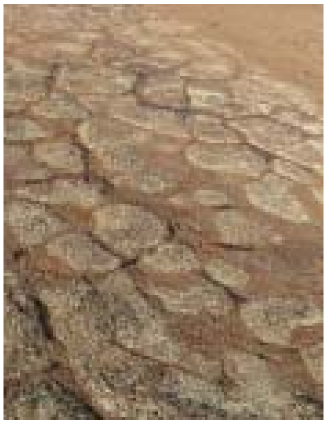
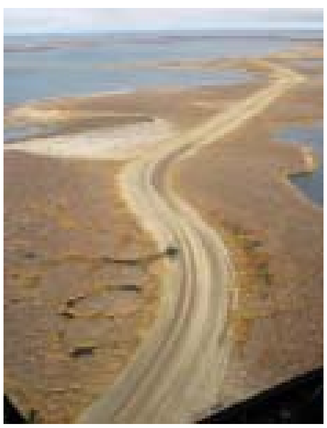
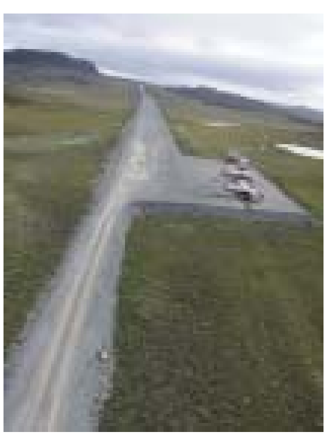
Transportation Association of Canada







Primer on

Developing and Managing Transportation Infrastructure in Permafrost Regions

Permafrost underlies about half of the landmass of Canada and our northern road, rail and air transportation system is reliant on the strength of permafrost soils. Defined as a ground condition of either soil or rock that remains at or below 0°C for long periods, permafrost is often a very capable foundation but it is very sensitive to changes in thermal conditions.

Traditional planning, design, construction and maintenance practices do not always suit permafrost conditions and climate change is adding uncertainty to performance prediction. Providing a reliable northern transportation system is a key factor in maintaining and improving the quality of life in the most vulnerable of Canadian communities, not to mention protection of our interests in terms of national security, Arctic sovereignty and the development of Canada's rich natural resources.

Through science, engineering and experience, some important lessons have been learned about developing and managing transportation infrastructure in permafrost regions. This primer highlights issues to be considered and emphasizes the importance of adopting good practices for development, planning, design, construction management, maintenance and rehabilitation of transportation facilities in regions of northern Canada with permafrost terrain.

Planning and Funding Issues

Climate change has added a new layer of uncertainty to the established practices of cold region engineering. Infrastructure that relies on properties of permafrost and ice for long-term stability must now be developed on a risk-based approach, with design processes which recognize and rationalize future uncertainty from changing climatic conditions.

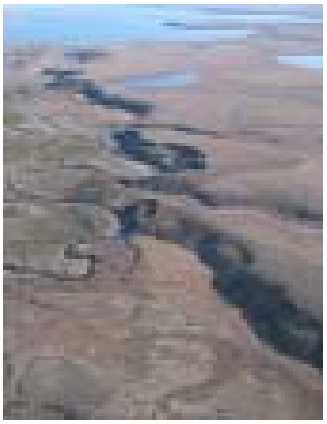
Another challenge is to find a practical balance between initial cost and performance, given that performance measures may be compromised in unstable permafrost conditions. The transportation infrastructure in Canada's northern communities has a complex history, involving collaboration between developers who built necessary access roads and federal spending for both road and air access to isolated communities. Future development of transportation infrastructure in Northern Canada will be prompted by mining and hydro power developments, greater expectations from northern residents for connections to southern Canada's road network, and national sovereignty and defence issues.

The overall decision-making approach for transportation infrastructure in permafrost regions should consider:

- maximizing use of existing road, rail, airport and marine infrastructure;
- building the minimum necessary new infrastructure;
- planning multi-user facilities by coordinating among all potential users;
- using life-cycle costing analyses;
- making the costs for government funded projects transparent; and
- involving engineers with permafrost experience and expertise at all stages.

