COLORADO
Department of Transportation
Division of Transportation Development

Research Brief

Office of Applied Research

Study Title

A Numerical Study of the Feasibility of Vertical Avalanche Defense Structures

Brief Type

Final

Date

April 2026

Study Timeline

June 2025 – June 2026

Principal Investigators

Francis Meloche
David Hamre and Associates
fmeloche@ethz.ch

Ron Simenhois, Colorado Department of Transportation, CAIC/CDOT Avalanche Forecaster and Data Scientist,
ron.simenhois@state.co.us

CDOT Contact Info

Study Champions

Ethan Greene, CAIC Director
Ethan.greene@state.co.us

Study Manager

David Reeves, Research Engineer, Office of Applied Research, Colorado Department of Transportation (CDOT)
david.reeves@state.co.us

Interested in Finding Out More?

TPF 5(497) – TARP 2

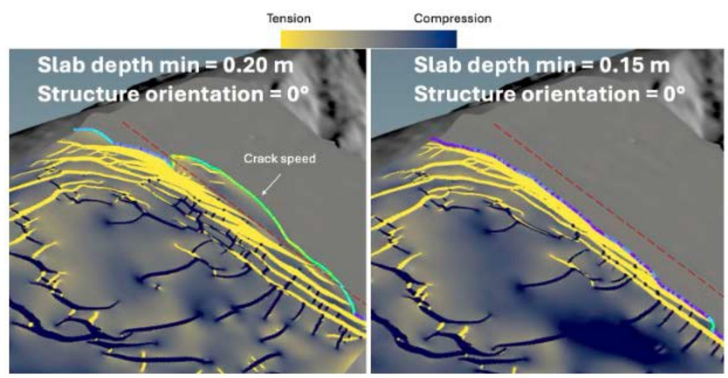
Research Program

A Numerical Study of the Feasibility of Vertical Avalanche Defense Structures (CDOT-2026-01)

Background

Traditional avalanche defense structures are costly to install and maintain, visually intrusive, and must be placed perpendicular to slopes. Many highway avalanche programs, therefore, rely on active measures like explosives, which carry inherent risks and may not prevent all large avalanches from reaching roadways. This project investigates an innovative alternative: vertical, downslope-oriented structures designed to arrest avalanche crack propagation at a fraction of the cost and visual impact.

Methods



Using over 300 numerical simulations, this study demonstrated the technical feasibility of vertical avalanche defense structures. The advanced depth-averaged Material-Point Method model—validated specifically for snow avalanches—examined crack propagation dynamics across simple slopes, complex analytical terrain, and real-world topography (Stanley Path, Colorado).

Results

Effectiveness Confirmed: Structures successfully arrested crack propagation when designed according to specific geometric and snow depth parameters. The primary mechanism is slab thickness reduction over the structure, promoting tensile fractures that halt avalanche development.

Clear Design Parameters: Critical thresholds were identified: (1) Minimum structure ratio (height/width) of 0.5 for buried structures; (2) Maximum snow burial depth of 0.15–0.30 m depending on snow density (maritime vs. continental climates); (3) Minimum width of ~0.6 m for unburied structures; (4) Downslope length extending to slopes ≤27° (snow friction angle).

Layout Optimization: Structure orientation and positioning matter. Downslope orientations (0° to 10° from slope-parallel) performed best, while orientations approaching cross-slope configurations (>20°) deviated from the core concept. Discontinued structures (mimicking natural obstacles) require precise spacing (~6 m) aligned with super-shear critical crack length.

Real-World Validation: Simulations on Stanley Path terrain, incorporating realistic snow distribution patterns from wind loading, confirmed that structures can arrest avalanches in complex topography when properly dimensioned and positioned between existing avalanche control systems.

Recommendations for Implementation

The numerical modeling phase has established robust scientific foundations and design guidelines. The next critical step is advancing to structural engineering and field validation. Phase 2 should focus on:

- **Structural Design Engineering:** Collaborate with geotechnical engineers specializing in alpine environments to develop structures that emerge from snowpack, resist wind loading, and withstand multi-year snow stress cycles. Incorporate 3D wind-field modeling to predict snow burial patterns.
- **Prototype Development:** Design lightweight, dual-wall configurations that maintain required width (≥ 0.6 m) while minimizing material use. Consider both earth structures (gabions) and metal stand-alone designs based on installation logistics and environmental durability.
- **Field Implementation:** Deploy prototype at Stanley Path, Colorado, leveraging existing Remote Avalanche Control Systems infrastructure. Monitor performance through multiple winter seasons to validate snow mechanics predictions and refine design parameters.
- **Validation Simulations:** If needed, conduct additional numerical simulations with finalized structural designs to confirm crack arrest effectiveness under realistic burial and loading scenarios.

Conclusion

The scientific verification phase has successfully established that downslope vertical avalanche defense structures can arrest weak-layer crack propagation and limit avalanche size. With clear design parameters validated across 300+ simulations and real-world terrain analysis, the project is ready to advance to engineering design and field testing.