IV.3. LOCATION AND CONSTRUCTION OF ROADS IN THE DISCONTINUOUS PERMAFROST ZONE, MACKENZIE DISTRICT, NORTHWEST TERRITORIES

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Popular opinion to the contrary, northern road construction is not necessarily more difficult than southern road construction. Frequently it is more costly, and certainly it is different. It is important to be fully aware of the differences, as they can be advantageous.

ADVANTAGES OF NORTHERN ROAD CONSTRUCTION

What are some of the advantages? Most of the land in the Northwest Territories is Crown-owned and the locating engineer has almost free-rein in selecting the best route. There is usually little cause for the engineer to worry about utility lines, access to private property, negotiating for right-of-way, procuring rights to gravel and borrow pits, and other typical southern problems. Similarly, the contractor does not have to worry about handling heavy traffic during construction. He has exceptionally long hours of daylight in which to work during the construction season. Total precipitation is relatively low and summer temperatures are moderate (at least in the southern portions of the Territories). Usually, there is a much lower rate of turn-over for workers, since competing employers are greater distances away from the project. The working season can be as long as in the south.

DISADVANTAGES OF NORTHERN ROAD CONSTRUCTION

In most northern centres there is no pool of skilled workers; labour rates are higher than in the south, as are catering costs; materials are generally more expensive; there are few garages, repair shops, parts depots or wholesale outlets; and commercial utilities are rarely available near the road project. Then there are the natural problems - much of the terrain is covered with moss and muskeg. Large deposits of good gravel are conspicuous by their absence; soils are predominantly silty and, finally, the well known problem of permafrost. This has added importance in the discontinuous zone, because its occurrence can often be erratic and entirely unexpected.

DIFFERENCE BETWEEN CONTINUOUS AND DISCONTINUOUS ZONES

The difference between building roads in the continuous and discontinuous permafrost zones might be compared with the difference between building construction and road construction. In building construction, one is generally dealing with uniform and standard materials of construction; that is, the bricks, plywood and nails are uniform throughout the project. Similarly, in the continuous permafrost zone, although the terrain might be unfavourable, the road foundation strength is reasonably consistent. In the discontinuous zone, as well as having the normal variations in type and quality of soils, there is the added factor to contend with that permafrost can be encountered anywhere on the line in the form of islands. This can adversely affect construction, even if the permafrost is below working depth and not visible during construction. These islands of permafrost vary in area, thickness and depth below the surface. They should be carefully measured if there is any thought of stripping or excavating through them. If they are more than a few feet thick the wisest course of action is to avoid disturbing them. If a deep island is opened during construction, it is necessary to restore insulation before placing the embankment or to accept unstable conditions at that section of the road for a number of years until a thermal balance is achieved.

RULES FOR CONSTRUCTION IN PERMAFROST ZONES

In other words, all of the cardinal rules of permafrost construction must be considered when building roads in the discontinuous zone. Some of these rules are:- Thorough pre-planning, passive construction rather than active construction, special consideration for drainage, and maximum flexibility.