Balancing transportation needs with viable operational scenarios will help to identify the types of infrastructure to be considered in each situation. Experience has shown that in permafrost regions, the high cost of developing linear transportation infrastructure (road, rail, and airstrip), the high level of environmental impact and the vulnerability of the infrastructure to climate change necessitate early planning-stage assessment of needs and analysis of operational scenarios based on multiple factors including capital construction costs, schedule, operating costs, regulatory conditions and environmental impact. When planning a new route or corridor, information on climate, terrain and other conditions must be acquired; design parameters, historical costs and standard engineering principles can be combined with the outcome of initial route (site) identification and evaluation phases to develop budgetary level cost estimates and funding requirements.

By systematically considering the sensitivity of the route, the type of infrastructure to be developed as well as potential damage resulting from changes in the permafrost regime, planners and designers can incorporate mitigative or adaptive measures into their design and future operations, or at least understand what the risk and cost implications are of not incorporating such measures. Planning must also incorporate a systematic approach to optimize costs at all stages in the project with full lifecycle planning including maintenance, rehabilitation and abandonment at end of use.



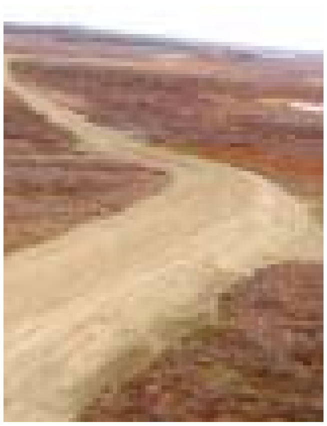
Route Investigation in Permafrost Regions

Transportation infrastructure design and construction in permafrost regions require thorough assessment of permafrost terrain along the proposed transportation corridor. The success of a road construction project in cold regions depends heavily on the quality of the available geotechnical information.

The approach to route investigation should involve going from the generally, easy to access information to specialized detailed testing and characterization of soils. The investigation should provide the answers to two key questions:

- What is the risk that the intended construction or rehabilitation works could induce permafrost degradation?
- What is the consequence of permafrost degradation in terms of severity and duration?

Quality equipment and experienced crews are required to collect geophysical data. Also, a very knowledgeable expert is required to interpret information obtained from geophysical surveys done in permafrost conditions. Better information and less risk is achieved by combining the geophysical results from several techniques which can often be done with small incremental cost. Spending additional money to enhance the geotechnical investigation program prior to and during construction is extremely beneficial to all projects in permafrost areas, and results in higher quality products, reduced risk during construction and long-term cost savings. Geotechnical investigation can also be beneficial when it comes to maintaining existing transportation infrastructure.



Embankment and Pavement Materials

Care must be taken when choosing the appropriate materials for embankment and pavement construction in permafrost regions, given that projects typically require more fill material – a non-renewable resource. Finding available granular material of sufficient quality and quantity, then planning for its use in a sustainable manner are important considerations to reduce costs and to minimize the impact footprint. Local environmental guidelines and policies must be respected and local stakeholders should be consulted.

It is most practical and appropriate to use existing borrow sites when available and feasible. If required, topographic and geological maps, along with aerial photographs and shallow manual sounding, can help identify potential new sites. The sites' suitability can then be confirmed via power excavators and auger drills, but heavy mechanical equipment should only be used late in the fall or during winter when the ground is frozen, depending on site-specific access considerations, to facilitate mobility and minimize damage to the ground. It is important to note that relying only on preliminary geotechnical investigation of potential fill/gravel sources can cause problems with construction logistics and lead to increased construction costs. To minimize the visual and the environmental impact of borrow site operation, fewer large borrow sites are generally preferred to many small ones, even if it involves slightly longer hauling distances.

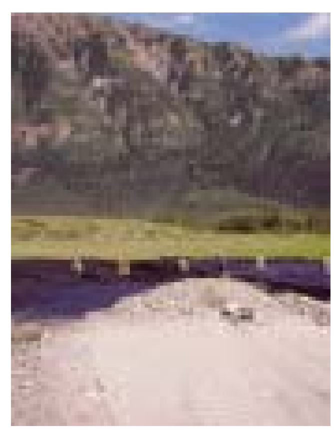
New pits and quarries may require the development of a site-specific "Pit Development Plan" (PDP) that presents a customized development and reclamation plan for a borrow site as well as providing the transportation practitioner with a tool to effectively manage the source over time. This includes minimizing the site's footprint, with special attention given to the operation's effect on permafrost, on all water bodies and water courses, and on any other environmentally sensitive areas. Site restoration to minimize the long-term impact of material extraction is also essential.

