47

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **47**

EFFECT OF WEATHER ON HIGHWAY CONSTRUCTION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREA OF INTEREST:
CONSTRUCTION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1978

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of special interest and usefulness to construction engineers and others seeking information on the effect of adverse weather on the quality of highway construction. Detailed information is presented on current practices used by construction agencies to obtain high-quality work while faced with adverse weather conditions.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Materials, equipment, personnel, and the quality and quantity of work can be adversely affected by weather. Delays in project completion and increased costs can also result. This report of the Transportation Research Board reviews measures taken by highway agencies to mitigate the impact of adverse weather conditions. Practices related to a number of specific construction activities are discussed.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Information on current practice was provided by many highway agencies. Their cooperation and assistance was most helpful.

EFFECT OF WEATHER ON HIGHWAY CONSTRUCTION

SUMMARY

The effect of adverse weather in the highway construction industry is a major problem that deserves increased attention and organized efforts to reduce its impact. The three areas of concern in seasonality work are (1) economic considerations for the highway agency and the contractor, (2) human factors for the workers, and (3) quality of the work and the end product.

Innovations in work organization and management, such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), have been widely used by transportation agencies and contractors to schedule work in a way that will minimize the effects of adverse weather. Contractors have used both short- and long-range weather forecasts.

It is the responsibility of the agency to identify items of work that may or must be continued or completed during the winter months and to specify the controls and conditions to be observed. The contractor must quantify the extra cost of performing work during adverse weather and organize and equip the organization as necessary.

The effects of adverse weather are not uniform on all items of highway construction. Clearing and grubbing can continue during cold weather, for example, but earthwork must be halted during subfreezing temperatures. Rain and wet conditions also delay earthwork operations.

Using bituminous plant-mix bases can extend base work into periods of adverse weather; however, it is essential that the subgrade be stable. During cold weather bituminous plant-mix for bases or pavements should be placed in thick lifts and compacted immediately. It is not common practice to continue portland cement concrete paving during cold weather.

Concrete structure work frequently is continued during cold weather because this work can be protected and heated during the curing period. Steel structure work also is extended into or scheduled for winter work.

Much incidental work, such as guardrail posts and rails, fencing, culvert installation, signing, and lighting, can be continued during adverse weather.

It is good practice to complete as much as possible of the construction survey work before the arrival of cold weather. Reference points should be clearly marked and well guarded. Special protection often is necessary for long-term instrument setup.

Construction inspection and field-testing are affected by cold temperatures. In some cases there is a loss of confidence in tests performed under winter conditions.

Winter conditions cause additional wear and tear on construction equipment and also increase fuel and maintenance requirements. Efficiency of both operator and equipment is reduced during severe cold weather.

The following comments highlight the main points made in this synthesis:

- All highway construction is affected to some degree by adverse weather.
- The most adverse conditions are created by rain or snow in combination with wind and/or cold temperatures.

- Recent developments in construction materials, equipment, and techniques have made it more practical to perform winter work.
- Innovative planning and scheduling enable much work to continue through the winter.
- Agencies should consider specifications that will reduce the contractor's risk with off-season work.

CHAPTER ONE

PROBLEMS WITH WEATHER

BACKGROUND

Adverse climatic conditions are a major factor affecting the economic vitality of the construction industry. The climatic conditions that most often affect construction work are precipitation, temperature, and wind. These conditions occur alone or in combinations. Rain, snow, or sleet that falls when the temperature is low and the wind velocity is high causes conditions that have the greatest effect on the comfort and safety of the worker, the quality of work, production, operating costs, and equipment wear (Fig. 1).

Bad weather can have a tremendous impact on construction progress. Construction work has a greater exposure to seasonal variations than any major industry except agriculture. A substantial part of this work is highway construction.

It is estimated that about 45 percent of all construction operations, or about $40 billion of work annually, are weather-sensitive. Wage losses due to weather delays are estimated to be a billion dollars annually. It is further estimated that equipment valued at $700 million is idle during the winter months, causing loss of productivity (*1*). Much of this loss involves highway construction. Because virtually the total work product is exposed to weather, highway construction is affected more adversely by winter weather than other construction. The increase in employment for all construction between February and August is 35 percent. The increase in employment for highway construction in this period is approximately 200 percent, reflecting the extensive reduction in work during winter (*2*).

	PRECIPITATION			TEMPERATURE		WIND		
	Rain	Snow	Sleet	Hot	Cold	0-10 Low	10-30 Med.	30 + High
WORK	S	S	S	L	M-S	L	M	M
MEN	S	S	S	L-M	M-S	L	M	S
EQUIP	M-S	S	S	L	M	L	L	M
MATERIALS	M	S	S	L	M	L	M	M

S - Severe M - Moderate L - Little

Figure 1. Effect of climatic factors on workers and equipment.

