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FINAL REPORT

WINTER HIGHWAY CONSTRUCTION

by

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ABSTRACT

This report focuses on the feasibility of extending the highway construction season further into the winter season than is currently practiced in Alaska. It reviews the literature of research and project experience in accomplishing several elements of successful highway construction in the winter. It summarizes the cold weather sections of highway construction specifications from 18 states, provinces and foreign countries. It reports on personal interviews and survey questionnaires with 24 Alaskan contractors who have been engaged in building highway elements in the winter.

The report concludes that additional winter highway construction should be permitted in Alaska and urges the Department of Transportation and Public Facilities (DOT&PF) to revise its specifications, on a trial basis, for selected projects in order to permit construction of embankments and asphaltic concrete pavements at below-freezing temperatures. Further research on "cold" concrete, additive materials in embankments and construction productivity is suggested.

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INTRODUCTION

Fifteen years ago, Robert G. Zilly (1971) made the following comment.

> "The Swedes handle winter construction with thermal underwear, the Russians do it with precast concrete and guts, the Canadians do it with modern technology and government support, and the Americans do it reluctantly if at all. In short, the United States construction industry has been too busy discovering why it cannot build in the winter, not busy enough discovering why it can."

Since that statement was written, developments in cold regions of the world have dictated a considerable increase in winter construction. In Alaska, the construction of the transAlaska oil pipeline brought about considerable progress in the technology of cold weather construction.

This report investigates the feasibility of increasing highway construction in the wintertime. I begin with a review of the cold weather construction literature, reporting on results of both research and practice relating to several of the operations associated with highway construction. I then review the cold weather aspects of highway construction specifications from 11 U.S. states, five Canadian provinces, and two foreign countries, to ascertain the operations that those jurisdictions permit in the wintertime. I discuss a series of interviews and questionnaires of 24 Alaskan highway contractors who report their experience with successful construction operations in the wintertime, give their views on limitations to cold weather highway construction and make suggestions for changes in the cold weather portions of the Alaska Standard Specifications for Highway Construction.

The final section of the report suggests several aspects of embankment, asphalt pavement and concrete construction that DOT&PF might consider allowing in the wintertime. I suggest that these be investigated either as portions of selected actual highway construction projects or as research efforts.

While constructing highways in the wintertime can be expected to involve additional costs for most operations, when compared to similar construction under milder conditions, there may be other advantages to building in the wintertime. Bieganousky and Lovell (1976) cite the following potential benefits of cold weather construction:

1. greater utilization of equipment and capital;
2. stable year-round work force of experienced operators;
3. availability of rental equipment because most equipment is idle during the winter;
4. opportunity to meet completion deadlines and hence, no penalty fees;
5. supplies readily available in the off-season;
6. reduction of costs, which can accumulate while construction jobs sit idle;
7. saving in unemployment insurance rates;
8. savings derived by not staffing a skeleton crew during shutdown; and
9. cost savings derived from easier construction under certain circumstances.

This report is presented in the hope of achieving some of those advantages for the Alaska Department of Transportation and Public Facilities.

LITERATURE REVIEW

One of the project's major efforts involved the review of articles and research reports related to several types of highway construction attempted in the wintertime, their degrees of success, and the efficiencies and costs of several activities when carried out in the wintertime. This section summarizes that review. Many of the experiences reported in the literature were also mentioned during the contractor interviews which are summarized later in this report.

Roberts (1976) reports that, with proper clothing and winterized equipment, work can be performed successfully at temperatures of -20°F;

equipment efficiency decreases by about 20%, while the efficiency of manual laborers decreases by 50%. All comparisons were based on 100% efficiency at conditions of 50°F air temperature, indirect sunshine and no precipitation. The efficiency of manual laborers decreases to 92% at dusk and to 56% in subarctic winter twilight, whereas the efficiency of construction machinery declines to between 88% and 96% at dusk, and between 65% and 82% during subarctic winter twilight. Roberts also found that heavy snow reduces the efficiency of manual laborers to 41% and the efficiency of construction machinery to between 73% and 76%.

Excavating Frozen Ground

The excavation of frozen ground appears to be gaining acceptance. Large ripping tractors are used routinely to excavate frozen ground (Yoakum, 1976). Ripping is limited by the type of materials that must be excavated. Some soil types that are saturated with ice often require blasting techniques (Tart, 1983). Frozen ground was routinely ripped at temperatures down to -40°F during the construction of the transAlaska pipeline.

In some cases, culvert excavation can be performed more easily and less expensively in the winter when the ground is frozen. The frozen ground keeps the excavated area free of excess groundwater. Likewise, large excavations, such as borrow pits and highway cuts, are often worked during the winter. Special techniques are required if the excavated material is to remain unfrozen. Once the area is opened to unfrozen material, work must be continued 24 hours per day, seven days per week, until it is completed. The excavation must be reduced to as small an area as possible to reduce the area exposed to freezing. Often, loading is done with power shovels or front-end loaders because the exposed area is the side of a high bank, rather than a horizontal surface where scrapers could be used (Bieganousky and Lovell, 1976).

Excavating Marsh, Muskeg and Peat

It is often advantageous to excavate material with low bearing capacity in the winter. One method is to allow the material to freeze to predetermined depths and then partially excavate the frozen material, allowing the remaining frozen material to support the weight of the equipment. The excavation is then allowed to freeze to additional depths and is further excavated. The process continues in stages until completion (Rafson, 1979).

Hauling, Spreading and Compacting Soil

The literature suggests that haul distances should be kept to a minimum in the winter. Short hauls reduce the chances of having the material freeze, and there is also less of a tendency to freeze to the bed of the hauling equipment. Diesel fuel and antifreeze are sometimes sprayed on the hauling beds to prevent adhesion of the material to the sides and bottom of the beds. Likewise, loading equipment may need protection to prevent material from freezing to buckets.