Engineering Considerations

Engineering considerations for working in permafrost regions are significant whether at the planning, design, construction, maintenance or rehabilitation stages of a transportation facility.

The objectives of the guiding principles include:

- researching past precedents in the region;
- understanding the nature of the permafrost soil;
- understanding the thermal regime first, then the mechanical implications; and
- preparing normally accepted design criteria.



The initial step is to assess the level of risk associated with construction in permafrost conditions, including soil type and ground ice content, and to consider both the likelihood and the severity of permafrost degradation that might result from construction and climate change. This step also includes the consideration of related consequences on the performance of the transportation facility and degradation of the surrounding environment.

Any change in soil conditions resulting from a modification to the surface, earthwork or embankment construction will unavoidably result in a change in the soil thermal regime. Colder soil conditions are likely to improve the stability of embankment foundations. Warmer conditions will result in permafrost degradation and poor performance of the transportation facility. Sound engineering work on permafrost requires good understanding and control of these possible changes.

When it comes to embankment design in permafrost conditions, the basic principle is to protect the integrity of the embankment's structural core; this can be achieved through both surface preservation and avoidance of cuts in thaw-sensitive soils. Cuts in the permafrost soil, as well as stripping or grubbing to remove the vegetative layer, may promote unwanted thawing and lead to settlement of the embankment.

Wide shoulders and gentle sideslopes will give an overall wider configuration to the embankment, which will in turn move settlements away from the structural core, mitigate the impact of thaw and help reduce snow accumulation. In permafrost conditions, it is advisable to undertake activities that are likely to improve slope stability or, at a minimum, avoid design and construction activities that promote instability.

When designing a structure requiring high reliability in very sensitive permafrost conditions, thermal stabilization using special protection techniques might be required. Consider techniques to reduce heat intake in the embankment during summer and allow heat extraction during winter and / or embankment reinforcement techniques.

Drainage and Erosion Control

Drainage and erosion control are critically important design considerations for roads, especially in northern permafrost environments. Poor drainage conditions along a road over permafrost terrain may cause surface water ponding, thermal erosion, thermokarst and or formation of icings. The effects of these processes may have a serious impact on the environment and traffic, and can lead to higher maintenance costs. Many potential drainage problems associated with new roads constructed in permafrost terrain can be avoided or minimized by careful selection of a road route and planning the alignment to minimize stream crossings.

In ice-rich soils, stream and surface water runoff hydrology during all seasons must be fully understood so that bridge span and foundation structures are appropriately designed. Ideally, bridges should be placed at narrow and straight channel locations, on bedrock or coarse, ice-poor, non-settling foundation soils.

Culverts in permafrost regions require constant maintenance and should be used only when necessary. Where large diameter culverts cannot be avoided, it is recommended to use riveted or bolted culverts and consider installation of polystyrene insulation beneath the culvert bedding material on the bottom and sloped sides of the excavation.

Erosion control design should be based on soil erosion codes and aimed at minimizing changes to existing drainage patterns. In addition to selecting correct erosion control structures for a specific road construction project, proper and environmentally friendly construction practices should be used during road construction to minimize the potential for erosion.

Construction

Construction in permafrost regions requires planning and techniques that are unique relative to construction in other areas. Well-planned logistics including transportation, staging, pit and quarry development, equipment use and other items cannot be taken for granted. Choosing to undertake construction in either the winter or the summer can have a significant impact on how permafrost issues are managed.

Construction projects located on permafrost terrain are often situated on sensitive tundra, which can be severely damaged by simply moving equipment over it. Construction activity can cause damage to the environment. It is therefore vital to minimize the construction “footprint” and implement an environmental management plan to cover such issues as tundra sensitivity, air quality and noise, terrain and vegetation, wildlife, fisheries and aquatic resources, waste management and fuel / oil management .

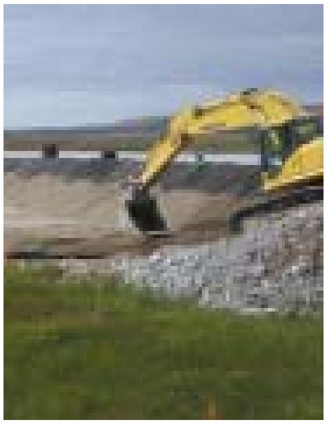
The design of projects in permafrost areas should incorporate the best practices for long-term permafrost preservation. Contractors should be cognizant of the need to preserve permafrost and the organic insulating layer in all the ancillary areas of their construction activities. In addition, maintaining existing drainage patterns is very important in preserving permafrost.

