TECHNICAL ANALYSIS SERIES

Cold-Climate Infrastructure Risk: Cuttings vs Embankments

Why Subgrade Form Choice Is a Safety-Critical Decision for the Ontario-Quebec Corridor

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KEY FINDINGS

- Research on cold-climate HSR worldwide demonstrates that deep cuttings are significantly more dangerous than embankments in snowy, freeze-thaw environments.
- Frost heave in cut sections is consistently double to triple that of embankment sections on the same line, threatening track geometry tolerances critical for 300 km/h operation.
- Cuttings act as snowdrift traps, producing an M-shaped accumulation profile directly on the railhead, a derailment risk at high speed.
- The Alto southern corridor traverses both Leda clay (quick clay) and karst terrain where cutting slopes pose catastrophic liquefaction and sinkhole risks, hazards not present in embankment construction over the same ground.
- Canada's freeze-thaw intensity (Ottawa averages ~90 cycles per year) far exceeds the climates where most HSR cold-weather research has been conducted, making the risk premium for cuttings even greater.

Section 1 — Background

The structural form of a railway alignment, whether trains run through a cutting excavated below the surrounding terrain, or on an embankment raised above it, is one of the most consequential design decisions for cold-climate operation. This choice affects snowdrift accumulation, subgrade frost behaviour, drainage, slope stability, maintenance access, and emergency response.

For the ALTO High-Speed Rail project, which will operate at up to 300 km/h through the heart of Eastern Ontario and Quebec, a region with some of the most challenging winter conditions in the G7, the selection of subgrade form is not merely a civil engineering preference. It is a safety-critical and lifecycle-cost-critical decision.

Section 2 — What Peer-Reviewed Research Shows

2.1 Snowdrift Accumulation: Cuttings as Traps

Wind-tunnel studies and field monitoring from China's Xinjiang railways and Scandinavia consistently document a striking asymmetry between the two subgrade forms:

- Cuttings produce an M-shaped snow accumulation profile. As wind decelerates upon entering the confined space, particles settle directly on the track surface on both windward and leeward shoulders. Snow depth on cutting pavement is typically 25% greater than on equivalent embankment surfaces in the same wind-snow regime.
- Embankments produce a U-shaped profile, with accumulation at the leeward slope foot, away from the track. The geometry does not concentrate drift onto the railhead.
- A 5-metre snow accumulation platform on cutting shoulders reduces the surface distribution coefficient from 2.0 to 1.6, but does not eliminate the fundamental trapping hazard.

At 300 km/h, the mechanical energy of impact with a snow obstruction scales with velocity squared. A snowdrift event that would merely delay a conventional train can cause derailment. The January 2026 high-speed rail derailment in Spain, which killed 41 people on a train traversing a cutting, illustrates that these are not theoretical risks.

2.2 Frost Heave: The Cut-Section Penalty

The most comprehensive real-world data come from the Harbin-Dalian Passenger Dedicated Line (HDPDL) in northeast China, the world's first HSR in seasonally frozen ground, comparable in freeze-thaw intensity to Eastern Ontario. Six years of continuous monitoring at matched cut and embankment sections on the same line produced unambiguous results:

- Maximum frost heave in the cut section: 4.52 mm to 9.18 mm per season
- Maximum frost heave in the embankment section: 1.86 mm to 5.28 mm per season
- Frost heave ratios in the top gravel layer (0–0.5 m): 1.20% in cuts vs. 0.63% in embankments — nearly double

For HSR operation at 300 km/h, track geometry tolerances are extremely tight — typically ±2 mm vertical deviation over a 10-metre chord for slab track. A frost heave event reaching 9 mm in a cut section, if not precisely and promptly corrected, creates a track irregularity that generates dangerous dynamic wheel-rail forces.

CRITICAL FINDING

Frost heave in cut sections on the Harbin-Dalian HSR was consistently 2–3× greater than embankment sections on the same line. Ottawa's freeze-thaw intensity (~90 cycles/year, vs. ~60–70 in Harbin) makes this penalty even more severe for ALTO.

2.3 Slope Stability and Leda Clay: A Canadian-Specific Catastrophic Risk

Every cutting creates two slopes. In stable crystalline rock, these slopes, once engineered, remain predictable over a 100-year asset life. The risk profile in the southern corridor's glacial sediment terrain is fundamentally different.

