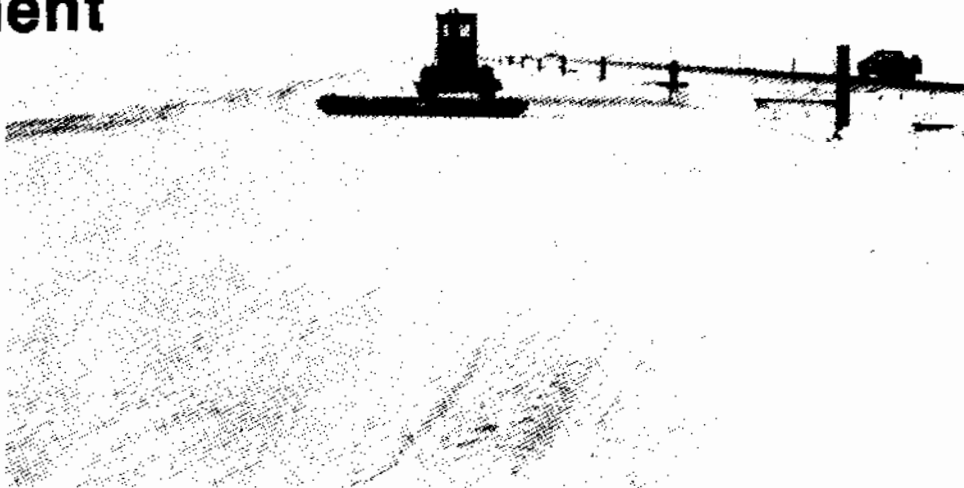


# Selecting the Right Arctic Road Embankment



## INTRODUCTION

Historically, an arctic or subarctic roadway generally costs the project sponsor a great deal for long-term maintenance. In general, these extra maintenance costs can be attributed to either (1) failure to use a road embankment design that is compatible with the road's intended use or (2) a lack of understanding, or possibly lack of appreciation, for the unique thermal state of the foundation soils and the often harsh and extreme conditions of the arctic climate.

To design, construct and maintain a driving surface that is in thermal equilibrium with the arctic environment requires a thorough understanding of heat transfer, arctic geomorphology, seasonal working restrictions, equipment productivity and material availability. Additionally, long-term site accessibility and general logistics must be considered.

This article suggests methods for logically considering all possible design alternatives for embankments and selecting one or more of the most overall cost-effective alternatives. Discussion here will be restricted to outlining the conditions for use and the associated cost of a given combination of embankment materials. Many of these guidelines are applicable to other types of construction in the Arctic as well.

## CONCEPTUAL DESIGN

Conceptual design, the first phase in road design, involves evaluating answers

**A finished snow road adjoining a permanent gravel road, Kuparuk oil pipeline. The temporary snow road was used for pipeline construction, and the gravel road will be used during pipeline maintenance. This cost-effective design minimizes environmental impact. (Photos courtesy of Alaska State Pipeline Coordinator's Office.)**

to nine basic design questions: (1) What is the road's use? (2) Is the project close to other permanent roads? (3) Can winter work be conducted? (4) What are the microclimatic conditions of the project? (5) What is the soil's thermal state and nature? (6) Will the design be of a mitigative or preventative type? (7) What materials are readily available and in what quantities (i.e., snow, water, gravel)? (8) What are the environmental restrictions? (9) Will the proposed design be within the project budget?

It is important that the arctic engineer understands why these questions must be answered, since the cost implications are great. This is illustrated by a sample cost analysis for seven design alternatives, developed by the author, for a 100-mile hypothetical project extending from Prudhoe Bay to approximately 30 miles north of the Kuparuk River crossing of the Dalton Highway. The analysis showed a direct cost ranging from \$50,000/mile for ice aggregate to \$625,000/mile for an

insulated gravel workpad. Specific comments on cost analysis will be presented in the discussion of question nine.

## Use

A road's intended use is a key factor in arriving at the total number of design alternatives to be considered in the design and cost analysis. For example, a public road usually is required for 25 years or longer; thus, snow cannot be considered as a construction material, except for temporary road detours. However, a road being used to install a pipeline, such as the Trans-Alaska Pipeline System (TAPS), is temporary. During pipeline construction, the road must be at least 50 feet wide to accommodate traffic, but once the pipeline is in place, the road driving surface need be only 15 to 20 feet wide for maintenance vehicles. This is an ideal situation for which to consider a 50-foot wide snowpad with a permanent gravel maintenance road being placed over the top of the buried sections of the pipe. Alternatively, a 20-foot wide gravel road

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adjoined by 30 feet of snow road is worth considering. Furthermore, by using a renewable resource (snow) the cost savings are potentially great, and a limited natural resource (gravel) is being conserved. Also, use of snow will typically cause only temporary damage to the underlying vegetation, on the order of 5 to 20%, whereas using gravel will typically cause 100% long-term damage.