In many jurisdictions, fill may not be placed on frozen ground (Bieganousky and Lovell, 1976). Therefore, successive lifts must be spread and compacted before the material below freezes. A ramp method of spreading and compacting fill is often recommended for embankments. Some states allow fill to be placed on frozen ground, as long as the ground has been properly compacted in the thawed state (Yoakum, 1976). Also, some states allow frozen materials to be used in embankments, but the limitations are stringent (Havers and Morgan, 1982). Havers and Morgan also report that some 15 states have constructed satisfactory fills when air temperatures were below 32°F. In northern Alaska, it is common practice to place fill material on frozen ground directly over the existing vegetation. Such practice allows the vegetation to be used as a layer of insulation, and it also allows improved trafficability during the winter months, when the otherwise spongy ground is frozen and able to support the weight of equipment.

Adequate compaction of well-graded aggregate at a temperature of +7°F has proven very difficult with present techniques. In one test, soil with a 2% moisture content (lower than naturally occurring gravel) was compacted with a jackhammer; the resulting density was well below that normally required (Kinney, 1984). Other studies have indicated that the effectiveness of field compacting is highly dependent on the moisture content of the soil (Haas et al., 1977).

The use of additives to depress the freezing point of granular embankment material has been tested with some success. Indications are that this method is costly and that further research is needed to determine less costly approaches using this method (Haas et al., 1978).

One further aspect of material excavation and placement is that of riprap. Bieganousky and Lovell (1976) report that such excavation and placement present little difficulty in cold weather.

A series of laboratory and field experiments conducted by the University of Oulu, Finland, investigated the feasibility of winter compacting of the embankment, "insulation course," and subbase course in road construction. Winter compaction of the embankment and insulation course was successful even below freezing, although highly dependent upon water content, whereas subbase compaction was less satisfactory. Saarela (1974) concludes, "On the basis of the test results presented above, the winter compaction of sand and gravel soils can be considered appropriate and practicable if it is done correctly. Otherwise, winter compaction can even make the construction layers of the road looser. It depends on conditions, soils and plant available what densities can be obtained. In specific cases additional compaction in summer would not be necessary."

Constructing Asphalt Pavement

With one exception, the literature lacks any reference to asphalt construction at temperatures below 35°F. The exception reports the paving of the Chicago Skyway Toll Bridge with bituminous concrete at "near zero air temperatures" (Bennett, 1975). In this project, insulated trucks were used to transport the hotmix. The material was placed and rolled in the cold weather, and left unprotected.

Research studies related base and material temperatures to resultant compacted densities of the asphaltic materials. One result was that compaction must be completed quickly at low temperatures (Eaton and Berg, 1981). Other studies investigated preheating the base using propane heaters (Shah and Dickson, 1976). A study by Maupin (1973) cites base temperature, laydown temperature, thickness of the fresh mat, and the lowest possible mat temperatures for compaction as the most important criteria when using asphalt for paving operations. This study resulted in a nomograph relating these factors.

Other studies of pavement design considered the use of embankment insulation which can be placed during the winter. Such insulation reduces thaw penetration and also reduces subgrade thaw settlement because of the lighter weight embankment design (Falls and Haas, 1979).

Concreting

Two basic approaches to cold weather concreting are used. The first uses cold concrete with no special precautions beyond the correct use of admixtures; this approach is not commonly used in western countries. The more common practice is to use standard concrete that is protected from freezing until it is adequately cured. The literature reports several examples of protected concreting for bridge construction, including: Vermont highway bridges in 1928 at temperatures as low as -20°F; deck concrete for a bridge at Ft. Pierre, South Dakota, at temperatures as low as -10°F in 1955-1956; the construction of piers for a highway bridge in Ontario during the 1957-1958 winter at temperatures as low as -30°F; and the concreting of a bridge deck at Bethlehem, Pennsylvania, in 1969-1970 while outside temperatures were 0°F and below (Bennett, 1975).

The American Concrete Specifications on Cold Weather Concreting (ACI 306, 1983) provides detailed guidance on the minimum temperatures of fresh concrete in thin, moderate and mass sections at different air temperatures. It also provides guidance for the duration of protection of air-entrained concrete placed in cold weather.

Havers and Morgan (1972) compiled specifications from several countries and organizations that indicated widespread differences in allowable practices. For example, the minimum practical air temperature for concreting ranged from -4°F in Sweden to +20°F in Denmark. Havers and Morgan also document the use of preheated water and aggregate for cold weather concrete.

Several approaches to the temporary protection and curing of freshly placed concrete have been reported (Bennett, 1977). Cautions related to heated enclosures include the need to ventilate combustion products from heaters and the fact that low humidity inside the enclosures tends to evaporate moisture from the concrete more rapidly than normal.

Methods of curing concrete include steam curing, "thermos" curing (using insulated forms to trap the heat of hydration), and electric curing, a method developed in the U.S.S.R. (Havers and Morgan, 1972; Thorpe, 1983).

A Report from Finland

To conclude this section, a report from a rather interesting research project conducted in Finland is summarized (Turunen, 1980). The report is based on a survey of road construction in the wintertime carried out under the auspices of the Roads and Waterways Administration of Finland. Nine projects, each involving major improvements of old roads, were closely followed and reported upon. The stated aims of the study follow.

1. "To calculate the relative costs of the different phases of construction in different seasons;
2. to characterize different aspects of road construction in winter conditions; and
3. to give recommendations for the working phases best suited for wintertime."