The effect of winter weather conditions on key operations in highway construction is shown in Figure 2. Clearing and grubbing, pile driving, dredging, and the installation of fencing, lighting, and signs usually can proceed during inclement weather without major loss of production. However, most of the critical operations, such as embankment construction, backfill, site grading, steel work, concrete work, and paving, are severely hampered during bad weather.

These effects can be reduced substantially by the use of techniques and procedures discussed later in this synthesis. In most cases winter work is more costly, and the increased cost may be greater than some agencies or contractors believe to be warranted.

The requirement of additional fuel is now a major factor to be included in a consideration of winter construction. The use of extra fuel must be weighed along with other factors, such as unemployment, productivity, and early project completion.

Although winter shutdown is the major delay factor in highway construction in many areas of the United States, other seasonal weather conditions also can cause serious delay. In some areas, rains, high temperatures, droughts, high winds, and seasonal storms and floods frequently have severe impact on the highway construction industry.

Some indication of the temperatures, rainfall, snowfall, and wind that might be anticipated in the United States is provided in the "Climatic Atlas of the United States," published by the Environmental Data Service. Examples of annual data are included in the Appendix. The atlas also contains monthly estimates.

Historically, all parties involved in bridge and earthwork construction have been reluctant to schedule and perform such work during inclement weather, primarily because of their concern for economic consequences, quality of product, and human comfort. Because of this reluctance, development of inclement-weather construction techniques and procedures has received little organized attention. Contract specifications generally have prohibited construction for certain types of work when weather conditions were unfavorable, and specifications for inclement-weather construction procedures and work-protection measures primarily have accommodated temporary, emergency situations.

The neglect of the problems of construction seasonality in the United States was recognized in 1967 in a publication by the Organization for Economic Cooperation and Development (*3*). The publication summarizes the reasons for this neglect as follows:

- The construction industry's inertia and resistance to change.
- Contractors', workers', and agencies' acceptance of winter shutdown as a normal way of life.
- Workers' preference for high overtime wages during the summer, with winter vacations financed by unemployment compensation.
- The tendency to exaggerate or overestimate the cost of winterizing construction sites.
- The lack of knowledge about what can be done to ease the seasonality problem.

The substantial growth of the highway and transportation construction industry during the 1960s, with the attendant large increase in employment, directed national attention to the adverse effects of seasonal work on the over-all employment situation. In 1968 Congress directed that studies be made under Title IV of the Manpower Training and Development Act, and by memorandum the President expressed concern and requested all departments and agencies controlling expenditure of construction funds to take the following steps:

1. Ensure that, in the planning and programming of construction activity, due consideration is given to reducing seasonal variation.
2. Make contracts and schedule projects with regard to local conditions.
3. Encourage the specification of completion dates and penalty clauses that facilitate the stretch-out of work into the off-season.
4. Determine whether current authorization and appropriation procedures introduce a seasonal pattern into the letting of contracts and the scheduling of construction.
5. Encourage recipients of federal grants and loans for construction to engage in activities that will reduce construction seasonality.
6. Identify and disseminate to appropriate recipients information on techniques and procedures for facilitating year-round construction.
7. Take additional steps as may be permitted by law that will promote the scheduling of construction activities during off-season periods and will not entail undue impairment of program goals or excessive additional cost.

This memorandum caused considerable activity within the Federal Highway Administration (FHWA), culminating in the issuance of Circular Memorandum of August 19, 1970. This Memorandum required all state highway agencies to submit, by May 1 each year, a report of what steps they had taken to reduce seasonal variations in construction activity and employment. Comprehensive review of specifications resulted, and actions taken by various states were reported, accumulated, and disseminated for general application where appropriate.

Parallel to this activity, the Associated General Contractors of America participated by holding a "Seasonality in Construction" conference in Washington, D.C., in November 1968 (*2*), and local chapters assisted highway departments in complying with the FHWA Circular Memorandum.

Other agencies also were active, and the net result was that this major employment problem received nationwide attention and there was progressive development of solutions to it. This synthesis summarizes the current status of these developments as they apply to the highway construction industry.