#### *Proximity to Permanent Roads*

Long-term access to the primary facility is extremely important when the facility is in a remote location, since no access means that the maintenance it requires generally will be quite difficult, if not impossible. However, if the facility is close to a permanent road system, then maintaining the facility is less of a problem. Long-term access must be carefully considered when snow/ice is used for road construction.

#### *Winter Work Operations*

A contractor with a project, or an oil company doing exploratory work, in a remote location may opt to move equipment during the winter months on snow roads rather than mount an expensive summer mobilization operation. With winter construction it is not unusual to be able to reduce an earthen embankment thickness by up to two feet, which on large projects means major savings. Despite such reasons for mounting a winter construction effort, careful consideration must be given to the reduced manpower and equipment productivity associated with the extremely low winter temperatures and reduced lighting.

#### *Microclimatic Investigation*

When winter construction is being considered for a thermal embankment design, a microclimatic analysis is essential. Basically, this analysis amounts to reviewing the best available information. The analyst may use data published by the U.S. Weather Service if the project is situated near a community with weather-monitoring instrumentation, or may use data published by the Institute of Water Resources at the University of Alaska-Fairbanks (*The Environmental Atlas of Alaska*) for projects in remote areas. The *Atlas* provides only information by regions, so when its data are applied to a

localized area the results can be misleading or even erroneous in some cases. (Since Murphy's Law always prevails, the more favorable the *Atlas*' data seem, the more imperative it is to verify them with field studies. When field studies are not possible, the analyst must be extremely cautious.) Information gained from this will assist the cost estimator/scheduler in developing production rates for the cost analysis. Similarly, if snow/ice road construction is contemplated, the wind direction and velocity plus average monthly temperature are necessary information, especially if a snow fence is to be used to collect the snow needed for construction. Also, the average monthly temperature can be used to define the allowable work period for the snow road, which is critical information to have when allocating road building machinery for greatest economy and efficiency.

#### *Soil Thermal State*

Knowledge of subsurface thermal conditions is extremely important. Designs for thawed soil can be made according to classical foundation theory. However, permafrost cannot be evaluated by classical foundation methods, and it is the one item which sets Alaska apart from her sister states with respect to solving soils engineering problems.

Permafrost soil is by definition a soil which remains at temperatures below 0°C (32°F) for two or more years; it is simply perennially frozen ground.<sup>1</sup> The distribution of permafrost is controlled by climatic, geologic, hydrologic, topographic and botanical factors. In Alaska, some 85% of the land is permafrost region.<sup>2</sup>

Permafrost regions can be classified as: *Absent* 0 to 10% of the soil mass is frozen; *Sporadic* — 11 to 50% of the soil mass is frozen; *Discontinuous* — 51 to 90% of the soil mass is frozen; and *Frozen* 91 to 100% of the soil mass is frozen.

The composition of soil within a permafrost region can be further classified as ice-rich (thaw-unstable) or ice-poor (thaw-stable). Construction on dry permafrost, such as frozen bedrock or a frozen coarse-grained gravel deposit, will present few construction and maintenance problems, since there is little or no ice present. However, an ice-rich permafrost, in addition to harboring a moisture content that is usually higher than the liquid limit,

generally contains segregated ice in the form of wedges, lenses, and crystals. It also is not uncommon to find massive ice structures incorporated within such soils. Ice-rich permafrost is commonly found in organic and fine-grained mineral soils.

Ice-rich permafrost, if placed in a state of thermal imbalance, can cause foundation subsidence, thermal/hydraulic soil erosion, frost heaving, creep, landslides, and icings. Thermal imbalance is commonly caused by stripping of the vegetative mat, placing a heat sink (roadway embankment) over the permafrost, making large localized roadway cuts, or burying a utility system within the permafrost. Obviously, it is the ice-rich permafrost that the arctic engineer must identify during the site investigation if the correct design is to be developed and costs are to be kept within the project budget.