Monthly reports from each project were analyzed, and construction site engineers and technicians were interviewed. The results indicated average costs for each of several road construction elements in both summer and winter for each project, an average cost for each element for all projects in both summer and winter, and an average unit cost per unit distance for a typical roadway section in both winter and summer. Table 1 lists the relative costs of winter construction for each element

TABLE 1. Relative costs of winter construction, assuming summer averages = 100 (from Turunen, 1980).

Work	Project									Average	Earlier Results	
											Finland	Sweden
	1	2	3	4	5	6	7	8	9		1969	1963
Clearing	158	111	92	110	176	180	196	239	219	165	170	172
Drainage with open ditches	132	282	--	132	262	--	--	84	53	157	175	174
Drainage with pipes	--	--	--	178	--	--	--	--	--	178	115	116
Culverts	27	157	96	129	153	208	124	--	--	142	110	111
Rock cuttings/rock fill embankments	107	--	--	--	--	--	--	--	--	107	105	105
Earth cuttings/ earth fill embankments	115	--	122	123	80	--	--	--	--	110	110	119
Filter course	71	77	--	130	101	--	87	--	129	99	103	
Subbase	118	--	--	103	105	82	89	--	175	112	103	103
Base course	--	58	--	117	141	150	--	--	41	101	112	107
Crushing	--	138	--	85	--	79	--	--	--	101	110	110

studied and for each project, as well as an average for each element and results from previous studies in Finland and Sweden.

Table 1 indicates that clearing, drainage and culvert operations were considerably more costly when conducted in the wintertime. For example, clearing had an average cost of 165 in winter, compared to summer averages of 100.

Many operations were slightly more expensive in the wintertime, and one operation (filter course installation) was slightly less expensive in the wintertime (99 in wintertime vs 100 in summertime) according to this study. The report observes, "In some cases it is cheaper to work in wintertime than in summer, because the frozen soil facilitates work-site traffic and transports."

Table 2 (also taken from the Finnish report) indicates the suitability of different construction operations in the wintertime based on the material presented in Table 1. The report comments, "For some activities, no single alternative could be given. The conditions on the working site decide whether the activity concerned is favorable for wintertime or not."

This comment underscores the importance of project specific conditions in deciding whether to conduct any construction activity in winter. The numerical results from the cited study should be used only as general guidelines.

In analyzing the overall cost difference of a typical roadway section constructed in the wintertime, the author concludes that the costs can be expected to increase by between 3.5% and 7.5%, with this range attributed primarily to the timing of the beginning of the construction. The report states, "The choice of startpoint to September, good planning of works and efficient execution keep the additional costs caused by winter to about 3.5%." Finally, the report warns, "If, in addition, the increased loss of materials and poor quality are considered, the realistic range could be some 5 to 10%."

TABLE 2. The suitability of different construction phases for wintertime (from Turunen, 1980).

Construction phase	Suitability		
	Very suitable	Suitable	Less suitable
Clearing			x
Drainage, open ditches			x
Drainage, pipes		x	x
Rock cutting/rock fill embankments	x	x	
Earth cutting/earth fill embankments	x	x	x
Filter layer, sand	x		
Subbase		x	
Base course			x
Crushing	x	x	x

SPECIFICATION REVIEW

This portion of the study reviewed highway construction specifications dealing with earthwork, concreting and asphalt paving at cold temperatures. Requests for copies of relevant specification sections were mailed to 28 U.S. states, Canadian provinces and foreign highway departments. Eighteen of these requests brought responses with materials useful to this study. Some went so far as to provide a complete set of all current highway construction specifications from their jurisdictions. Of the 18 responses, 11 were from U.S. states, five from Canadian provinces and two from other foreign countries. Table 3 lists those jurisdictions whose specifications were reviewed.

TABLE 3. Winter highway specifications reviewed.

United States	Canada	Foreign
Alaska	Alberta	Denmark
Colorado	Manitoba	Sweden
Maine	Nova Scotia	
Michigan	Ontario	
Minnesota	Saskatchewan	
New Hampshire		
New York		
North Dakota		
Vermont		
Washington		
Wisconsin		

Earthwork

Table 4 summarizes highway construction specifications for earthwork. Some specifications make no mention of specific weather limitations on winter work, while others specify that no frozen materials shall be used in the construction of embankments.

Four jurisdictions allow placement of frozen materials under some conditions. Minnesota allows frozen lumps up to six inches maximum dimension to remain in the embankment, while lumps greater than that dimension can be used in the portion of the embankment outside a 1:1 slope down and outward from the shoulder line. New Hampshire also allows frozen lumps outside the limits of a 1.5:1 slope from the shoulder line. In Vermont, rocks and granular material may be placed while frozen. In Sweden, frozen material may be placed outside a 1:2 slope from the shoulder line.

Six jurisdictions allow the placement of embankment materials on frozen ground in some circumstances. Alaska, Michigan and North Dakota state that such placement is possible with written permission of the engineer. Maine allows construction on frozen material, provided the total depth of the added fill, plus the depth of the frozen material beneath, does not exceed five feet, and provided further that the material has been properly compacted prior to freezing. In Minnesota, an embankment can be placed on frozen ground provided the soil is not frozen to a depth greater than four inches. Furthermore, no material can be placed if it begins to freeze before it is properly compacted. New Hampshire allows base course materials to be placed on frozen material if the depth from the top of the base course to the bottom of the frozen material does not exceed 2.5 feet. Some locations limit earthwork construction by season or atmospheric temperature rather than material condition. For example, New York prohibits winter earthwork to be constructed between November 1 and April 1 without written permission from the regional director. In Saskatchewan, the specifications require that base courses may not be spread and compacted if the atmospheric temperature is below 36°F.

TABLE 4. Summary of highway construction specifications for earthwork.

