Feasibility of Cold-Weather Earthwork

C. W. LOVELL, JR., Associate Professor in Civil Engineering, Purdue University, and A. M. OSBORNE, Purdue Fellow in Latin America, Santiago, Chile (Formerly Graduate Assistant in Research, Purdue University)

Most earthwork operations are more costly in the cold season than in the warm. However, the benefits of keeping construction forces and equipment more continuously operative, plus advancing the completion date of a modern, safer facility, may more than compensate for the increase in unit costs.

The cold-weather earthwork experiences of the northern states of the United States, the provinces of Canada, and the Scandinavian countries have been studied in the literature and by brief questionnaires. This effort has served to define (a) the manner in which the winter weather and soil conditions restrict the length of the construction season, (b) the designs and construction practices employed to cope with the winter conditions, and (c) an estimate of the relative unit costs for various winter operations.

The advantages of cold-weather earthwork have been defined in a simple linear economic model. An assessment of deterrents and benefits leads to the conclusion that cold-weather earthwork is economically as well as technically feasible on many highway projects in the frost area of North America.

*UNTIL* a few decades ago, cold-weather earthwork was strictly avoided in highway construction. [The term "earthwork" is used in a comprehensive manner to include any excavation, handling, placement, or compaction operation with any "earthen" material—soil, rock, peat.] The requisite technology was recognized to be more complex and costly in the winter, and this factor was presumed to override the benefits that could be derived from earlier completion dates, continuous use of construction forces and equipment, and the like.

As the demand for new highway facilities accelerated, some penetrations into the traditional cold-weather shutdown were accomplished. These developments have been concentrated in the cold regions, where the long duration of the poor weather has the most restrictive influence. However, the feasibility of "stretching" the construction season is also of growing interest where the winters are relatively mild.

In long-range and total perspective, the need is for development of design and construction technology that will permit year-round earthwork operations in all climates and under almost every meteorological variation.

COLD WEATHER EFFECTS

Workers and Equipment

The U. S. Army (3) reports that the elements which govern the comfort, and consequently the efficiency, of workmen are air temperature, wind velocity, and relative humidity. Air temperature and wind velocity are combined in a "windchill" index, shown in Figure 1 for dry, shaded conditions.
Earthen Materials

The most dramatic effect on earthen materials is the production of a surficial zone in which some of the water is frozen. As ground temperatures are lowered below the value of initial freezing, additional portions of the pore water are changed to ice and the earthen material becomes stronger (7). The availability and transmissibility of water (8) are the keys to the character of the frozen ground, as well as to its condition during
Figure 2. Percent of time when severe windchill occurs at selected Indiana weather stations.

Figure 3. State of winter earthwork in the northern United States.

Excavation of Frozen Soil
Permitted
Encouraged
To depth of:
6"
2'
Over 2'
By:
Ripper + Scraper or Dozer
Scraper, Dozer, or Shovel alone
Uses Permitted:
Waste
Fill, Berms, or Stockpile

Fills Built with
Frozen Soil are Satisfactory

Conditions Causing Winter Shutdown
Frozen Borrow Area or Fill
Rain or Snow
Cold Air Temperature

Embankments Built When Air Temp. is
Below 32°F but Material is Unfrozen
Yes
Are Satisfactory
thaw. Concomitant with the cold weather are reduced evaporation rates and, sometimes, increased precipitation. In the southern United States, frost is not a major problem, but heavy winter and spring rains cause suspension of work operations (13).

Soil is not usually placed or compacted in a partially frozen condition, but compaction of cold (yet unfrozen) material is feasible. Limited data on low-temperature compaction (6) show that in general the maximum unit weight is decreased and the optimum water content is increased, relative to compaction at normal construction season temperatures. However, the changes are minor. Work at Purdue University with both sand and silty clay showed no systematic temperature dependence (13), and further study on the temperature variable is presently under way.

CURRENT STATE OF COLD WEATHER EARTHWORK PRACTICE

Since the literature on this subject is quite limited, additional information was sought via questionnaires to state and provincial engineers and contractors. The response was very gratifying.

Northern United States

The practices of the states in the area of significant frost were compared (13) and found to vary widely. Some of the variation can reasonably be assigned to differences in climate and in the predominant nature of the surface soils. An abbreviated summary of cold weather practice is presented in Figure 3.

Excavation and Placement—Excavation of any soil frozen to limited depths is generally viewed as a practical operation. Ripping along a grid pattern, followed by loading into conventional rubber-tired scrapers is the most common method. Rock excavation can be carried out in about the same manner as in warm weather, while peat excavation is advantaged because access to these deposits is improved by ground freezing.