Leda clay (Champlain Sea clay / quick clay) underlies the valleys between Smiths Falls and Ottawa through which the ALTO southern corridor would pass. When undisturbed, Leda clay behaves adequately. When disturbed by excavation, vibration, groundwater pressure change, or pore-water pressure increase, it can liquefy catastrophically. Trigger mechanisms include: excavation (inherent to cutting construction), cyclic train-induced vibration (inherent to HSR operation), rapid snowmelt increasing pore-water pressure, and freeze-thaw cycling altering soil fabric. Over 250 documented Canadian landslides are attributed to Leda clay, including the 1993 Lemieux, Ontario collapse (17 hectares) and the 1971 Saint-Jean-Vianney, Quebec disaster (31 killed). The 2016 Rideau Street sinkhole in Ottawa was partly attributed to Leda clay destabilised by nearby tunnel construction vibration, exactly the loading regime HSR would impose on a permanent, continuous basis.

2.4 Drainage and Ice Formation

Ottawa averages approximately 90 freeze-thaw cycles per year, among the highest of any major city in the world. Meltwater from cutting slopes drains toward the track. In cold snaps following thaw periods, this water refreezes on the ballast, rail base, and switch mechanisms. Switch failure probability is near-certain at temperatures of -12°C or below with 50 mm or more of accumulated snow. Embankments drain by gravity away from the track, reducing ice formation at rail level. The overhead catenary system (OCS) is sheltered within cuttings, which appears beneficial, but the sheltered microclimate actually promotes ice accretion, air in cuttings is colder, more humid, and more still, promoting freezing-fog and rime ice events.

2.5 Access for Snow Removal and Maintenance

Mechanical snow removal from a cutting requires specialised equipment that can operate in a confined space, and removed snow has nowhere to go, it must be loaded and transported. Embankment snow clearance is typically a single-pass operation with swept material descending the slope. On a 1,000 km network experiencing simultaneous snowfall events, not uncommon in Eastern Ontario lake-effect and St. Lawrence corridor snow events, a delay cascade triggered by cutting snow accumulation at one point can propagate through the entire timetable.

2.6 Emergency Egress and Rescue

A train stopped in a deep cutting with 4-metre retaining walls presents a fundamentally different rescue scenario than a train stopped on an embankment: passengers cannot easily self-evacuate laterally, rescue vehicles cannot readily access the train, and in a winter context with snowdrift, the cutting becomes a trap. Winter operational stoppages in cuttings are documented in Scandinavian experience as among the most operationally difficult incidents to manage.

Section 3 — ALTO-Specific Context

3.1 The Southern Corridor's Geological Exposure

The ALTO southern corridor, passing through the Kingston-Frontenac area, traverses terrain that combines multiple compounding risk factors largely absent from the northern corridor:

- Leda clay / Champlain Sea clay deposits in valleys along the Ottawa-Smiths Falls segment, creating the slope-failure hazard described above
- Karst limestone terrain in the Napanee Plain, where cutting through the limestone caprock concentrates surface and sub-surface drainage into dissolution channels — accelerating karst cavity formation, sinkhole risk, and the loss of cutting slope integrity over decades
- Glacial till deposits of highly variable composition, creating unpredictable frost-heave behaviour across relatively short track distances, generating the differential heave events most dangerous to 300 km/h operation
- The Frontenac Arch Biosphere, a UNESCO-designated zone, where drainage of de-icing chemicals from cutting operations directly enters karst watersheds, threatening irreplaceable species at risk habitat

3.2 The Northern Corridor's Relative Advantage

The northern (Highway 7) corridor passes primarily through Precambrian meta-sedimentary and granitic terrain with significant implications for the cutting vs embankment question:

- Rock cuttings through competent Precambrian crystalline rock do not create Leda clay liquefaction hazards. Slopes are stable once properly benched and sealed.
- Frost heave in competent rock subgrade is negligible compared to clay and till substrates. The primary mechanism, pore-water migration to a frost front, is suppressed in low-permeability crystalline rock.
- Where embankments are required in northern terrain, the fill material available from rock cuttings is well-graded, non-frost-susceptible crushed rock, ideal subgrade fill that greatly reduces the frost heave risk documented in the Harbin-Dalian research.