Highway department	Specs for winter highway construction	Have specs for earthwork	Allow frozen material placement	Allow placement on frozen ground
Alaska	yes	yes	no	no(1)
Colorado	yes	yes	no	---
Michigan	yes	yes	no	no(1)
Maine	yes	yes	no	yes(5)
Minnesota	yes	yes	yes(2)	yes(6)
New Hampshire	yes	yes	yes(3)	yes(8)
New York	yes	yes	---	---
North Dakota	yes	yes	no	no(1)
Vermont	yes	yes	no(4)	no
Washington	yes	no	---	---
Wisconsin	yes	yes	no	---
Alberta	yes	no	---	---
Manitoba	yes	no	---	---
Nova Scotia	yes	no	---	---
Ontario	yes	no	---	---
Saskatchewan	yes	yes	---	---
Denmark	no	no	---	---
Sweden	yes	yes	yes(7)	no

(1) Can be placed with written permission of the engineer; some designs require placing embankments over frozen ground.

(2) Sod and frozen lumps less than six inches can be placed inside a 1:1 slope.

(3) Frozen material shall be placed outside a 1.5:1 slope from the break in the shoulder.

(4) Rocks and granular material may be placed when frozen.

(5) Provided the total depth of the added fill and subbase, plus the depth of the frozen material does not exceed five feet.

(6) Embankment can be placed on frozen ground provided the soil is not frozen to a depth greater than four inches.

(7) Frozen material may be placed outside a 2:1 slope.

(8) Frozen lumps of material may be used outside the limits of an assumed 1.5:1 slope from the break in the shoulder line and inside the designated or ordered slope line.

Concreting

Table 5 summarizes highway construction specifications related to concreting operations. Of the 11 U.S. states whose specifications were reviewed, only Colorado has no specifications for cold weather concreting. Of the five Canadian provinces, only Alberta has no specifications related to any cold weather highway construction. Neither Denmark nor Sweden includes cold weather concreting in its highway construction specifications.

Most specifications provide considerable details with regard to the accepted means of heating water and aggregate in cold weather. The combined temperature of the aggregate and water before mixing with the cement is usually limited, to avoid flash setting of the mixture due to high temperatures. Most jurisdictions do not mention the use of admixtures. Only Minnesota (of those reviewed) allows admixtures with approval of the engineer. Alaska and North Dakota specifically prohibit the use of admixtures to lower the freezing point of concrete. All jurisdictions prohibit the placement of concrete on frozen ground.

Minimum air temperature at the time of concrete placement, if the concrete is not protected, varies from 25°F in Michigan to 50°F in Saskatchewan. In most jurisdictions, the minimum temperature requirement is higher for concrete pavement than for structures, although Michigan requires "25°F and rising" for concrete pavement and "45°F and rising" for structures. The Vermont specifications allow concrete placement at temperatures as low as 10°F with written permission of the engineer. Specifications dealing with temporary protection of concrete after placement are generally concerned with either the surface temperature of the concrete or the air temperature inside the enclosure.

Curing times vary from three to seven days, depending upon the type of cement and the ambient air temperature during the curing period. About half of the states reviewed allow decreasing the curing time with the use of high early strength cement. Minnesota and Michigan use anticipated compressive strength and flexural strength for determining the proper curing period.

TABLE 5. Summary of highway construction specifications for concrete.

Highway department	Minimum placement temp (°F) no protect	Cold weather concrete specs	Allow admixtures	Curing temp (°F) and days
Alaska	40	yes	no	50 @ 5(2)
Colorado	40	no	---	50 @ 5
Michigan	25(3)	yes	---	(4)
Maine	40	yes	no(1)	50 @ 4
Minnesota	40	yes	yes	(5)
New Hampshire	(6)	yes	---	(7)
New York	40(8)	yes	---	7 @ 45-85
North Dakota	35	yes	---	50 @ 3(10)
Vermont	10(1)	yes	no	(9)
Washington	35(10)	yes	---	35 @ 7
Wisconsin	40(1)	yes	---	(12)
Alberta	---	---	---	---
Manitoba	40	yes	---	32 @ 7
Nova Scotia	41	yes	---	50 @ 5
Ontario	50	yes	---	32 @ 7
Saskatchewan	59	yes	---	41 @ 7
Denmark	---	---	---	---
Sweden	---	---	---	---

(1) Concrete can be placed with written permission of the engineer.
(2) The temperature shall be 70 @ 3 or 50 @ 5 for Type I or II, and 70 @ 2 or 50 @ 3 for Type III.
(3) The temperature shall be 45°F and rising for structures, and 25°F and rising for concrete pavement.
(4) The concrete shall be protected from freezing until it has reached a flexural strength of at least 100 psi.
(5) The concrete must be properly cured as determined by the engineer and shall reach 70% of its Anticipated Compressive Strength for bridge slabs and girders.
(6) All material coming in contact with the concrete shall be at or above 50°F, and all frost shall be removed.
(7) The concrete temperature shall be maintained between 50 and 100°F for the first 72 hours, and between 40 and 100°F for the next 48 hours. The concrete shall then be cooled at a rate not to exceed 1°F per hour.
(8) The concrete mixture for structures shall be preheated between 50 and 70°F, and protected when poured. The 40°F temperature pertains to pavement.
(9) The curing times were not sent with the abstracts from the specifications.
(10) For Type III portland cement.
(11) Below this temperature, the aggregate and water must be preheated.
(12) The contractor shall take all precautions necessary to prevent freezing of the concrete and to produce quality concrete.

NOTE - The placement temperatures may be lowered when cold weather concreting specifications apply. Placement temperatures are generally stricter for concrete road surfaces than for structures.

Asphalt Pavement

Table 6 summarizes highway construction specifications for asphalt placement by listing minimum placement temperatures for various operations. All jurisdictions with cold weather highway construction specifications have sections dealing with the placement of asphalt products. Most departments prohibit the placement of asphalt material if the roadbed is frozen or wet. Minimum placement temperatures are limited by the thickness of the asphalt concrete layer in five of the specifications studied.