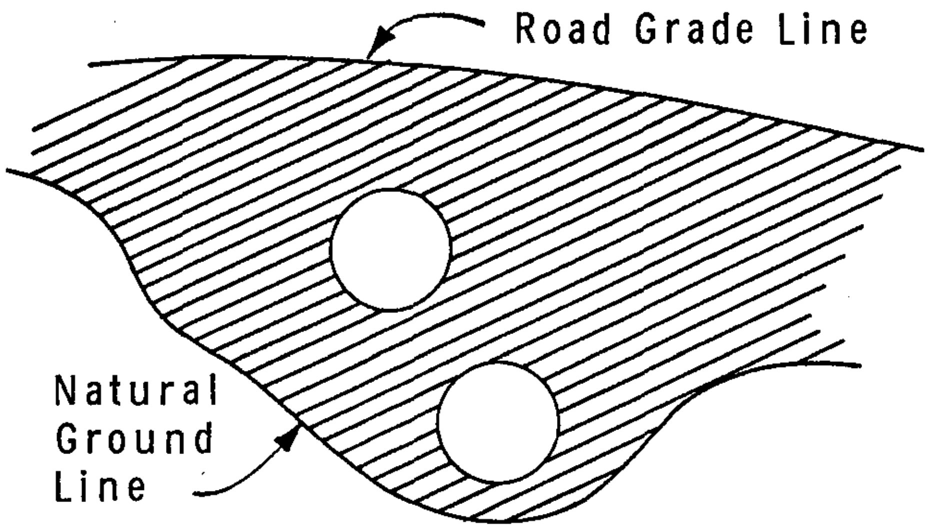
(1) Complete pre-planning is essential before undertaking any northern field work. Transportation facilities may be restricted or non-existent at certain seasons of the year and it is essential that men and equipment are ready to move when conditions are favourable. If the requirements for materials, equipment or men are not planned in detail, costly delays can occur during a project and often a full season can be lost.

(2) Passive construction rather than active construction - that is, disturb the existing thermal regime as little as possible. This applies to engineering work as well as construction. If vehicles are run over the insulating mat of vegetative cover in permafrost sections during location, the insulating value is reduced and a water-filled canal is left as a foundation for the embankment. There is generally an unnaturally high water content in permafrost soils. Uncontrolled stripping of the vegetation mat can result in large settlements and turn the terrain into a quagmire. This is closely related to the next problem - drainage.

(3) Drainage must receive special consideration in the North. Maintain existing drainage patterns as much as possible. Avoid carrying water for long distances on the right-of-way. If it is necessary to disturb the insulating mat when placing drainage structures, this must be compensated for during construction. The normal rules for calculating the size of drainage structures are only a guide as far as northern installations are concerned. Permafrost greatly retards the natural downward movement of surface waters. Therefore, flash flood conditions are much more common in the North than in the South. Structures must be large enough to accommodate the peak spring runoff. It is easy to miscalculate the required size of drainage structures if the drainage basin is not thoroughly studied. There may be a substantial depth of thawed soil at the site of the drainage structure, while the drainage basin contains very little thawed materials over the permafrost. This will result in much greater volumes of surface runoff than could be anticipated from the soil condition at the drainage structure site.

Flowing water tends to thaw the permafrost, and where velocities are not controlled in new construction, serious erosion can result in the silty soils.

There is also the problem of icing. Icing is a condition that has been discussed in a number of technical papers and a number of solutions have been developed. Probably the best known of these is to transfer the icing from the structure to a location where it will do no harm, by some means such as erecting low barriers in the stream to generate icing in advance of the structure. This does not work at every location and other means have to be developed to ensure that the drainage structure will have sufficient clear capacity to handle spring runoff and avoid road washouts during break-up. One system used with some success on the Mackenzie Highway south of Hay River has been dual-staggered installations of culverts where icing is anticipated.



SIDE VIEW OF DUAL-STAGGERED CULVERTS

These installations are in relatively high earth fills. A pipe is placed in the lower portion of the fill to handle normal summer flow. Some icing-up of this structure can be tolerated but the design is intended to prevent complete icing-up. A second pipe is installed in the fill, above and to one side of the first pipe. This second pipe normally does not carry any flow during the summer or early winter season, so little or no icing occurs and its full capacity is available for spring flooding conditions. There might be some backing up of water during the early stages of the peak runoff but the ice decays rapidly in the lower pipe and its capacity is soon available to handle the peak flow conditions. Staggering the two pipes means that less vertical distance is required for the dual installation, reduces the amount of initial back-up and reduces the chance of washout from having too large a plane of weakness in one cross-section of fill.

There is not sufficient space in this paper to discuss the many other aspects of drainage that must be considered in northern road building. It is sufficient to say that the importance of drainage cannot be overemphasized.