Accordingly, because ice-rich permafrost occurs unpredictably, detailed information must be collected during site investigation to ascertain (1) permafrost distribution plus the conditions under which it exists and (2) the mechanical properties of the permafrost (i.e., ice content, grain size, bearing capacity). On larger projects this information normally is collected in three phases: (1) a preliminary office study, (2) a field investigation, and (3) a final report including laboratory analysis.<sup>3</sup>

The preliminary office study should include a general review of local geological and soil mapping plus use of available aerial photography. Interpretation of aerial photography can provide a wealth of permafrost information if certain geomorphic features are identified: soil polygons, stone nets, regional drainage, and solifluction sheets. Additionally, ground relief from contoured maps and identification of vegetative types can be used to locate permafrost. Careful planning and scheduling of the field investigation is of the greatest importance in this phase, since the mobilization of a field investigation task force is expensive.<sup>3</sup>

Field investigations generally are conducted on two levels. The first is usually on a macroscale. The second level will occur during final design when site-specific information is required for a special engineering analysis, such as slope stability, frost heave, etc. Techniques and



**The permanent maintenance road adjoining the Kuparuk oil pipeline is gravel, designed in the mitigative mode (controlled subsidence). The line was constructed by equipment working on a snow (natural) road adjacent to the gravel, satisfying construction needs for a wide workpad.**

devices commonly used in the field to obtain subsurface information include: new aerial photography; thermistor strings; piezometers; seismic surveys; hand probing, test pitting, and grab sampling; electrical resistivity surveys; slope stability indicators; drilling and sampling; visual observations of drainage patterns, auffs, and snow depths; gathering meteorological data; and geologic mapping.

The information gathered in the field and in the laboratory through the analysis of soil samples is then reviewed in detail. Following this detailed review, the conclusions made during the preliminary office study are reassessed and necessary revisions are made. A final geotechnical report is then written and presented to the design engineers for use in choosing the design alternatives at specific sites.

On smaller projects, with tight budget constraints, elaborate investigations generally are not possible. However, a thorough preliminary office study with minimal to moderate field investigation still can yield a wealth of information when evaluated by a skilled investigator. The main point is: No matter what the budget constraints may be, a site investigation is mandatory! These investigations are an essential step in arriving at the cor-

rect design, thus ensuring a project constructed and operated within the allotted budget.

#### *Design Mode*

The collected soils/thermal data together with the microclimatological data will dictate the design mode, which for an earthen workpad can be either preventative or mitigative.

The preventative design is used to maintain the current thermal state of the soil, and is very expensive. Conceptually, this means the depth of thaw is either not permitted to enter into the subgrade or is allowed to extend down into the subgrade only for a given distance. The two basic designs that provide this action are an all-earthen embankment or insulation board with a reduced earthen embankment thickness. The preventative mode is seldom used on very long linear projects south of the Brooks Range, since most project sponsors believe the construction costs for this mode are too high; it may nevertheless be the most economical in certain situations. Generally, however, a mitigative design is used to place an earthen embankment on permafrost soil in the southern two-thirds of the state.

The mitigative mode allows for a controlled subsidence of the foundation.

Knowing what the thaw strain of the soil is will then allow the designer to include an additional embankment thickness for this controlled subsidence of the road. The thaw strain of a soil describes the probable consolidation of the soil when it thaws. Depending on the soil type and the design project life, several feet of additional material may be required to compensate for this subsidence in a very ice-rich material. Again, if the predicted foundation subsidence is large, a snow/ice road may be the preferred design.

Whether a preventative or mitigative design is selected, a thermal analysis is required to determine the required embankment thickness correctly on permafrost soils. Failure to conduct this analysis generally will produce long-term maintenance problems, and sometimes can result in a classic foundation failure. In either case, these dollars being spent were not included in the original project budget.

In areas where the soil is thawed, a structural workpad can be designed. A structural workpad is a road in which the principal consideration for the design embankment thickness is based on the total number of vehicle wheel passes anticipated over the project life, in combination with the weight of the equipment being placed on the road.

In recent years, the use of a construction material called Geofabric has become increasingly popular in constructing Alaska roads. This fabric has been used on permafrost-free soils to improve the load-bearing capability of those soils with a California Bearing Ratio (CBR) less than four, and on permafrost soils to prevent the subgrade soil from migrating into the embankment.