CONSTRUCTION OPERATION	Low Temperature	Rain	Sleet	Snow	Ice	Frozen Ground	Wind
Traffic handling	L	M	S	S	S	L	L
Layout and staking	M	S	S	S	S	M	M
Clearing and grubbing	L	M	M	M	M	L-M	L
Material delivery & storage	L-S	S	S	S	S	L-M	L
Excavation	L	S	M	M	M	M	L
Embankment construction	M-S	S	S	S	M	M-S	L
Structure site grading	M-S	S	S	S	M	M-S	L
Pile driving	L	M	M	M	M	M	L
Dredging	M-S	L	L	L	S	L	M
Erection of coffer dams	M-S	M	M	M	S	L	L-M
Form work	M	S	S	M	S	L	L-M
Steel erection	M	S	S	M-S	S	L	M-S
Placing of reinforcing steel	M	S	S	S	M-S	L	L
Mixing and placing concrete	S	S	S	M	M	L	L
Curing concrete	S	M	M	M	S	L	M
Stripping forms	L	M	M	L	M	L	L-M
Backfill	S	S	S	M	M	M-S	L
Base placement	S-M	S	M	M	M	M-S	L
Paving	S	S	S	S	S	M	L
Landscaping and seeding	S	S	S	S	S	S	L
Painting	S	S	S	S	S	-	M
Fencing	L	M	M	M	M	M-S	L
Lighting	M	M	M	M	M	L	L
Signs	L	M	M	M	M	M	M

S - Severe M - Moderate L - Little

Figure 2. Effect of winter weather conditions on highway construction operations.

ECONOMIC CONSIDERATIONS

General

It is difficult to compute accurately the real costs of highway construction work during adverse weather. This fact alone has been sufficient reason for highway agencies and contractors to be cautious in scheduling work during the winter months.

There is little question that, in terms of direct cost, the cost per unit of work in the highway construction industry, almost without exception, increases during adverse weather. It follows, then, that such work can be justified economically only through offsetting indirect cost benefits to either the contractor or the owner. To reduce the impact of seasonal fluctuations in heavy construction, it is essential that there be a better understanding of both direct and indirect costs.

The impact of adverse weather can vary from minor to major, depending on the degree of deviation from normal, the combination of elements involved, and the type of work being pursued. For example, freezing weather (25 to 32 F—4 to 0 C) would have only minor impact on grading work (providing there is no rain or snow), whereas it would seriously impair bridge concrete work or paving work. A prediction more than a few days in advance of work is a gamble at best and one a contractor can not afford to make without a reduction in risk or assurance of payment for extra costs.

In many cases specification concessions, alternate work procedures, special materials, and extra payment must be approved by the agency if work is to be continued during adverse winter conditions.

Estimates indicate that winter construction costs may be as little as 1 percent higher than usual for building construction and as much as 10 percent higher than usual for highway construction, excluding grading operations in material other than rock or fairly clean gravels. Winter construction costs for grading in other materials during wet or cold months can skyrocket beyond all economic justification and are seldom warranted. The exact cost will vary with project size, weather extremes, type of work, and special procedures or protection required.

One effect of adverse weather on winter construction that has not been fully evaluated is the cost and availability of fuels for heating personnel areas, equipment, materials, and work sites. With today's energy shortages, this factor alone could determine the feasibility of performing winter construction in a given situation. Increase in the cost of fuel must be considered along with relative priority for use.

Transportation Agency

From the agency's standpoint, the following cost factors warrant consideration:

- Maintenance of the project during winter shutdown. Costs can be in the form of agency-force work (i.e., the contract provides for agency maintenance) or contract payments (i.e., winter shutdown maintenance is part of the contract work).
- Deferral of the completion date. Road user benefits, economic impact on the area served, return on capital investment, and traffic safety benefits resulting from the completed facility can be substantial.
- Public safety during winter shutdown. Construction-zone traffic control can be hazardous as well as costly. Temporary traffic safety facilities may be necessary.
- Productive use of construction inspectors and other field personnel during winter shutdown. The time-honored practice of "locate in the winter—construct in the summer" has become almost nonexistent as a solution to the problem, because location work has become highly specialized and demands constant year-round effort.
- Unionization of public employees. Unionization has drastically limited an agency's ability to assign construction field personnel temporarily to other work. In some instances agencies have been forced to consider winter layoffs, use more temporary help during construction, and contract for engineering and testing services, all of which have tended to increase the cost of contract administration.
- Inflation. The current rate of inflation and its effect on project costs may be substantial. The higher costs of winter work may be less than the inflated costs of work done at a later date.