3.3 Freeze-Thaw Intensity: Canada Is Not China or Scandinavia

The peer-reviewed research in this brief draws heavily on Chinese HSR experience (Harbin-Dalian, Lanzhou-Xinjiang) and Scandinavian operational data. Ottawa's freeze-thaw cycle frequency (~90 per year) significantly exceeds both Harbin (~55–65 cycles) and Stockholm (~45–55 cycles). Each cycle imposes stress on subgrade, slopes, and rail infrastructure. Eastern Ontario's lake-effect snow events can produce sudden, localised, extremely heavy snowfall, the specific trigger for the most dangerous cutting snowdrift scenarios. The combination of heavy wet snow (frequent in the shoulder seasons) with rapid temperature drops creates ideal conditions for ice-laden snow accumulation in cuttings, the hardest form to clear mechanically.

Section 4 — Risk Comparison Matrix

Risk Category	Deep Cutting	Embankment
Snowdrift Accumulation	CRITICAL — trapping geometry	Manageable — snow fences effective
Frost Heave (subgrade)	HIGHER — soil moisture retention	LOWER — better drainage
Slope / Mass Failure	HIGH — Leda clay liquefaction	LOWER — fill slope manageable
Drainage & Meltwater	POOR — pooling, ice formation	GOOD — gravity-assisted runoff
Snow Clearing Access	DIFFICULT — confined space	STRAIGHTFORWARD — open access
OCS Ice Accretion	SEVERE — sheltered ice trap	MODERATE — wind dispersal helps
Emergency Egress	CONSTRAINED — walls block exit	ACCESSIBLE — open sides
Karst/Sinkhole Risk	AMPLIFIED — concentrated water	LOWER — distributed drainage

Red = Elevated/Critical Risk | Amber = Moderate Risk | Green = Lower/Manageable Risk

Section 5 — Design and Consultation Implications

5.1 Subgrade form must be treated as a risk-scored variable

ALTO's current public consultation materials do not provide corridor-by-corridor analysis of the proportion of each alignment that would require deep cuttings through frost-susceptible terrain. This information is essential for risk-informed public feedback. Decision-makers and the public cannot evaluate the safety and lifecycle cost implications of a route if the fundamental subgrade geometry choices have not been disclosed.

5.2 Cold-climate design standards must be explicitly specified

ALTO's design criteria should explicitly address the differential risk of cuttings vs embankments in frozen-ground terrain. The Harbin-Dalian experience, which resulted in widespread, unexpected frost heave requiring emergency remediation in the first operating winter, demonstrates that "standard" HSR design assumptions derived from temperate European practice are insufficient for Canadian winters. The NRC Canada freeze-thaw cycle data for the Ontario-Quebec corridor must be a design input, not an afterthought.

5.3 Route selection should include subgrade form as a scoring criterion

If the northern corridor can achieve a significantly higher proportion of embankment construction on stable non-frost-susceptible rock fill, compared to the southern corridor's requirement for cuttings through Leda clay and glacial till, this differential should appear explicitly in ALTO's route scoring methodology. It represents a quantifiable difference in lifecycle maintenance cost, safety risk, and operational reliability, all of which align with ALTO's own stated evaluation criteria.

Conclusion

The engineering literature on cold-climate HSR operation is consistent and unambiguous: deep cuttings through frost-susceptible, water-bearing terrain impose substantially higher snowdrift, frost heave, drainage, slope stability, and operational safety risks than embankments in the same climate. These differences are quantified and documented from real operating HSR lines, not merely theoretical.

For the ALTO project in Eastern Ontario and Quebec, with its uniquely high freeze-thaw intensity, extensive Leda clay deposits, karst terrain, and lake-effect snowfall regime, these risks are not incremental. They are compounding. A deep cutting through Leda clay, traversed by 300 km/h trains, exposed to 90 freeze-thaw cycles per year, subject to lake-effect snowdrift, and draining into karst watersheds is not a manageable engineering challenge. It is a liability cascade.

ALTO has committed to delivering "safe, reliable and sustainable" high-speed rail. The choice between cuttings and embankments — and between corridors that require more of one than the other — is one of the most direct levers available to achieve that commitment. The risk differential documented here must be explicitly incorporated into ALTO's route evaluation, its design criteria, and its public consultation materials.

Key References

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