Minimal scientific data have been gathered during actual construction to define accurately the exact soil conditions necessary for soil pumping to occur. It is known that a fine-grain frozen soil must be present under thawing conditions, with excess pore pressures developing in the soil. The author has observed this soil pumping problem develop under two different construction conditions: first, where the vegetative mat has been broken by turning equipment in the early summer months, before or while the gravel embankment is being placed; second, in

wetland areas with ice-rich soils during mid to late summer when the gravel embankment was in place. In this second situation a plastic condition was typically visible on the embankment surface when the construction equipment drove over it. When this occurred the normal solution was either to increase the embankment thickness (up to 24") and thus redistribute the loading on the subgrade, or the construction traffic was removed until these excess pore pressures dissipated in the subgrade soils. These excess pore pressures are of a very short duration, usually 2-4 weeks; but unless this condition is accounted for in the design, the subgrade will fail when subjected to the impact loading of heavy construction equipment or commercial traffic.

In recent years the use of Geofabric has become quite popular, in lieu of the increased embankment thickness, to alleviate this instability problem which, in most cases, will prevent the development of a pumping problem. For our hypothetical project, using Geofabric produces a direct cost saving of \$156,000/mile.

Since so little is known about the exact soil conditions that cause soil instabilities/pumping, a designer who is not using actual field test data can only make an educated guess when deciding where additional gravel or Geofabric is required. These educated guesses can result in calling for 20-30% more gravel than is really required, but experienced construction engineers will recognize this danger. It is strongly recommended that the designer show the Geofabric or additional gravel on the construction plans/bid document as a contingency item to be applied at the discretion of the construction engineer. Ideally, additional research will be done in the near future on this problem to provide the designer with the necessary tools for accurately identifying those soil conditions that cause soil instabilities/pumping.

#### *In-Situ Materials*

By now, the designer is beginning to formulate the various design alternatives to be considered for the project. However, before a final report is written and presented to the cost/scheduling group for costing, there remains one final question to be answered. That is the availability of *in-situ* material.

The materials and methods available for construction of the facility must be carefully evaluated. On small projects, the engineer/planner normally is restricted to use of a single construction material and method due to cost restraints. However, on larger projects, such as TAPS, the engineer has more of an opportunity to utilize state-of-the-art design to lower construction costs while protecting the environment through a wise choice of construction materials and/or methods.

In the Arctic there are two main types of construction materials, earth (i.e., gravel, shotrock, silt, etc.) and snow. These two materials can be used in combination with others to lower construction costs and minimize impact to the arctic environment. At present there are six design options: earth, earth with insulation, earth with engineering fabric, natural or manufactured snow, ice aggregate and ice roads.

Depending on the intended use of the road, the construction season, the embankment thickness, material type, and construction methods, costs will vary greatly. For example, if the primary use of the road is for construction, such as it was on the TAPS project, the engineer/planner can optimize construction costs by scheduling winter and summer construction with these six design options. However, if the project is a public roadway, such as a state highway, the engineer/planner normally is restricted to use of the earth design options with late spring to late fall construction scheduling. In general, the design quantity of earthen construction material can be greatly reduced with winter construction. However, such scheduling may increase project costs due to decreased productivity of labor and equipment. This is not true with natural snow and ice aggregate; considerable short- and long term cost savings may be realized using these materials.

A further consideration is the available quantity of local material and the haul distance. If suitable material, such as ice aggregate or gravel, is in short supply and has to be hauled long distances, the associated cost may make an otherwise less desirable design option equally or more attractive than the preferred design. The availability of construction material

and its haul distance are therefore key pieces of information to be included in the report to the cost estimating group.

#### *Environmental Considerations*

In selecting the construction season, material and method to minimize costs, the design engineer must further consider satisfying the environmental restrictions (such as the presence of protected species like peregrine falcons, fish spawning protective restrictions, etc.). Many years ago, environmentalists had little impact on project costs. However, this is no longer true, and environmental concerns also must be carefully considered if the project is to be constructed and the costs kept at a minimum.

#### *Cost Analysis*

Once the cost/scheduling group has completed its analysis, the designer can then assess the overall project cost in relation to the preferred design options along the project route. For our discussion let us assume the cost/scheduling group on the hypothetical North Slope road has submitted unit costs for the seven design options found in Table 1.

