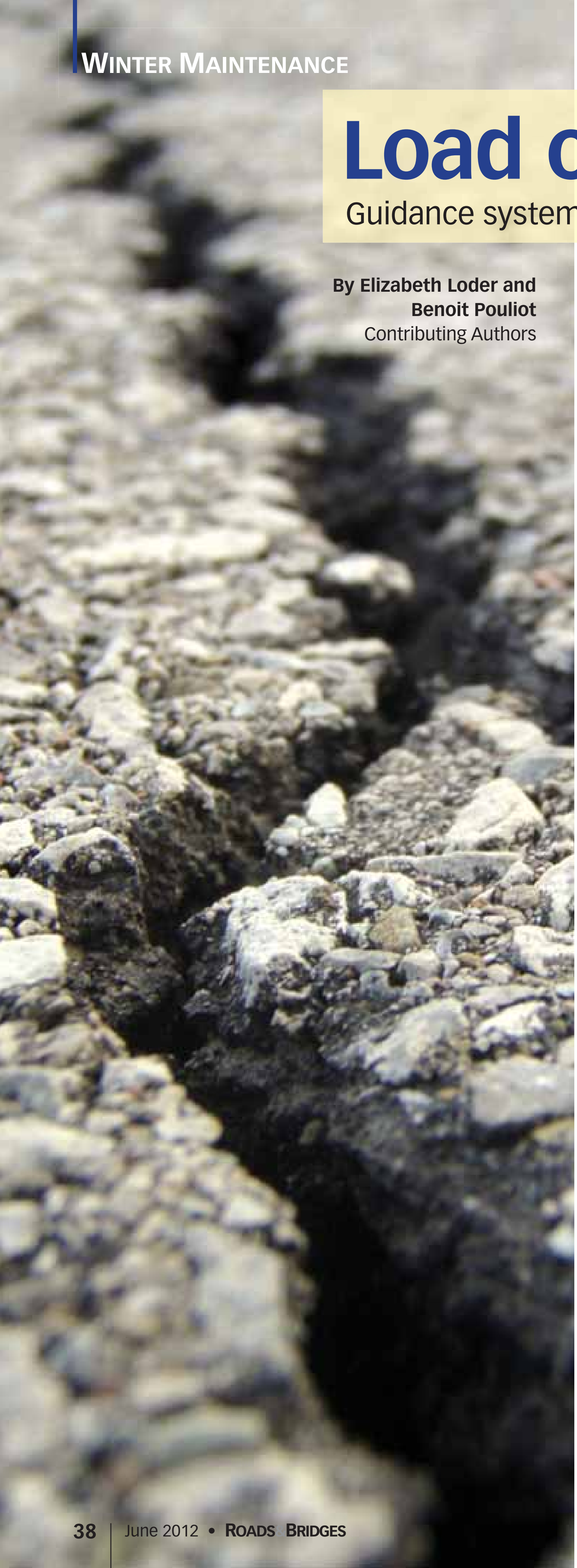

Load of help

Guidance system helps fight frost heave in pavements

By Elizabeth Loder and
Benoit Pouliot
Contributing Authors

One of the largest challenges for departments of transportation (DOTs) is the wear and tear that industrial traffic imposes on the roadway pavement.

Road infrastructure must endure a relatively constant flow of heavy vehicles, while the subsurface conditions below the pavement change with the seasons. Pavement strength is highly dependent on the strength of the roadbed beneath it, and the roadbed strength in turn is highly dependent on the temperature and moisture properties.

Heavy traffic during the spring thaw causes faster degradation of the pavement and leads to increased maintenance fees. To reduce the damage, many jurisdictions implement spring load restrictions for heavy traffic. Given that conditions often veer from climatology, imposing load restrictions at fixed dates every year is not optimal. If restrictions are imposed too late, it can lead to increased road damage. If restrictions are put into place too early, it translates to increased costs to the transportation industry. There is a need to balance the mandate of the DOTs to protect their infrastructure investment with the mandate of the trucking industry to maximize their weight per axle.

AMEC has developed an objective guidance system to help Canadian DOTs in Nova Scotia and the Northwest Territories determine the appropriate dates to begin and end seasonal load adjustment periods based on the subsurface conditions. Arrays of subsurface probes combined with intelligent subsurface forecasts provide advance warning when restrictions will be needed, giving the road-transportation industry advance warning to adjust their plans.

Riding the thaws

Each year in Canada, the onset of cold winter temperatures causes roadbeds across the country to freeze from the top down. A frozen roadbed generally means more weight can be accommodated on the road without structural damage, and some jurisdictions take advantage of this in the form of a Winter Weight Premium (WWP). During the WWP, heavy haulers are allowed to increase their weight per axle, effectively reducing transportation costs.