(4) Flexibility in men, equipment and design is essential to achieve efficiency and economy of operations. Flexibility is closely related to planning and has added importance in the discontinuous zone; for example, in the choice of transportation and construction equipment. Transport must be able to traverse muskeg, boulder-strewn country and bedrock outcrops as well as more regular types of terrain. Construction equipment also must be able to contend with the varying conditions that are encountered particularly in the discontinuous zone. It is well to avoid too many extremes in the size or type of equipment. A D-6 might be most economical for some small items of work on a project and a D-9 might be the most logical piece of equipment for other items of heavy work. On the average northern job, it is probable that neither unit can be employed continuously, with an acceptable degree of efficiency, on all the different work encountered. Usually, contractors achieve a greater degree of flexibility by employing mid-range equipment.

The field construction engineer must be sufficiently flexible in outlook to handle the unexpected. For example, during construction north of Fort Providence, very little permafrost was encountered in the first hundred miles of road. It was encountered, however, at Birch Creek, one of the two streams on that section of road. Its occurrence at a stream crossing was completely unexpected because of the known fact that flowing water promotes thawing of permafrost.

The road designer must incorporate the maximum degree of flexibility in his designs to meet not only variations in conditions along the route, but overall changes that occur from year to year.

Because cost is a most important consideration for northern roads, flexibility must extend to the selection of embankment soils. Some authorities suggest that northern road embankments should be entirely constructed of granular material and it is commonly accepted in the south that silt should be completely excluded from roads. These principles are desirable, but if we attempted to follow them religiously in the Territories, we could not afford to build many miles of road. Economic considerations have forced us to use native materials, within reasonable haul distances. This means that the majority of our embankments are built of silty materials. Much of the highway north of Yellowknife is built of a soil which has 95 per cent or more passing a 200 mesh sieve. This road is standing up well to heavy loading and high speed traffic.

ROAD ENGINEERING AND CONSTRUCTION TECHNIQUES

Since 1956 the Federal Government has been carrying on a regular program of road construction in the Northwest Territories and a large part of it has been in the discontinuous permafrost zone around Great Slave Lake. Engineering and construction techniques have gradually been evolved to meet the unique challenge presented by this region.

Location

Because placing and maintaining large survey parties at northern locations is costly, every effort is made to do as much of the preliminary engineering as possible before the main party moves into the field. R.C.A.F. air photo coverage is available for much of the North. When the general location for a proposed new highway has been established, air photo mosaics are prepared, a detailed stereoscopic examination is conducted and an approximate route selected. Alternate locations are also indicated. An interpretation report is prepared for the guidance of the field engineers.

A location engineer then makes a complete aerial reconnaissance of the route with a light aircraft or helicopter. If terrain permits, he lands at a number of points to check or supplement information supplied. On the basis of this reconnaissance, a final route is selected and route report is augmented with the observations of the reconnaissance engineer. Depending upon the complexity of the location, scarcity of good construction materials, etc. a decision may be made at this point to arrange for low level photography and a further route refinement. If possible, an 8 to 10 foot wide line should be cleared along the approximate route before the low level flying, since this will prove of considerable benefit to the interpreter and will also provide access for the location party.

Wherever possible, arrangements are made to bulldoze this base line before the main location group moves into the project. The bulldozer is guided by a location engineer. Where there are few landmarks, the location engineer frequently employs a light aircraft with two-way radio contact to put the bulldozer on line. As part of this same operation, the bulldozer builds small airstrips, provides access to lakes, checks gravel pits and places temporary fills across streams. It is possible to average as much as 5 miles of line per day with this technique. Once the proposed line has been cleared, the main location group moves in with trucks or track vehicles to complete the detailed work of location without being delayed for line clearing. Aside from the economy, this method simplifies servicing problems and makes it possible to take maximum advantage of the short season suitable for location work.