Contractor

From the contractor's standpoint, the following cost factors warrant consideration:

- Maintenance of the project during winter shutdown. Even though agencies may take over routine roadway maintenance where traffic must pass through the project, it is usually the contractor's responsibility to maintain permanent and temporary drainage facilities, preserve completed work, and repair or replace damaged work. Under competitive bidding practices, contingency amounts included in the bid to cover these costs often are conservative, and the risk of overrunning costs often is quite high.
- Stopping work in the fall and starting in the spring. A number of factors are involved, including lost work; installation and removal of temporary drainage facilities, detours, paving, barricades, and signs; protective covers for completed work and installed materials; storage of materials; demobilization and remobilization of equipment and field facilities; and protection of site-stored equipment and materials from vandalism and theft. Uncertainty as to when the shutdown or start-up will occur and what the level of job progress will be at time of shutdown makes it difficult to predict at time of bidding what these costs will be.
- Retention of key personnel through the winter months. In many cases supervisors, foremen, and key skilled personnel are kept on the payroll through the winter months even though little or no work is done. In many areas assurance of year-round employment is essential for retention of the better equipment operators.
- The potential for excessive unexpected costs related to financing a project. An extended period of low income resulting from weather shutdown can create cash-flow problems and unexpected financing costs because of higher-than-expected inventories of stored materials, longer-than-

expected idle time for owned equipment, excessive lost work caused by emergency project maintenance, and damage to completed work.

- The economic benefits accruing from early completion, including early release of retained funds, release of construction bonds, reduced period of insurance coverage, and accelerated availability of bidding capacity for new contracts.

HUMAN FACTORS

General

When considering work under adverse weather conditions, agencies and contractors alike need to give consideration to potential employee inefficiency caused by such conditions. Generally there is a tendency to overestimate the effect of low temperatures and to underestimate the effect of wind, rain, and high temperatures.

Actual effects are difficult to predict, because human tolerances and personal comfort preferences vary greatly. Notwithstanding this fact, research studies on the effect of weather on worker efficiency can be helpful in an estimation of the cost of work done in adverse weather.

One study concerning the effect of temperature establishes that colder temperatures do not affect efficiency as much as one might expect and that equipment operators are affected substantially less than manual laborers (*4*). More importantly, the study concludes that work efficiency is reduced as much by hot temperatures of 80 to 100 F (27 to 38 C) as by cold temperatures approaching 0 F (−18 C). The report establishes a point that may surprise many contractors: a manual laborer's efficiency is the same at 0 F as it is at 80 F. These comparisons are shown in Figure 3.

Studies of windchill factors are helpful in areas where the frequency and velocity of wind increase in winter. As shown in Figure 4, wind can cause a drastic lowering of "effective," or "equivalent," temperature.

Rain and snow certainly reduce efficiency, but very few study data are available. Rain and snow usually affect the material being worked with and the operation of the equipment being used to such an extent that inefficiency due to human discomfort is difficult to isolate. In other words, where rain and snow are involved, the quality of work generally becomes critical before human inefficiency becomes an influential factor.

Snow, rain, and wind, either separately or combined, often create a safety hazard that must be considered over worker efficiency.

Means available for reducing worker inefficiency caused by adverse weather are presented in Chapter Three.

QUALITY OF WORK

General

The potential for poor-quality work as an outgrowth of adverse weather conditions is important to both agency and contractor.

Of major concern to agencies is the possibility of undetected structural or material deficiencies that may endanger the safety of the facility or lead to premature failure, with attendant high maintenance costs and untimely replacement. Of next concern is an increase in borderline, or marginal, work—work that is barely within specification tolerances and is of poorer quality than normal.

Of major concern to contractors is the completion of work that does not meet specification requirements and that they will have to remove and replace at their own expense. Of next concern is loss of pride of workmanship and of a firm's reputation for producing a quality product. For some firms the second factor overrides the first.

Two elements need to be considered by both agency and contractor: the physical effect of the weather on the material or equipment used and the effect of the weather on the workers doing the work or the inspecting and testing.

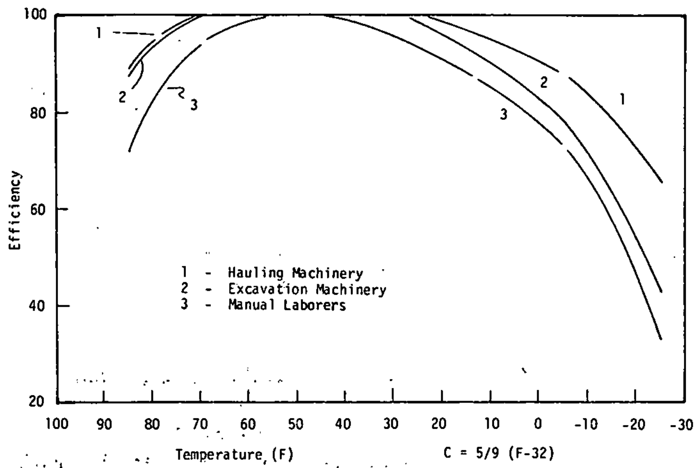


Figure 3. Effect of temperature on construction workers (after Osborne from Ref. (4)*).*