The following summarizes the average minimum temperatures for each type of operation reported in Table 6.

Prime and tack coats	48°F
Seal coat	60°F
Traveling plant mix	45°F
Central plant hotmix	43°F
Central plant coldmix	44°F
Treated base course	44°F
Asphalt wearing course	47°F

In addition to temperature restrictions, many specifications limit the placement of asphalt products to certain seasons. For example, in New Hampshire, the wearing course may not be placed after October 1. In several jurisdictions, however, the engineer may waive seasonal restrictions, "when the engineer determines that it is in the best interest of the state."

CONTRACTOR INTERVIEWS

The final major portion of this project involved personal contact with Alaskan contractors who have had experience with highway and related construction in the wintertime. The purpose was to have them report their experience and observations relating to several aspects of winter highway construction, and to suggest possible changes to the cold weather provisions of the Alaska Standard Specifications for Highway

TABLE 6. Minimum placement temperatures (°F) according to highway construction specifications for asphalt.

Highway department	Prime and tack coats	Seal coat	Traveling plant mix	Central plant hotmix	Central plant coldmix	Treated base course	Asphalt wearing course
Alaska	45,40	50	---	40	40	60	60
Colorado	50(1)	70	50	50	50	40	50
Michigan	35-50	50	35-50(2)	35-50(2)	35-50(2)	35-50(2)	---
Maine	35-50(3)	---	35-50	50	50	35-50	50
Minnesota	50	---	50	50	50	40	50
New Hampshire	---	---	40-50(2,3)	40-50	40-50	---	---
New York	50	50	40-50(2)	40-50	40-50	45	45
North Dakota	60	---	45	32	40	---	---
Vermont	---	---	40-50(2,3)	40-50	40-50	---	---
Washington	50	---	---	25-55(2)	---	---	---
Wisconsin	40	60	50	---	35	35	35
Alberta	---	---	---	---	---	---	---
Manitoba	---	---	43	43	43	43	43
Nova Scotia	45,41	---	41	41	41	41	41
Ontario	50	---	50	45	50	50	50
Saskatchewan	36	68	41	36	41	---	---
Denmark	---	---	---	---	---	---	---
Sweden	(4)	(4)	(4)	(4)	(4)	(4)	(4)

(1) Temperature and weather conditions can be waived by the engineer.

(2) The temperature varies depending upon the thickness of the asphalt layer.

(3) The temperature varies with the season and location.

(4) Placements is limited by degree days of freezing and time of year.

NOTE - The engineer can waive the weather and temperature restrictions in most cases. When rising and falling temperatures are mentioned, the more conservative falling temperature is listed.

Construction. This section of the report is divided into several subsections corresponding generally to the several questions asked of the contractors.

Contractors responded to either a questionnaire or personal interview. A total of 24 contractors contributed to the study, of whom 17 were interviewed and seven responded to the questionnaire. Appendix II lists those contractors upon whose contributions this section is based.

Successful Construction Operations Below Freezing

The contractors were asked to describe operations that they had conducted successfully below 32°F and to estimate the temperatures at which these operations were conducted (Table 7).

Table 7 indicates many construction operations have been conducted at temperatures well below freezing. These operations range from asphalt paving at temperatures as low as +20°F to constructing ice roads and offshore islands between -50°F and -60°F. The list includes excavation, hauling, placement and (in some cases) compacting of embankment materials, bridge and culvert installation, concrete work, dam construction and guiderail installation.

The inclusion of Table 7 is primarily to indicate that some construction operations have been performed "successfully" at low temperatures. The reader is cautioned that these lists are presented without other information about specific project conditions and specifications.

Unsuccessful Operations

The contractors were asked to describe any unsuccessful winter operations they might wish to identify. Although few operations were reported, they are discussed here briefly.

One such project failed to place filter fabric over frozen material; since the material was frozen, it did not appear unstable. Installation of slope protection for offshore islands has been difficult or impossible because of the problem of working below the ice level. On

TABLE 7. Successful contractor operations at various temperatures, based on interview responses.

Temperature range (°F)	Description of operation
+20 to +32	Subdivision road construction, including gravel pit development. Concrete placement (without protection) (two responses). Asphalt paving (four responses). Three were during snowfall; three were at 20°F.
+10 to +20	Gravel compaction for agricultural road. Placing shot rock overlay. Earthfilled and concrete dam construction. Bridge pier and abutment construction. Guardrail installation.
0 to + 10	Gravel excavation and hauling. Peat excavation. Production of shot rock for overlay. Concrete placement (with protection). Concrete placement -- chemical additives, protection and heaters. Dam construction.
-10 to 0	Stripping for mining operation. Rock excavation for crushing. Excavation for highway project. Gravel pit development. Road construction over tundra. Concrete placement (with protection). Concrete building foundations -- chemical additives, visqueen and heaters. Bridge construction. Culvert construction. Guardrail installation.
-20 to -10	Excavation below water table. Gravel compaction around culverts. Construction of access roads and work pads. Compaction of roadway material with normal truck traffic. Construction of gravel pads for frost heave test site. Construction of gravel building pad over fabric. Bank stabilization with rock and gravel.
-30 to -20	Excavation of high-moisture permafrost. Excavation of silt with high ice content. Excavation of gravel (two responses). Excavation, hauling and placement of talus material. Airstrip construction using unfrozen gravel. Drilling, blasting, hauling and placing gravel for roads and work pads. Gravel haul and placement for offshore island (two responses). Ice road construction (two responses). Concrete placement -- heated water, aggregate and forms; protected. Concrete placement -- protected; steam cured. Installation of culverts. Erection of structural steel.