Where the tree cover is not too heavy and there are a number of small lakes, the bulldozed line is eliminated; two or three location groups are placed in light fly camps and leap-frogged along the line with float planes. In all cases, the exact method of location is adapted to terrain and weather conditions.

Construction

Generally, an advance notice of tender call is advertised many months before the actual tender call, to give the contractor ample opportunity to inspect the project at his leisure so that even if tenders are called in the winter, he has had an opportunity to make a careful assessment of the terrain.

The Federal Government has tried different types of bid contract for northern road projects. It has been found preferable to contract rather than construct with government forces and equipment. A number of types of contract are possible, such as, cost plus, lump sum, equipment rental and unit price. Each has advantages and disadvantages. For example, on lump sum contracts, while the government has a fixed, guaranteed price for the project, the contractor has to introduce a wide safety margin in his price for unknowns and variables. The cost plus contract and the equipment rental contract do not provide sufficient incentive for the contractor to use his ingenuity in planning and execution of the work. They provide, however, for complete flexibility in changing construction procedures, alignment, gradients, etc. and often have low engineering costs. In particular, they eliminate the cost of re-measurement and quantity calculation. The unit price contract is the most popular type for highway construction because it encourages the contractor to operate at maximum efficiency. It does require comparatively rigid design and a high engineering expenditure. Under this type of contract, the engineering costs on a northern development road can approach the engineering costs of a high-class highway.

SPECIAL FORM OF CONTRACT FOR DISCONTINUOUS ZONE

The attempt has been made to develop a type of contract for roads in the discontinuous zone, that includes the maximum number of advantages, and the minimum number of disadvantages of all the possible contract types. This has resulted in a contract combining cost-per-mile and unit price items. In drawing up the plans and specifications for this form of contract the emphasis has been on the end product; i.e., what is the objective rather than how is it to be achieved? The objective is to build a gravel road for year-round use, requiring the minimum practical amount of maintenance, at the lowest engineering and construction cost. This means that the contractor must be given sufficient information on terrain and soil conditions to enable him to calculate his bid with reasonable accuracy. He must also be given enough leeway to change sources of material, types of material, and construction procedures during the course of the work, so that he can operate at peak economic efficiency throughout the contract. This is how the objectives are achieved.

Contract plans show three typical types of cross-section identified as 'A', 'B' and 'C' (Figure 1). Type 'A' is the conventional side ditch type commonly used in the South. In the discontinuous zone, this type is used where permafrost is below working depth, materials on the right-of-way are suitable for embankment construction, and drainage conditions are not too adverse. Type 'B' is a fill section which may or may not be constructed with pilot ditches along the edge of the right-of-way. This cross-section is designated for areas where permafrost is within working depth, or where muskeg and moisture conditions rule out side ditch excavation. The final type, Type 'C', is the cut or fill rock section.

Plans

The typical plan-profile sheet shows the following information:- type of tree cover, location of low-lying land, ground contours and centre line profile. Also centre line borings which indicate soil types and horizons as well as water and permafrost levels. The designer also indicates the proposed centre line grade as well as the location of borrow material where there is any possibility of insufficient material on the right-of-way for embankment construction. The location and length of offtake ditches is shown, as well as the location, size, and elevation of drainage structures. Requirements for side ditch drainage are shown for both sides of the right-of-way. Finally, the recommended type of cross section - 'A', 'B' or 'C', is clearly marked on the plan.