Excavated rock, reasonably dry sand and gravel, and peat can be placed in the same locations and by substantially the same methods as for normal season construction. However, the disposition of most frozen soil is limited. As illustrated in Figure 4, it can be (a) wasted, (b) stockpiled for use after thawing and draining, and (c) used in noncritical portions of an embankment section, i.e., outside a limiting slope line (say 1:1), or in berms. The reader will recognize that disposition (c) corresponds to that of inferior unfrozen material (9).

Once the frozen crust has been excavated and disposed of, attention must be directed toward the prevention of freezing of the underlying material, until it can be excavated, placed and compacted in fill. The primary rule is to minimize the area exposed to...
freezing, as well as the time of such exposure. Accordingly, active excavation and compaction areas are kept small. Michigan reports use of a "ramp" placement and compaction method (Fig. 5), which can limit the extent of an overnight or weekend freeze of the exposed layer of a partially completed embankment.

Compaction—Adjustment of the compaction water content is a much more difficult operation in cold weather, which means that compaction must be accomplished at about the natural water content of the excavated soil.

One might expect natural water contents to be higher in the winter and spring than in summer and fall. The authors used reports of subsurface investigations for portions of the Interstate system in Indiana to study the values of natural water content. Projects were selected to cover many of the physiographic subsections of the state, and to produce a good seasonal distribution. The samples examined were of material to be used in fills.

The standard AASHO optimum moisture content was either known or estimated for each sample, and natural water contents expressed as deviations from this value were plotted against the date of sampling (13). Most moisture values were on the "wet side," but no seasonal trend was distinguished. About 23 percent of all moisture values were within ±2 percent of the standard AASHO optimum.

Granular soils can probably be adequately compacted even when frozen. If the material is placed as frozen chunks, it can effectively be disaggregated by rolling (vibratory smooth wheel and grid wheel rollers were cited in the review of practice). On the other hand, it is important to monitor both depths of freezing and in situ moisture contents for those fine-grained deposits planned for cold-weather excavation and compaction. Both the compaction specification and the selection of the design section must be amenable to low-temperature and (probably) wet-side compaction.

Canada and Alaska

The questionnaire responses from Canada and Alaska cited several practices that supplement those reported for the Northern States. The cold season is used to build access roads in swampy areas—taking advantage of the improved mobility of equipment on the frozen ground. Once opened, borrow areas may be worked around the clock to circumvent surficial freezing. Embankments may be raised to within 5 feet of the sub-
grade level and left to be finished in the next warm season. One province has tried alternate embankment lifts of frozen fine-grained soil and frozen granular material. The latter technique is analogous to alternate dry and excessively wet lifts in warm weather construction (4). Such embankments are compacted as thoroughly as practicable when placed, but are allowed to thaw and settle in the spring and summer before construction of the pavement.

Scandinavian Countries

The authors were particularly impressed by the content of a Swedish report entitled "Eliminating Seasonal Variations in Road Construction" (2) and had it translated in part. Due to a combination of political, economic, and geographic factors, the art of cold-weather highway construction is relatively advanced in Sweden.

Data are organized with respect to four climatic zones, and these zones correspond in terms of temperature and snowfall to the United States areas shown in Figure 6. The relative costs of many constructional operations are tabulated (2, 13). In the absence of first-hand information, these tables, used in conjunction with a climatic correlation like that of Figure 6, permit prediction of the increased costs of cold weather construction in the United States. [The increase may be quite small (rock blasting, loading, and crushing), or costs may even decrease, as in the case of peat excavation.]

The Swedish report (2) further presents total construction project cost comparisons, assessing some of the major benefits that accrue because of the cold-weather activity, and balancing these against experience relative to unit costs in the various seasons and geographic zones. Table 1 shows a net cost advantage for cold-weather work of about 5 to 15 percent of the total construction cost. Two items of planning are implicit in the benefit: (a) the project length is great enough to encompass a wide variety of earthwork operations, and (b) the various operations are carefully scheduled so that each is begun at a time that is as optimal as can practically be arranged.

ECONOMIC FEASIBILITY IN NORTH AMERICA

With the encouragement afforded by a review of the current state of the art of cold-weather earthwork, this study sought to be definitive about the kinds and magnitudes of
its benefits. The focus was on Indiana, but the general conclusions should reasonably apply to any part of the frost zone in North America.

While the weighing of economic benefits against increased cold-weather operational costs is a necessary test, it is not a sufficient one, since there are human benefits over and above those reducible to economic terms.