Agency

The agency must consider the following:

- Will the final "as-built" condition of the material meet specification requirements? Cold weather may preclude drying of soils, or rainfall may increase the moisture content to a point above optimum and thus prevent compaction to the required density; hot weather may cause premature drying of the surface of fresh concrete, causing loss of strength; freezing weather may cause incipient cracking of concrete during the cure period; cold-weather paving with bituminous materials may prevent adequate compaction.
- Can accurate survey layout and control work be performed? Cold or freezing weather can affect the accuracy of survey instruments; metallic tapes and chains must be calibrated for temperature changes when precision is required; freezing ground may move control stakes or reference points.
- Can necessary quality-control tests be performed with reliability? Field density tests can be affected by hot or windy weather as well as by cold or wet weather; wind can cause loss of fines during gradation tests; accuracy of weighing scales may be affected; low humidity and hot weather may affect moisture tests.

Equivalent Temperatures (F)

Wind Speed (miles per hour)																	
Calm	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	33	27	21	16	12	7	1	-6	-11	-15	-20	-26	-31	-35	-41	-47	-54
10	21	16	9	2	-2	-9	-15	-22	-27	-31	-38	-45	-52	-58	-64	-70	-77
15	16	11	1	-6	-11	-18	-25	-33	-40	-45	-51	-60	-65	-70	-78	-85	-90
20	12	3	-4	-9	-17	-24	-32	-40	-46	-52	-60	-68	-76	-81	-88	-96	-103
25	7	0	-7	-15	-22	-29	-37	-45	-52	-58	-67	-75	-83	-89	-96	-104	-112
30	5	-2	-11	-18	-26	-33	-41	-49	-56	-63	-70	-78	-87	-94	-101	-109	-117
35	3	-4	-13	-20	-27	-35	-43	-52	-60	-67	-72	-83	-90	-98	-105	-113	-123
40	1	-4	-15	-22	-29	-36	-45	-54	-62	-69	-76	-87	-94	-101	-107	-116	-128
45	1	-6	-17	-24	-31	-38	-46	-54	-63	-70	-78	-87	-94	-101	-108	-118	-128
50	0	-7	-17	-24	-31	-38	-47	-56	-63	-70	-79	-88	-96	-103	-110	-120	-128

Figure 4. Windchill factors ("Winter Storms," Dept. of Commerce, 1970).

- Will the discomfort and attitude of the inspector cause inaccurate control measurements and tests?

Contractor

The contractor must consider the following:

- How does the weather affect the material being handled? In hot weather, concrete may take a premature set and be difficult to place or finish; in cold weather, concrete may set slowly and gain little strength during normal cure periods, requiring forms to be left in place longer and thus delaying finish; paints and epoxies may set too quickly in hot weather and too slowly in cold weather; prefabricated steel sections may not fit during weather extremes and thus cause lost time; excessive rolling may be required in compacting bituminous materials during cold weather; wait time before rolling may be excessive during hot weather.
- How does the weather affect the construction process being used? Rainfall may wet materials being crushed to the extent that screens plug up; wind may cause loss of crusher fines; wet stockpiled materials for bituminous paving mixtures may require excessive drying time and fuel; during cold weather, long hauls for hot paving material may result in excessive loss of heat.
- Will the discomfort and attitude of the worker cause a critical loss in quality of product?

Seasonality in the highway construction industry is a major problem. As such, it is a substantial impediment to the economic and social welfare of the country and thus deserves increased attention and organized efforts to reduce its impact to a more acceptable level.

The three principal areas of concern in the over-all problem are (1) economic considerations, (2) human factors, and (3) quality of product. Each of these areas currently has an unduly large adverse impact on efforts to solve the problem because of a lack of knowledge and understanding about them.

The following chapters summarize current knowledge and practice and furnish some guidance to agencies and contractors who must make decisions concerning work in adverse weather. It is hoped that this synthesis provides an awareness of deficiencies in knowledge and consequently encourages additional studies and data development that will further enhance our ability to reduce the problem to an acceptable level.

CHAPTER TWO

PROJECT PLANNING AND PREPARATION

GENERAL CONSIDERATIONS

The major impediments to working on highway projects during adverse weather can be offset substantially by adequate planning and preparation on the part of the owner-agency and the contractor.

Innovations in work organization and management, such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), have been widely used by transportation agencies and contractors. Items of work that can be completed during bad or winter weather can be identified and, if necessary, noted in the contract or on the plans.

In planning for cold-weather operations, making a long-range estimate of the most severe condition and deciding which work can be continued are early considerations. Historical data on temperature and precipitation are available from the U.S. Weather Service. A study of these data helps the contractor decide just how extensive the preparations should be for work to be done during any season. It also helps contractors and agencies to schedule critical work in such a way as to avoid extremely cold temperatures or excessive precipitation. This type of study helps both agency and contractor to prepare in advance for the most frequently encountered conditions.