Specifications

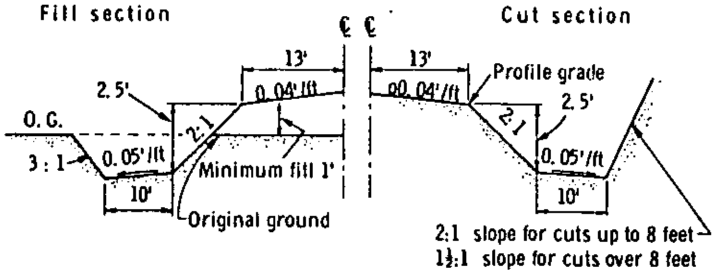
The standard job specification of this contract is presented here. First, the clearing and grubbing specification directs that all clearing on the right-of-way shall consist of cutting trees and brush to within 1 foot of the original ground line, whether in permafrost areas or not. Permafrost areas are shown as "special clearing areas" on the plans and all operations must be performed so that the existing insulation of fibrous material is not damaged. Furthermore, in these areas all cleared material must be placed in a flattened layer over the embankment area to improve the insulation. In the non-permafrost sections, the clearing debris is either burned or disposed of by other approved methods. Grubbing is only performed on areas specifically designed by the engineer (that is under shallow fills or in excavation areas). Clearing and grubbing on the right-of-way are both paid for on the unit price basis.

The main job specification, that is roadway construction, includes the formation of all roadway ditches and embankments. The contractor is allowed to use any non-organic material for embankment construction except material specifically reserved, such as gravel for surfacing or concrete construction. Since the contractor is free to take embankment material from any source, clearing of borrow pits is listed as an incidental item; that is, there is no direct payment. If, at any location, the contractor wishes to construct a section type different from the one shown on the plans, (such as 'B' section instead of an 'A' section) the variations are permitted if approved by the engineer. For example, if the contractor is having trouble moving wet side ditch material, he can move his machines to a drier borrow area. The engineer establishes the minimum acceptable dimensions of the variation in order to achieve consistency of design.

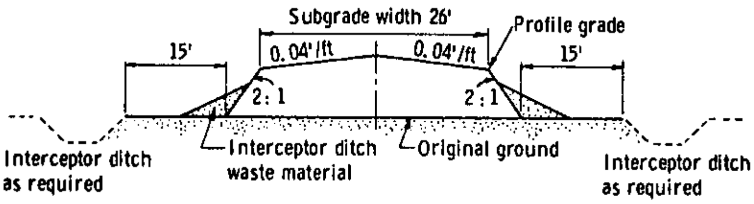
The specifications also state that the grade line shown on the plans is the minimum acceptable standard for the specified section type. Aside from areas where it is necessary to control rigidly the grade line such as bridge approaches, the contractor may have to adjust the height of grade depending on the type of embankment material he uses, so that the end product will be able to stand up to an 18,000 lb. repeating axle load. Rock excavation is paid for on a unit price basis, but all other work involved in the roadway construction item is part of the per-mile bid price.

Offtake ditches, supply and installation of culverts, and supply and haul of gravel surfacing are all paid for on a unit price basis. This gives the required degree of flexibility to meet changes in drainage and soils encountered during construction.

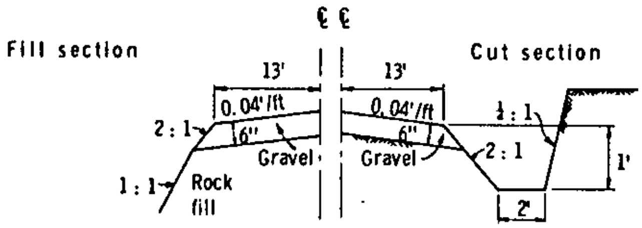
With this type of contract there is no stinting on preliminary engineering or design work because it is deemed necessary to give the contractor complete information on a project to make intelligent bidding possible. Substantial savings are achieved on construction engineering costs. The job crew is only half the size of the crew required for a unit price project and it is able to submit final estimates on jobs almost as soon as the project is finished rather than spending many weeks in re-measuring and calculating pay quantities. This saving in engineering costs can be in the order of $2,000.00 per mile or more. There is also an appreciable saving in contract costs owing to the greater freedom given to the contractor to improvise and use his ingenuity.