Serious problems arise in the spring as the roads thaw. Thawing also is a top-down process, which creates a thawed layer consisting of the roadway and part of the substrate while still leaving a hard, still-frozen layer beneath. This traps spring rains and winter snow-melt water in between the hard road surface and the ice layers at depth and seriously reduces the integrity of the road structure. During the period of spring thaw, roads may lose in excess of 70% of their load-bearing capacity.

To reduce structural damage, most provinces in Canada implement spring weight restrictions on susceptible roads, particularly on secondary roads in areas where there is heavy logging and industrial activity. The traditional approach of imposing fixed climate-derived calendar-based load restrictions to minimize the damage has drawbacks: Dates often vary from one jurisdiction to another, and static dates do not take into account the actual strength of the road. These restrictions create a variety of logistical difficulties to loggers, haulers and other stakeholders who utilize the roads.

With global climate change, mid-winter thaws are expected to become more frequent and more pronounced. Final early spring thaws are now often occurring before the historically traditional dates for the imposition of spring load restrictions. Road engineers use deflectometers to measure a road's load-bearing capacity. However, with the more frequent mid-season thaws and the earlier spring thaw, operating budgets are being stretched thin to cover increased testing.

Nova Scotia is a province with a very active forestry industry. Traditionally, restrictions were implemented on most local and secondary roads primarily using freeze-thaw indices to determine when roadbeds were at risk. In addition, the restrictions would sometimes be lifted at night when the forecast was predicting air temperatures of -5°C or colder along with cold 40-cm subsurface at nearby road weather information system (RWIS) stations.

An evidence-based approach to preserve the infrastructure without imposing undue restrictions on its use is highly desirable when the thaw date changes from season to season. In the cold continental climate of the Northwest Territories, where colder temperatures create a deeper and more persistent frozen layer, similar monitoring and forecasting approaches also are required to protect expensive infrastructure without stifling the trucking industry.

The six sensors

The seasonal load adjustment (SLA) sites consist of temperature (thermistor) and moisture (conductivity) sensors mounted on a column. The six SLA sites in Nova Scotia measure subsurface temperatures and moistures. They were installed in 2010 and are mostly located on secondary roads. At each site, the sensors are distributed every 5 cm along the probe from 10 cm below the surface down to a depth of 60 cm, at which point they are distributed every 10 cm down to a depth of 110 cm. The thermistors at the single site in the Northwest Territories are set up in a similar fashion. Data are collected from the sensors at hourly intervals and made available in real-time to clients.

The network of RWIS sites in Nova Scotia consists of 45 RWIS stations with a meteorological tower and pavement sensors at each site. Pavement sensors are located at the surface, in the pavement, 40 cm under the surface and 150 cm below the surface. Two SLA sites are co-located with RWIS sites. There is a single RWIS site at Chan Lake in the Northwest Territories, and it is co-located with the SLA site.

The complete forecast

A subsurface temperature forecasting system was implemented in 2009-10 to offer operational daily forecasts for the six Nova Scotia sites and for one site in the Northwest Territories. A complete physical deterministic approach to forecasting was used. The basis is a thermal-balance model, driven by initial conditions provided by the SLA observation sites and surface boundary conditions provided by a numerical weather-prediction model.

The subsurface model used is SNTHERM, developed by the U.S. Army Cold Regions Research and Engineering Laboratory. SNTHERM requires surface-boundary conditions in the form of meteorological data: temperature, relative humidity, wind speed, rain amount, snowfall amount and radiation fluxes or cloud cover. The U.S. Global Forecast System, one of the world's leading global numerical weather-prediction models, and the Canadian GEM Global models are used to provide these forecast weather conditions. To date, forecasts have been run out to five days as a compromise between the requirements for a useful product for decision making and the diminishing accuracy of numerical weather prediction models as lead time increases.

Temperature and bulk water density at each layer are needed as initial conditions for SNTHERM. The SLA observation sites provide direct measurement of temperatures at many depth levels while the bulk water density has to be derived from the measured relative humidity. Conditions at intermediate model layers are interpolated linearly from the nearest observations.

Frosty response

Both the 2010-11 and the 2011-12 winter seasons were particularly warm in Nova Scotia, and frost was delayed in penetrating beneath the surface. The buildup of frost in the early winter is generally gradual from top to bottom, while in the spring the frost layer has been observed to break down in only a few days in Nova Scotia. In contrast, in the Northwest Territories, typically frost will advance steadily downward past 150 cm early in the winter and will remain frozen at depth into the spring while the upper layers begin their thaw cycle.