Short-range weather forecasts also have proven useful to contractors, particularly for planning and scheduling week-to-week and day-to-day work during the winter months (*5*). In addition to the U.S. Weather Service, there are individuals and other services that specialize in weather information and predictions. Some contractors have found it desirable to have a weekly estimate of anticipated conditions supplemented with a daily update. Any changed condition that might affect work is reported to the contractor immediately by telephone or radio. Advance weather information can help the contractor plan cold-weather work and in many cases may mean the difference between a heavy loss and a reasonable profit. Several state agencies contract for advance weather information during the winter season so they can prepare for snow and ice removal. However, the use of private weather services to alert construction inspectors is not a common practice. Most highway agency field personnel rely on local weather service broadcasts or share the weather information procured by the contractor.

The agency establishes the contract terms and work specifications that control projects; following is a discussion of actions the agency can take during construction in adverse weather. Many agencies already have considered most of these actions and, to varying degrees, have implemented some of them in their planning techniques; however, to ensure comprehensive coverage of the subject, it is assumed here that current practice follows the tradition of avoiding work during inclement weather except where absolutely necessary for some reason peculiar to a given project.

AGENCY CONSIDERATIONS

Productive advancement toward extending the construction season by working during adverse weather will not occur when contract terms and specifications are not clear and precise in defining what will be expected and required of the contractor or when the agency relies on a tight time schedule and severe monetary assessments for time overruns in order to force the contractor to work during adverse weather. Advancement can best be achieved when the contract terms:

- Clearly define specific work that must be performed during adverse weather and the quality specifications that must be met, and provide a means for bidding on them.
- Clearly define specific work that may be performed during adverse weather at the contractor's option, and include definitions of "go - no go" limits, approval requirements, and responsibility assignments that minimize the contractor's risk and increase the potential for lowering the extra direct costs. (Contract provisions for payments to offset the extra direct costs of cold-weather work may be warranted.)
- Clearly define the authority of the agency to order that work be performed during adverse weather, and provide a means for payment of extra costs incurred.

To incorporate the above features into contract specifications to a realistic and justifiable extent, the agency should first evaluate the benefits that may result. The agency should review the potential cost benefits outlined in Chapter One and develop cost-benefit factors to be used in the project planning process. Through this procedure "reasonable extra cost" levels can be established for off-season work and specific actions developed.

To evaluate fully the degree to which adverse-weather construction can be extended and the attendant extra cost, the agency should:

- Review and revise current agency standard specifications to eliminate unnecessarily restrictive specifications (both general and technical) and to add appropriate specifications permitting and encouraging the continuation of construction during adverse weather as long as the quality of the work meets reasonable quality specifications. Calendar date limitations should be reviewed and replaced with measurable physical controls, such as temperature and moisture content, that are directly related to achieving the quality desired. These and other considerations for specification improvements are set out in Chapter Three.

• Review project scheduling procedures to determine whether they discourage off-season work. When projects involve work adaptable to off-season construction (e.g., clearing and grubbing, aggregate production, steel fabrication, grading with clean gravels, and rock excavation), early fall contract lettings should be considered. The formation of separate, short-term contracts for such work may prove advantageous. The completion of large, complicated projects may be advanced substantially by the early award and construction of such work. Many agencies now use CPM or PERT programs or similar project planning techniques to identify projects or work items that can be performed during the off-season and to schedule such work so as to attain the best possible plan for year-round construction. Some agencies do not charge time during winter months even though work is performed.

• Develop planning procedures for identifying specific project work that can be performed during adverse weather and estimating the attendant extra costs, if any. For this type of planning, information is needed on the anticipated weather conditions, natural drainage, topography, flow levels for streams, types of soil and rock involved in excavation and embankment construction, and probable sources of and haul routes for construction materials. Other factors to be considered are the availability of construction labor, special union requirements for off-season work, and the need for special or modified equipment.

Accomplishment of the above should ensure adequate consideration and evaluation of those factors favorable or unfavorable to adverse-weather construction and give the agency a basis for implementing such work either by making specific requirements or by permitting the contractor to choose among alternatives. Chapter Three discusses many of the areas potentially applicable to adverse-weather construction.