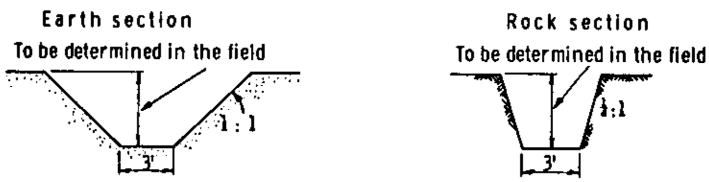
TYPE 'A' SECTION - CONTIGUOUS DITCH



TYPE 'B' SECTION - FILL AREAS



TYPE 'C' SECTION - CONSTRUCTION THROUGH ROCK



INTERCEPTOR AND OFFTAKE DITCH SECTION

Note:

(1) Slopes & distances shown are minimum
(2) Subgrade widened 2' on curves
(3) Interceptor ditches will be constructed
if indicated on the plans

Not to Scale

FIGURE 1

TYPICAL CROSS-SECTIONS N.W.T. DEVELOPMENT ROADS

This style of contract is not foolproof but it has proved satisfactory in the discontinuous zone around Great Slave Lake, and may have equal merit in other regions of the North. There is every intention of practising what is advocated by maintaining a flexible attitude to all aspects of northern road building, both engineering and construction.

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Discussion

J.L. Charles asked why there is a grade line on the Yellowknife Highway at Franks Channel. The author replied that it was required to provide a sufficiently high bridge for boat traffic between Fort Rae, N.W.T. and Great Slave Lake.

R.A. Hemstock enquired whether Type 'B' construction was used in any areas where brush is not available. In the tundra or high arctic, where no brush is available, will there be sufficient insulation material available? J.J. Wallace replied that there were many instances of Type 'B' roads being constructed without using brush. The author added that the road surface may shift slightly but there is not sufficient movement to affect traffic. Out of 10 culverts, 1 or 2 might have to have riprap. J.L. Charles commented that in 1926 many miles of track for the Hudson Bay Railroad were laid on the tundra surface with no brush being used. The track was laid in winter and the natural ground surface was not disturbed.

G.H. Johnston asked if there is a minimum depth of fill used in the Type 'B' section. Savage replied that the minimum depth is 2 feet. In reply to a further question by G.H. Johnston asking whether the road fill is constructed prior to the thawing season, the author replied that construction begins when the contractor arrives at the site. Finally, G.H. Johnston asked whether any difficulties had been experienced in these sections. The author stated that ditching before the fill is placed is the answer to northern road construction.

R.S. Taylor enquired what is the working depth in the Type 'A' road, for example. The author replied that a 4 to 5 foot depth of centreline borings is considered the working depth. The main concern is not with ditch sloughing but the road itself.

R.A. Hemstock asked if all road construction is carried out in summer. Savage replied that the season lasts from late May to November. R.A. Hemstock commented that analysis in Sweden showed that it was more economical to work throughout the year and not spend time and money moving construction crews to and from the site. The author replied that climatic conditions are less severe in Sweden than in northern Canada but this practice is being tried in Manitoba. During construction of the Yellowknife Highway, equipment was moved into the area in early spring and ruined by the severe climatic conditions and abrasive soils. Contracts are drawn up on a unit price basis. The contractor decides on the length of the construction season and arrangements must be flexible. J.L. Charles pointed out that much of the construction of the Great Slave Railway to Pine Point was done in winter from granular borrow pits. Savage commented that silty soil is very hard on equipment. J.L. Charles commented that it is advisable to work in winter because the trafficability is better than in summer. The author replied that the choice is left to the contractor.

K.O. Anderson asked whether northern roads will be paved and how much reconstruction would be required. Savage replied that considerable work would be required to prepare roads for paving. The Alaska Bureau of Roads has experienced failure of black top over permafrost in Alaska. T.A. Harwood commented that the black top on the Alaskan portion of the Alaska Highway had caused slow differential thawing of the underlying permafrost. This has resulted in a series of long gentle undulations in the road which are dangerous for high speed traffic. This problem has not arisen on the unpaved Canadian section.

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