In January 2011, the St. Andrew's, Nova Scotia, site experienced shallow freezing down to 20 cm early in the month, and the frozen layer advanced deeper to 40 cm late in the month. By mid-February 2011, observations were revealing a 70- to 75-cm-thick frozen layer.

This past season the frost layer was not as pronounced, reaching a maximum thickness of approximately 50 cm. In past seasons, we have typically seen frost reach depths of at least 100 cm in February.

In March of both seasons the frozen layers began to erode. In 2011, the frozen layer collapsed relatively quickly over March 15-22. In 2012, the frozen layer showed an earlier collapse, disappearing completely before March 15. For the past two seasons, a calendar-based restriction would have missed the mark and left the roads vulnerable, but instead the observation-based guidance system detected the early weakness and triggered earlier restrictions.

In comparison, the Northwest Territories, which experiences much colder atmospheric temperatures in the winter, typically sees the frost layer reach a depth of 150 cm before Jan. 1. The 2010-11 season and 2011-12 season show comparable patterns, with frost reaching the 150 cm depth in both seasons in December and not starting to show any possibility of weakening until March. In both cases, there is still a substantial frost layer at middle depths going into May.

Chance to do more

Model performance deteriorates with longer lead times in a manner similar to the atmospheric models it relies on as inputs. The impact of the numerical weather-prediction model errors is significant at the surface, and as depth increases, SNTHERM's errors become dominant. SNTHERM has a marked cold bias at the surface in the morning where actual temperatures rise much faster than forecast. This error dampens with depth but is still noticeable down to 40 cm. Some conditions are poorly handled by SNTHERM, presumably related to the limited ability of SNTHERM to handle water flow in the ground. Despite these limitations, forecasts in Nova Scotia have proved sufficiently accurate. Error rapidly decreases with depth, as can be expected. However, the Northwest Territories forecast has proven more challenging. AMEC will focus on improvements to the modeling techniques in the next few seasons of the project by testing other subsurface models such as FAAST.

The next step is to determine how to translate subsurface temperature data into an explicit measure of road strength. To achieve this goal, Nova Scotia is planning to execute a series of deflectometer tests at the SLA sites in a future season to correlate subsurface temperature directly to load-bearing capacity. With this approach, it may be possible to greatly reduce the amount of deflectometer testing required by the region. The Forest Engineering Research Institute of Canada and the University of Waterloo have implemented related studies in the provinces of British Columbia and Ontario. They provided seasonal load-restriction exemptions to trucks with tire-pressure control system technology, measuring the impact on the pavement by utilizing repeated portable falling-weight deflectometers.

There also may be an opportunity to leverage the denser RWIS network that offers temperature observations at pavement level (40 cm and 150 cm). Using these limited observation levels from the RWIS network, more complete data sets from SLA stations, some knowledge of road and substrate construction and composition, and the pavement model, road strength could be estimated for these sites as well.

Taking advantage of strength

Nova Scotia Transportation and Infrastructure Renewal reported that the subsurface observation network is a useful tool to determine road weight-bearing capacity. The measurements were successfully used in conjunction with long-range weather forecasts and input from the local managers to reach a decision on the date of the beginning of spring weight-restriction season.

Prior to the subsurface network in Nova Scotia, weight restrictions were lifted on nights when specific cold air temperatures were forecasted because it was presumed that the roads were strong enough to accommodate increased weight. This offers heavy haulers a means to maintain nearly constant hauling costs while limiting road damage. Once the subsurface network was installed, the data from the frost probes was used to determine if the weight restrictions would be lifted at night. For overnight openings, the data had to demonstrate sufficient frost depth. Due to the mild nature of these past two seasons, subsurface data proved that the ground was too weak to handle overnight openings, and no restrictions were lifted.

This dynamic application of load restrictions illustrates the direct benefit of these observations and forecasts in critical periods. The observations and forecast can help identify the appropriate narrow window of time when deflectometer testing would be most appropriate, ensuring maximum throughput at lowest cost on the road infrastructure while ensuring its preservation. DOTs have an increasing need to be able to justify and defend their restrictions, and this is a very transparent way to be accountable to the trucking industry. Armed with data and forecasts, DOTs and industry can simultaneously take advantage of road strength and respect losses in road strength. **R&B**

Loder is a project engineer and meteorologist for AMEC, St. John's, Newfoundland and Labrador, Canada. Pouliot is a meteorologist with AMEC, Halifax, Nova Scotia, Canada.

For more information about this topic, check out the Maintenance Channel at www.roadsbridges.com.