TABLE 7. Continued

Temperature range (°F)	Description of operation
-30 to -20 (continued)	Installation of vertical support member. Installation of foundation piling and sheet piling.
-40 to -30	Rock excavation and riprap placement. Excavation for drainage channel. Gravel road construction over tundra. Drilling and shooting of gravel deposits. Excavation, placement and compaction of unfrozen gravel. Loading, hauling and placing gravel embankment. Bridge pier construction. Well head completion work.
-50 to -40	Development of pits and haul roads. Concrete placement (with protection). Bridge pier construction -- piling, cofferdam, rock armor, concreting. Pipe bridge construction. Guardrail installation.
-60 to -50	Offshore island construction. Ice road construction.

one project, the contractor depended upon a winter haul road which was subsequently ruined by an unseasonable thaw. Another contractor found it difficult to haul thawed material from a pit when the temperature was about +20°F, because the material tended to stick to the bed of the hauling unit. A contractor found that some excavation work in the months of November and December was unsuccessful because material tended to contain high degrees of moisture and the soil froze quickly.

The next sections deal more specifically with contractor comments on certain highway construction operations carried out in the winter.

Winter Operations -- Soils

Several contractors discussed the placement and compaction of soils under below-freezing conditions. One contractor commented on the need for low moisture content and said that material can either be thawed prior to placement of the fill or can be compacted after it thaws in the spring. Another said that, on the North Slope, gravel is often placed full depth in the winter and compacted the following summer. Another suggested that unfrozen materials can be placed and compacted successfully if relatively thick lifts are used (several inches thicker than the standard six to eight inches). One contractor had been successful in placing material in 12 inch lifts and spreading it with a bulldozer. This operation successfully produced an embankment five feet deep, but there was a need to compact the final layer in the summertime.

The following quotation seems representative of many contractors' opinions: "If the gravel has a relatively low moisture content, you might get 85% (compaction), but that is the highest possible. Road embankments are soft during spring breakup and may become impassable for a short time. However, compaction efforts in the spring will give a satisfactory result, and after the first year, no major problems will be noted." The definition of "major problems" depends, of course, upon the expected level of service.

Several contractors commented on problems of the material freezing in the hauling unit and sticking to the sides and bottom if the material is not dry. The higher expense due to loss of productivity and extra effort was mentioned by several contractors.

Winter Operations -- Concrete

Most comments on winter concreting operations are captured in Table 7, which reports temperature ranges at which various concreting operations were performed. In addition, contractors noted the successful use of water-reducing agents, super plasticizers and accelerators. Several noted the extra costs resulting from the use of admixtures and the need to keep newly placed concrete warm early in the curing period. One contractor described a project in which bridge piers were constructed inside a dewatered cofferdam making the concrete easy to heat. After 48 hours, the forms were removed and the cofferdam flooded. Water flowing in the river, above 32°F, cured the concrete successfully. One other comment concerned the risk factor involved with heating freshly placed concrete; if the source of heat ceases to operate inadvertently, the entire pour may be lost.

Winter Operations -- Paving

Four contractors reported placing asphalt paving below 32°F with what they considered satisfactory results. Three of the contractors had applied asphalt paving during a snowfall. One of them reported working under such conditions down to +20°F in another state; since the owner was anxious to have the project completed, the highway construction specifications were waived for that portion of the project. One contractor noted the importance of shortening the length of the paving operation and using material somewhat warmer than normal.

Winter Operations -- Bridges and Culverts

Several contractors commented on the advantage of driving foundation and sheet piling in the wintertime when the ground is frozen. One contractor mentioned the advantage of wintertime erection of the bridge structure, when the work can be done from the ice as a working platform. Problems that can arise in the winter erection of bridge structures include stored parts that become frozen together, superstructure icing that makes footing slippery, and equipment problems due to low temperatures. Another noted that welding operations require preheating during the wintertime.

With regard to culvert construction, one noted that sometimes this construction is easier in the wintertime since there are no problems with flowing water; he recommended that the cut not be made until the culvert is ready to be placed. Two contractors mentioned problems with achieving proper compaction of the culvert fill material.

Winter Operations -- Other Elements

Several contractors mentioned successful installation of guiderails but noted that post holes must be drilled with auger drills if the ground is frozen. One noted that this operation often is done after freeze-up, in an attempt to complete a highway project whose major effort has taken place the previous summer. Two contractors said that electrical work can be done successfully during the wintertime, if conduit and lighting bases have already been installed. One noted that cable trenches cannot be compacted properly after freeze-up.

Other successful winter operations included hand and machine clearing and burning, maintenance of traffic over permafrost and the installation of augered thermal piles.

Equipment Performance

Contractors were asked to indicate precautions they take with equipment operating in extreme cold. They were also asked to note equipment problems that typically occur in cold weather. Their responses dwelt more on precautions than problems.

Table 8 lists the precautions mentioned by contractor respondents. Among the most common precautions were the use of lightweight oil and grease, idling equipment overnight, changing the airflow by reversing the radiator fan so that the fan draws warm air to the radiator, and

TABLE 8. Precautions taken with equipment operating in extreme cold.

Action	Numbers reporting this action
Lightweight oil and grease	8
Idle overnight	7
Change airflow by reversing fan	6
Skirting to shield engine or radiator	6
Circulating heaters	4
Cabs	4
Antifreeze	3
Special fuel	3
Spray bed of hauling unit with antifreeze or diesel fuel	2
Chains	1
Weed burners to heat block	1
Change plastic to copper tubing	1
Heat tracing or circulating system on hydraulics	1
Heated space for servicing	1

providing canvas skirting around the radiator or engine. Since this was an open-ended question, respondents offered actions that came to mind rather than checking off precautions from a list. Therefore, it should not be assumed that only three contractors use antifreeze in their vehicles, for example! Nonetheless, it is interesting to note the precautions that seem to be considered most important.