Benefits are of two interrelated types: (a) those which result from an earlier completion date, and (b) those which accrue from reduction (or even elimination) of the seasonal interruption in construction.

The implicit difficulties of cold-weather earthwork mean that one month of such activity will reduce the time required for project completion by only a fraction of a month. This fraction was assumed as \( \frac{1}{2} \), which means that working 2 winter months will advance the completion date by 1 month. The economic benefit model that follows is a simple linear one, i.e., benefits are simply summed, without consideration of interactions.

Benefits of Earlier Project Completion

Construction costs will undoubtedly continue to rise in an inflationary drift. This trend can be reduced to a monthly rate \((\text{MID})\) and applied as follows:

\[(\text{MID})(\text{AC})(\text{NRT}) = \text{Benefit}\]

where \(\text{AC}\) is the annual cost, and \(\text{NRT}\) is the number of months that project completion is advanced.

Earlier completion can also reduce the interest charges on money borrowed by the contractor to finance his operation. An important factor is the time lag between contractor expenditures and payment for completed work. For purposes of sample calculations, this lag was expressed as one-fourth of the annual construction cost. Reducing interest charges to a monthly basis \((\text{MIC})\):

\[(\text{MIC})\left(\frac{1}{4}\right)(\text{AC})(\text{NRT}) = \text{Benefit}\]

where all terms have been previously defined.

Inserting values of \((\text{MID}) = 0.25\) percent and \((\text{MIC}) = 0.58\) percent, the total benefit accrued through reduction in inflated costs and interest charges is 0.40 percent of the annual construction cost for each month that project completion is advanced.

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**TABLE 1**

<table>
<thead>
<tr>
<th>Construction Season</th>
<th>Nature of Cost</th>
<th>Central Sweden</th>
<th>Upper Northern Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost of project</td>
<td>Cost of project, incl.:</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>A. Increased costs for operations started at most suitable time</td>
<td>+6%</td>
<td>+12%</td>
<td></td>
</tr>
<tr>
<td>B. Reduced costs for</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Elimination of suspension and resumption of work</td>
<td>-3%</td>
<td>-6%</td>
<td></td>
</tr>
<tr>
<td>2. Better exploitation of contractor's resources</td>
<td>-8%</td>
<td>-14%</td>
<td></td>
</tr>
<tr>
<td>3. Better exploitation of employer's resources</td>
<td>-1%</td>
<td>-2%</td>
<td></td>
</tr>
<tr>
<td>4. Lower interest charges for employer</td>
<td>-1%</td>
<td>-4%</td>
<td></td>
</tr>
<tr>
<td>Total costs</td>
<td>93%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>Maximum increase due to starting of operations at least suitable time.</td>
<td>+3%</td>
<td>+7%</td>
<td></td>
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</tbody>
</table>
A second class of benefits applies to the highway user, in that the new facility is both safer and more convenient than the highway mileage effectively replaced by it. For example, on completed sections of the Interstate System the fatality rate is only about one-third that on older highways in the same traffic corridors (11). With an average daily traffic (ADT) of 15,000 (1), there is a reduction in the fatality rate of 0.40 per mile of new Interstate per year. Following a simple expedient of prorating all accident costs on the basis of fatal accidents (1), and using national values of 49,000 deaths and $8,900,000,000 in costs (12), the realized annual economic benefit is $73,000 per mile of new Interstate. A one-month advance in availability of the new facility would reduce accident losses by about $6,000 per mile.

There are travel-time delays incident to the existence of construction areas, since vehicles must continue on the old route and/or follow special detours. The economic detriment of such delays is of course greater in and around urban areas. Assume that 5,000 persons are delayed 5 minutes per day. With the value of travel time taken as $0.86 per hour (1), a loss of $10,700 per month is incurred. In addition, where construction activity requires rerouting of high traffic volumes, accident costs will rise well above the average values previously cited.

**Benefits of a More Continuous Construction Operation**

The benefits from reduction in seasonal interruptions of construction relate to three resource categories: labor, contractor, and highway agency.

The non-supervisory persons normally engaged in earthwork operations undergo a seasonal layoff, and either enter secondary temporary employment or qualify for unemployment compensation. In Indiana (5) the potential benefit of an added month of construction activity would be about $175 per month (unemployment compensation not paid) per worker.

A part of the wage differential between northern and southern workers can logically be assigned to the smaller number of months of regular employment in the north. Assume that half of the wage differential can be so ascribed. For Indiana, as compared with the southern states (14), this is about $50 per month per worker. If the northern worker is employed only part of the winter, this value must be reduced proportionately.