Here the cost engineer has developed two unit costs, \$/CY (cubic yard) and \$/Mile. It is quite obvious that the two design options that should be given first consideration are ice aggregate and natural snow, which offer a potential savings of \$300-600 million on this 100-mile project. Historically, these two alternatives plus manufactured snow have been the least preferred design options for larger projects; earth has been the preferred road embankment material. This preference is primarily due to the lack of construction experience with snow and ice.

An abundant water supply is required for snow/ice construction. Manufactured snow and ice roads with a density of 0.6 gm/cc (grams per cubic centimeter) require approximately 2,000,000 gallons/mile, whereas natural snow and ice aggregate require 100-200,000 gal/mile. On the North Slope water is in short supply, so careful consideration should be given to developing a renewable water supply to avoid impact on the environment. One possible solution is to deepen the anaerobic ponds typically found on the North Slope, and place a snow fence

**TABLE 1**  
**COST/CY**

MATERIAL	*DIRECT COST
Manufactured snow (12")	\$17.56/c.y.
24" gravel w/2.5" insulation, Thermal Emb.	16.07/c.y.
Natural snow (12")	9.88/c.y.
Ice aggregate (12")	7.46/c.y.
Gravel (72"), Thermal Emb.	5.14/c.y.
Gravel (54"), Summer	5.14/c.y.
Gravel (30"), Winter	4.78/c.y.

**COST/MILE**

MATERIAL	*DIRECT COST
24" Gravel w/2.5" Insulation, Thermal Emb.	\$625,000/mile
Gravel 72", Thermal Emb.	448,000/mile
Gravel 54", Summer	423,000/mile
Manufactured snow (12")	304,000/mile
30" Gravel w/GeoFabric	239,000/mile
Gravel (30"), Winter	200,000/mile
Natural snow (12")	83,000/mile
Ice aggregate (12")	53,000/mile

\*Costs are based on The Blue Book rental rates for 1981 and Alaska labor rates for 1982.

partially around the pond. The snow fence can capture additional snow, which when melted in the spring will drain into the deepened pond.

Also, a thermal (preventative) embankment usually is required for a driving surface on the North Slope. Knowing this, there are essentially five design options to be considered:

- 1) 6' of gravel \$448,000/mile
- 2) 2' of gravel w/2.5" of insulation \$625,000/mile
- 3) 1' of manufactured snow \$304,000/mile
- 4) 1' of natural snow \$ 83,000/mile
- 5) 1' of ice aggregate \$ 53,000/mile

If this were an actual project one of the following designs might be recommended for the situations described:

1. In remote areas for projects requiring long-term year-round accessibility, a thermal workpad (option 1 or 2) would be recommended.
2. In remote areas for projects requiring short-term winter accessibility, such as mineral exploration, a snow/ice road (option 3, 4 or 5) would be recommended.
3. In areas with permanent roads adjoining the project (assume an oil or gas pipeline) a combination of options 1

through 5 could be recommended depending on scheduling and the pipeline's alignment with a permanent road (i.e., long-term access to the pipeline).

Note that the cost of installing drainage structures and material site restoration was not included in the earthen cost estimates; these two items typically will increase the cost of the earthen roadway by another \$50-75,000/mile. It also was assumed that the revegetation cost of earth vs. snow/ice is equal, which is not quite true; using snow/ice workpads would provide an additional savings of \$10-20,000/mile.

**COMMENTS**

Costs can be presented in many ways, depending on the individuals presenting them. This is particularly true when costs are presented for review to another organization. As will be noted in Table 1, natural snow costs \$9.88/CY and is the third most expensive design alternative, but is the second least expensive when compared on a \$/mile basis. When looking at overall project design, i.e. 100 miles of snow road vs. 100 miles of gravel road, the designer must always ask for unit costs per mile or the total cost. However,

if only a small segment of the proposed project is being considered for snowpad, a second cost analysis should be requested for this site-specific situation, since over short lengths there may be a break-even point where gravel construction is cheaper than snow.

One final caution on cost estimates: Be careful that the reported unit cost is not an "apple and orange" comparison. This means that one unit cost developed specifically for a given project should not be compared with a borrowed unit cost from another without first analyzing it. Such comparisons can be extremely biased without it being obvious to the unskilled analyst using this borrowed cost; for example, the original project may have confronted obsolete equipment, inappropriate construction techniques, extreme haul conditions, or poor weather conditions. A skilled cost estimator would make the necessary cost adjustments to eliminate this bias or might include it deliberately to cover appropriate contingencies, depending on the purpose of the cost estimate.

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