CONTRACTOR CONSIDERATIONS

The contractor's preplanning for adverse-weather construction is, of necessity, controlled by cost considerations. Competitive bidding demands that a contractor minimize cost in order to be the successful bidder; and, once work is under way, cost minimization is essential to staying in business. Because of this, adverse-weather construction usually is implemented voluntarily by the contractor only when an economic advantage exists and the risk of loss is low. This is not to say that there is no potential for increased adverse-weather construction through contractor initiative in planning work. On the contrary, many opportunities for construction are overlooked because contractors rely largely on direct-cost accounting data in their decision-making processes and do not evaluate adequately the less-obvious, indirect-cost benefits that may accrue through judicious use of adverse-weather construction. This is compounded by estimators' tendency to overestimate the direct cost of such construction.

To ensure that economically beneficial opportunities are not overlooked, contractors should attempt to:

• Quantify the extra cost of performing work during adverse weather by using the most current data available.

• Quantify the economic value of indirect benefits as set forth in Chapter One. These values may best be expressed in terms of value of time of contract completion.

• Use CPM, PERT, or other work scheduling systems to identify work that can be performed during adverse weather and the contract time that might be saved.

The contractor who has a clear understanding of the above will be in a position to either initiate certain adverse-weather work or submit properly priced alternate proposals for owner consideration.

CHAPTER THREE

CONSTRUCTION PRACTICES FOR ADVERSE WEATHER

CLEARING AND GRUBBING

Cold Weather

Clearing and grubbing of brush and trees in preparation for earthwork is not appreciably more difficult during cold weather unless the ground is frozen to a considerable depth. In fact, the removal of merchantable timber is often easier during cold weather when hauling units can travel over soft ground that is frozen. Where burning is permitted, the hazard of vagrant fires often is reduced during the winter months. Efficiency of workers is not impaired greatly unless extremely low temperatures prevail (Fig. 3).

Wet Weather

Heavy rainfall makes equipment operation difficult and more costly and may cause stoppage of work. Also, with current environment-oriented restrictions on damage to existing natural areas, wet-weather operation of heavy equipment must be minimized. Moderate rainfall, however, may improve conditions by reducing fire hazards.

Hot Weather

Increased fire hazards (frequently resulting in mandatory work shutdown in some areas) and reduction of worker efficiency are the greatest deterrents to performing clearing and grubbing work during hot weather. Equipment may need special spark arresters on exhausts, and fire guard patrols and standby fire-fighting equipment may be required. Disposal by burning may be prohibited.

Summation

Clearing and grubbing generally can be accomplished during cold or moderately wet weather. Hot, dry weather, extremely wet weather, and cold weather combined with heavy snowfall may stop such work. Fire hazards may control the work. Environmental Protection Agency (EPA) regulations may delay or stop some of the work.

The advantages of performing clearing and grubbing during the winter in preparation for grading are substantial and may warrant the letting of separate contracts. When clearing and grubbing are included as part of a grading contract, a late summer or early fall contract award usually will make it possible to reduce over-all contract time.

EARTHWORK

Cold Weather

It is standard practice for most northern highway agencies to curtail earthwork during the winter season. Some specifically prohibit embankment construction with frozen soil. Field experience has shown that neither cohesive nor granular soil can be compacted satisfactorily while frozen. The effect of temperature on densities produced in the laboratory by AASHTO T 99 and T 180 compactive efforts is shown in Figure 5 (*6*). The optimum moisture content varies with temperature and affects the shape of the density curve. It is almost impossible to add moisture to dry soil if the temperature is much below freezing.

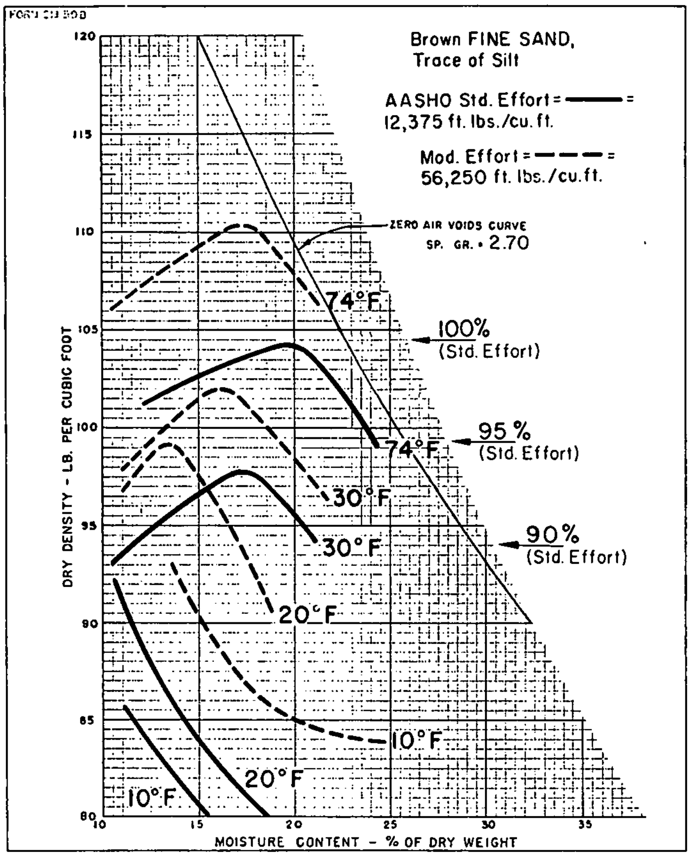


Figure 5. Effects of temperature on moisture-density relations (New York)(6).