In principle, and over the long run, cold-weather construction would reduce the wage differential between locations of severe and mild winters.

Contractor resources of supervisory and professional personnel and capital equipment must be maintained year-round, whether or not they are in effective use. Swedish experience (2) shows a benefit of 2 percent of the annual project cost for each month that suspension of activity is avoided. Further, if the construction function can be carried out around the calendar, an additional benefit of 3 percent of the annual cost will accrue through elimination of the expense of suspending and resuming work.

Questionnaire responses from contractors in the south and southeast (13) reinforced the contention that large benefits can be incurred by contractors able to reduce or to avoid totally the seasonal suspension of operations. It was further stated that employer-employee relations were significantly improved when the seasonal layoff was eliminated.

A number of the points made with respect to contractor resources are equally valid for the resources of the state highway agency—particularly the construction division. Personnel would not need to be shifted to secondary functions during the winter, but could continue to be used in their areas of primary interest and competency. Once organizational adjustments were made, it is estimated (2) that a saving could be realized which amounts to ¼ percent of the annual project cost for each additional month of cold-weather activity.

Table 2 summarizes all economic benefits that have been stated to accrue, for a case where the elapsed calendar time for project completion was reduced one month by undertaking two extra months of cold-weather earthwork. The decision to undertake cold-weather activity on a given highway project would be economically justified when the sum of benefits outweighs the predicted increase in cost of field operations.
TABLE 2
SUMMARY OF ECONOMIC BENEFITS DERIVED FROM FINISHING ONE MONTH EARLIER BY WORKING TWO MONTHS LONGER

<table>
<thead>
<tr>
<th>Source of Benefit (Conditional Assumptions)</th>
<th>Benefit as Percent of Annual Cost of Urban Project Unless Otherwise Stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less inflation and interest</td>
<td>0.4%</td>
</tr>
<tr>
<td>Reduced accident losses</td>
<td>$6,100 per mile</td>
</tr>
<tr>
<td>Reduced construction area delays</td>
<td>$10,700 per month of earlier finishing</td>
</tr>
<tr>
<td>Reduced unemployment compensation (4/5 weeks per month)</td>
<td>$346 per worker</td>
</tr>
<tr>
<td>Reduced wage differential$ ^2</td>
<td>$24 (N_w/N_l) per worker</td>
</tr>
<tr>
<td>Better contractor resource utilization$ ^3</td>
<td>$4%</td>
</tr>
<tr>
<td>Better state resource utilization$</td>
<td>$/%</td>
</tr>
<tr>
<td>(conventional season was 8 months per year)</td>
<td></td>
</tr>
</tbody>
</table>

^ Rural project figures would be the same except for a reduced value for construction area delays.
^2 (N_w/N_l) is \( \frac{\text{No. of weeks total working season planned}}{\text{No. of months workers were previously inactive}} \)
^3 Bonus benefit if working 12 months per year = 3% of annual cost of project should be added.

SUMMARY AND CONCLUSIONS
1. The present state of the art of cold-weather earthwork was reviewed for the northern United States, Canada and Alaska, and the Scandinavian countries. This experience provides a substantial base for further controlled experimentation.
2. An assessment of the technological deterrents to cold-weather earthwork was made, with emphasis on the degree of difficulty afforded in Indiana.
3. The benefits to be derived from an earlier completion date and/or more continuous operation were categorized as to (a) the highway user, (b) the labor resource, and (c) contractor and state highway organizations.
4. The sum total of the findings is encouraging, and it is likely that year-round earthwork is both economically and technically feasible for many highway projects in North America.
5. To advance the state of the art, a three-pronged research effort is recommended:
   a. An important part of the economic justification of cold-weather earthwork lies in the earlier availability of a safer and more convenient facility. These benefits need to be quantified as to magnitude and distribution among various classes of users.
   b. It is also contended that year-round utilization of the resources of the firms doing construction, as well as of agencies exercising engineering control over the construction, produces economic benefits. The magnitude and distribution of these gains can be accurately assessed only by detailed studies of the organizational setups and operational systems of these firms and agencies.
   c. The excavation, placement, and compaction of soils at low temperatures and high moisture contents are effectively discouraged by current state specifications. To provide a rational basis for liberalizing the specifications, both laboratory and field experimentation are in order. The laboratory phase would quantify the effects of low temperature and high moisture on soil properties and characteristics, and the field phase would test the performance of real highway sections in which the modified procedures were followed.

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REFERENCES