Among the problems cited with respect to equipment performance, metal failure was most often mentioned. Problems included broken ripper shanks, dozer arms and scraper aprons. There was some disagreement over the temperature at which metal failure becomes important. One contractor insisted he had had no problems with metal failure above -30°F, while another suggested caution below -10°F. Other problems cited included the need for more time to warm equipment up if it is not idled all night, the extra fuel requirement associated with idling, and brittle belts at cold temperatures.

The Human Element

The contractors were asked to comment on the effects of cold weather on productivity of construction workers. Table 9 lists important factors that decrease human productivity. Mittens and bulky clothing were most often mentioned, followed by the time necessary to warm up inside a building or other heated enclosure, and the necessary caution due to ice and snow.

TABLE 9. Factors decreasing human productivity.

Factor	Number citing this factor
Mittens and bulky clothing	8
Time to warm up inside	5
Caution due to ice and snow	5
Frosted windshields and goggles	1
Darkness	1
Time to change clothes	1

No statistical study was attempted on efficiencies at various temperatures, but the following comments make it clear that efficiency can decrease drastically at cold temperatures.

"Mittens and bulky clothing lead to 50% efficiency."

"If the operation is heavily labor-intensive, productivity can decrease to 50%."

"It takes two times as long to change an engine compared with summertime."

"The replacement of a broken hydraulic hose that would take two hours in the summer months will take four to six hours in severe cold weather."

"At -45°F to -50°F, there is a 40% reduction in efficiency."

"There is little effect if a worker is inside a cab, but working outside can reduce efficiency by 30%."

"We figure a 50% efficiency factor on the North Slope compared with 100% in Anchorage."

"Work in the rain in southeast Alaska has about a 70% efficiency factor."

In terms of a limit below which construction workers cannot or should not work outdoors, responses varied from +20°F to -40°F, although five of the 10 who suggested a cutoff temperature gave -20°F as the lower limit.

Another comment mentioned by several contractors was the idea that it is more difficult to motivate workers in the fall than in the spring. One said that mental attitude is extremely important and that the attitude tends to be much better in spring when the workers are "chafing, ready to start."

Other comments with regard to the human element in winter highway construction included the importance of having each shift work in some daylight, if possible, the need to provide proper food ("We could learn from the Eskimos!"), the advantage of wearing several thin layers of clothing rather than one bulky layer, and the importance, when working inside a cab, of having a carbon monoxide indicator and always working in a group.

Factors Other Than Temperature

Contractors were asked to cite those factors other than cold temperatures that, in their experience, influence construction productivity in the wintertime (see Table 10). The most frequently cited factor is winter darkness, with its necessity to move more slowly and carefully, and with its impact upon attitude and morale. Other factors cited by at least four of the contractors were snow, ice and wind.

TABLE 10. Factors other than temperature that influence winter construction productivity.

Factor	Number citing this factor
Loss of daylight	16
Snow	9
Ice	4
Wind	4
Bright sun on snow	1
Spring load restrictions	1
Diet	1
Unavailability of support personnel (such as material suppliers)	1

Suggested Changes in Specifications

The contractors were asked whether they believe the State of Alaska should change its standard specifications for highway construction to allow different approaches to the construction of highways in the wintertime. Of the 24 contractors, 14 replied that the specifications should be changed. Comments centered around two aspects of the highway construction process -- embankment construction and asphalt paving.

Ten of the contractors suggested allowing more flexibility in embankment construction. They recommended two strategies. First, some suggested that the placement of frozen material should be allowed, if it was not frost susceptible. They would then compact this material after the spring thaw. Second, some would allow the placement of unfrozen materials and would place these materials in thicker lifts than normal. They believe the succeeding layers can be placed before the last layer has frozen, if the work is managed properly, even at extremely low temperatures. Each lift would be compacted just after placing but prior to the placement of the next lift.

Five contractors urged that asphalt paving not be restricted to certain dates. They believe that surface temperature is a better measure of whether the material can be placed successfully.

Miscellaneous Comments

Finally, contractors were invited to make any other comments and suggestions related to the project. One said he was glad that DOT&PF was considering more winter construction, and he urged that they get bids out earlier in the year. Another indicated that DOT&PF was very easy to work with, while another urged better communication in the field between owner and contractor.

Among the types of operations not covered previously that are well-suited to winter work, the contractors mentioned the crossing of swamps and tundra which would not be possible in other seasons, land clearing, peat excavation and the crushing of graded material with low moisture content. Another urged that the use of roller compacted concrete, which is used in Finland and Canada, be considered. One mentioned a project near the Canadian border that was carried out during the summer. He suggested that it would have been much more successful had it been done in the wintertime when the underlying material would have remained frozen. No mention was made of whether performing the work in the summer was the contractor's choice. Often, Alaska DOT&PF gives the contractor the option of choosing the time of year for certain portions of such projects.

RECOMMENDATIONS

After reviewing the literature, studying highway construction specifications from 18 states, provinces and foreign countries, and discussing winter construction with 24 contractors, it seems appropriate that DOT&PF consider taking the following actions.

1. On a selected project, change the specifications to allow the wintertime placement of nonfrozen, nonfrost-susceptible material in lifts of 12 inches or greater, provided the material was compacted prior to placement of the next lift. Final compaction of the top lift would wait until after breakup in the spring. Performance of the embankment would be monitored over three to five years.

2. On a selected project, change the specifications to allow the placement of frozen material in the embankment outside a 1:1 slope from the shoulder line. Performance of the embankment would be monitored over three to five years.

3. On a small section of a selected project, allow the placement of nonfrost-susceptible material in the frozen state. Compaction of the top lift would be carried out after the spring thaw.