In permafrost regions, unforeseeable conditions are commonly encountered during construction. Recognition of these conditions and willingness to adapt designs during construction could avoid costly reconstruction in the future.

Maintenance

Preserving the initial investment in transportation infrastructure requires routine and major maintenance operations at the local level. While this is true of transportation infrastructure in all regions, it is most relevant in sensitive permafrost conditions, where for example, minor incidents of ponding water, if left unaddressed, can quickly escalate to a system failure.

Routine maintenance refers to day-to-day or frequent and regular activities that are undertaken with the priority of maintaining surface conditions and traffic control provisions of the facility. One example is daily maintenance patrols, which are particularly important in the case of infrastructure built on thaw-unstable permafrost as road surface subsidence can happen rapidly due to melting of massive ice in the subgrade. Similarly, snow removal is an essential part of routine maintenance, not only to make a roadway safely navigable but also to minimize the insulating effect of the snow.



Major maintenance refers to planned and seasonal activities to maintain surface conditions / traffic control provisions, and to promote preservation of the investment. Rehabilitation activities are necessary when a failure has occurred and cannot be easily addressed through routine or major maintenance. Maintenance activities must cover all aspects of the infrastructure, including keeping all components of the drainage system operating at the designed or desired capacity.

Surface deficiencies, including cracking in gravel surfaces, could be consequences or symptoms of more significant problems. It is important to understand and confirm underlying problems through visual observations, bearing capacity measurements and ground penetrating radar scans. Once the cause has been identified, judgment must be used to determine when routine maintenance activities will suffice, and when to escalate activities to rehabilitation. When the root causes of surface deficiencies are understood, key decisions can be made to undertake rehabilitation activities before a catastrophic event occurs.

Emerging Technologies

Several promising concepts related to the development of transportation infrastructure in permafrost conditions are currently being investigated. They include:

- Heat extraction using air convection in embankments on permafrost. This involves cooling embankments in an effort to maintain or cool frozen ground conditions.
- Heat extraction using “hairpin thermosyphons” (passive cooling) in embankments. This technology will be expensive to employ, so it is probably not suitable for widespread application, but may be an effective alternative for site-specific stabilization.

- Snow accumulation on sideslopes can lead to permafrost degradation; researchers have developed a heat drain to facilitate heat extraction from the embankment during winter. This method is relatively easy to implement.
- Ground-Penetrating Radar (GPR) technology is being considered for use to determine baseline subsurface conditions for recently-constructed gravel roads in permafrost regions as the initial step in performance monitoring programs.
- Profile measurements (roadway roughness and rutting) have been successfully used to detect and characterize frost-related problems. Although not an emerging technology, profile measurements taken by increasingly sophisticated profiling vehicles are likely to

become effective tools for permafrost related problems on paved roadways.

- Insulating the permafrost to mitigate thawing has been shown to be effective. Foamed in place, polyurethane insulation may be a cost effective alternative, with respect to installation and shipping, to rigid board insulation.
- In some conditions, soil stabilization has been used to reduce frost action in subgrade soils. Stabilization techniques may be the only alternative when granular or quarry materials are not readily available. Even in sandy environments, geofiber and synthetic fluids for stabilizing marginal soils have been effective.
- Since research has demonstrated that a pavement surface having a high albedo (surface solar reflectivity) minimizes heat transfer to the underlying subgrade, work is being done to develop durable, light coloured pavement for use in permafrost environments.
- Lightweight cellular concrete products are being considered for the thermal protection of frost-heave susceptible soils under roadways as well as the thermal protection of permafrost.

More Information

The information in this primer has been extracted from a Transportation Association of Canada publication, entitled *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions*. The guide provides a compendium of best practices for development, planning, design, construction management, maintenance and rehabilitation of transportation facilities in regions of northern Canada with permafrost terrain. It is intended to be a practical, easy-to-read guide for those directly involved in any aspect of the life cycle of infrastructure in northern Canada. This publication is available for purchase in TAC's online bookstore.

Disclaimer

Every effort has been made to ensure that all information in this primer is accurate and up-to-date. The Transportation Association of Canada assumes no responsibility for errors or omissions. The primer does not reflect a technical or policy position of TAC.

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