4. On a selected project, change the specifications to allow the placement of asphalt concrete pavements at temperatures lower than 40°F. I suggest that various low-temperature limits as low as 25°F might be used on a trial basis. The placement process and

environmental conditions must be documented, and the pavement's performance should be monitored over three to five years.

5. Support a modest research program to investigate the use of so-called "cold" concrete. Short sections of portland cement pavement containing admixtures to lower the freezing point would be placed at various temperatures, but no temporary protection or heating would be used. The pavement's performance would be monitored over two to three years.

6. Consider a research project to investigate the use of chloride additives to facilitate compaction of embankment materials.

7. Support a research program to study the variation in construction productivity at different environmental conditions. Several basic field operations would be performed at different temperatures and other conditions, and the productivity rates would be ascertained for each.

LITERATURE CITED

American Concrete Institute. "Cold Weather Concreting." ACI No. 306 R 78, Rev. 1983.

Bennett, F.L. "A Half-Century of Cold-Regions Construction." Journal of the Construction Division, ASCE, Vol. 101, No. C04, December 1975, 839-851.

Bennett, F.L. "Temporary Protection of Wintertime Building Construction." CRREL SR 77-39, November 1977.

Bieganousky, W.A., and C.W. Lovell. "Do Earthwork in the Cold?" Transportation Research Record, N702 1976, pp. 133-139.

Eaton, R.A., and R.L. Berg. "Field Cooling Rates of Asphalt Concrete Overlays at Low Temperatures." CRREL Report 80-30, December 1981.

Falls, C.G., and R. Haas. "Pavement Design for Permafrost Conditions." Transportation Research Record #755, 1979.

Haas, W.M., B.D. Alkire, and T. Kaderabek. "Increasing the Effectiveness of Soil Compaction at Below Freezing Temperatures." CRREL SR 78-25, November 1978.

Haas, W.M., B.D. Alkire, and J.E. Dingeldien. "Winter Earthwork in Upper Michigan." CRREL SR 172, May 1977.

Havers, J.A., and R.M. Morgan. "Literature Survey of Cold Weather Construction Practices." CRREL SR 172, May 1972.

Kinney, T.C. "Thaw Strain of Laboratory Compacted Frozen Gravel." Department of Civil Engineering, University of Alaska-Fairbanks, 1984.

Maupin, G.W. "Development of Cold-weather Paving Specifications." Journal of Testing and Evaluating, November 1973.

Rafson, G.J. "Treatise of Frozen Earth Construction." October 1979.

Roberts, W.S. "Regionalized Feasibility Study of Cold Weather Earthwork." CRREL SR 76-2, July 1976.

Saarela, A. "On the Influence of Winter Compaction on the Densities of Subgrade and Unstabilized Courses in Road Construction." University of Oulu, Finland. Series C Technica No. 4, Artes Constructionum No. 1, 1974.

Shah, N.D., and P.F. Dickson. "Design Consideration for a Direct Fired Propane Heater to Preheat the Base for Cold Weather Paving." Transportation Research Record #549, 1976.

Tart, R.G. "Cold Regions Earthwork." Cold Regions Construction, ASCE Technical Council on Cold Regions Engineering Monograph, 1983.

Thorpe, D.J. "Cold Regions Concreting." Cold Regions Construction, ASCE Technical Council on Cold Regions Engineering Monograph, 1983.

Turunen, R. "Winter Construction." Nordiska Vegtekniska Forbundet, Report No. 15, 1980.

Yoakum, D. "A Survey of Winter Construction Practices, Earthwork, Concrete and Asphalt." CRREL SR 76, July 1976.

Zilly, R.G. "The Construction Industry." Contractor's Management Handbook, J.S. O'Brien and R.G. Zilly, Editors, McGraw-Hill Book Co., Inc., New York, 1971, p. 1-21.

APPENDIX I - HIGHWAY CONSTRUCTION SPECIFICATIONS REVIEWED

Alaska Department of Transportation and Public Facilities. Standard Specifications for Highway Construction. 1981.

Alberta Transportation. General and Construction Specifications. Contracts Engineering Branch, Edmonton, Alberta, Canada. 1984.

Colorado State Department of Highways. Highway Construction Specifications. 1984.

Denmark, Country of, Road and Highway Departments. Standard Specifications. 1985.

Maine Department of Transportation, Augusta, Maine. Standard Specifications. January 1984.

Manitoba Highways and Transportation. Standard Specifications. Winnipeg, Manitoba, Canada. 1984.

Michigan Department of Transportation. 1984 Standard Specifications for Construction.

Minnesota Department of Transportation, St. Paul. Specifications Relating to Cold Weather Construction, Protection, and/or Restrictions. 1984.

New Hampshire, State of, Department of Public Works and Highways. Standard Specifications for Road and Bridge Construction. 1983.

New York, State of, Department of Transportation, Albany, NY. Standard Specifications: Construction and Materials. 1978.

North Dakota State Highway Department, Bismarck. Standard Specifications for Road and Bridge Construction. October 1976.

Nova Scotia Department of Transportation. Standard Specifications for Highway Construction. 1982.

Ontario Ministry of Transportation and Communications. Standard Specifications for Highway Construction.

Saskatchewan Highways and Transportation. Highway Construction Specifications. Regina, Saskatchewan, Canada. 1984.

Sweden Highway Construction Specifications. 1984.

Vermont Agency of Transportation, Montpelier, Vermont. Standard Specifications. 1983.

Washington, State of, Department of Transportation. Highway Construction Specifications. 1984.

Wisconsin, State of, Department of Transportation. Standard Specifications for Road and Bridge Construction. 1981.

Wisconsin, State of, Division of Highways and Transportation Facilities. Supplemental Specifications, Revised November 1983.

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