If there is a surplus of excavation, the contractor may be permitted to waste material during the winter months. In some cases where daytime temperatures are above freezing, the frozen crust is removed from both the surface of the embankment and the cut, and grading work continues. The frozen material that is removed may be used for flattening slopes or landscaping, or it may be wasted (Fig. 6) (*7*). The agency and the contractor must agree on who is to pay for the cost of any extra handling of frozen materials and, when required, the cost of replacing wasted soil with borrow. In some cases specific bid items may be required.

Equipment that is now available can rip soils that are frozen 2 ft (0.6 m) or more in depth. Steam- or gas-burner heat has been used to thaw small areas of frozen material for structure or building excavation. Insulation materials, such as straw, have been used to prevent small areas of ground from freezing. When soil *must* be compacted at subfreezing temperatures, antifreeze solutions may be added to combine with the moisture in the soil. However, this treatment usually is too costly for anything but structure foundations and special backfill.

Frozen soil that is placed in large stockpiles may cause further problems in the spring or summer. The interior of the pile may remain frozen and be difficult to handle. If it does thaw, it may be so wet that further handling and drying are required before it is placed in an embankment. Failure occurred on one embankment in New York when frozen soil with a high moisture content was placed in the embankment (Fig. 7). The cost of removing and replacing a major embankment usually is sufficient to discourage fill construction with high-moisture soils during cold weather.

Only a few highway agencies permit either the placement of frozen soil in embankments or the construction of embankments or additional lifts on material that is frozen deeper than a few inches. Many states, however, permit placement and compaction of unfrozen materials at temperatures below freezing.

Most agencies permit the placing of clean, coarse granular materials and ripped or blasted rock in embankments throughout the winter months. This encourages contractors to strip the soil overburden from rock or gravel cuts before winter.

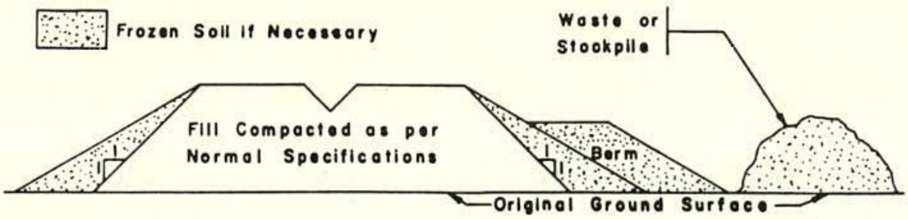


Figure 6. Locations where frozen soil can be used without detrimental effects (7).

Wet Weather

Rain, during all seasons, continues to be the leading cause of delays on earthwork construction. Once the maximum allowable moisture content in the embankment material has been exceeded, work is halted. To decrease drying time, the top layers of embankments often are aerated by discs or plows. Another common practice is to bring in dry materials for mixing with the wet layer. Wet materials also may be spread in thin lifts over dry materials or wasted on or off the project. When suitable granular borrow is available, designers may provide for placing drainage layers of granular material alternately with the wet material. Hydrated-lime treatment also has been used to accelerate drying in critical areas. Because of the relatively high cost of all of these procedures, either the contract must contain bid items for payment or the agency and the contractor must negotiate mutually acceptable distribution of costs.

Making a decision about whether to continue grading work during wet weather requires consideration of potential damage to completed embankments and drainage facilities as well as to embankments and cuts under construction. Continued heavy hauling over completed grades may accelerate and increase penetration of moisture into the embankment and cause instability. With embankments of fine sandy or silty soils at or near the optimum moisture content, continued heavy hauling may cause overcompaction and supersaturation, with attendant instability. Also, temporary surface drainage may be destroyed, causing washouts and embankment loss.

Figure 7. Embankment failure caused by placement of frozen soil (New York).

Rock-excavation material and clean gravels normally can be placed in embankments during wet weather. Placement and compaction actually may be eased by moderate rainfall. If haul roads, other embankments, and drainage facilities are not damaged by continued operations, the benefits of continuing work may offset increased direct costs.

Hot Weather

Hot weather normally does not have an adverse effect on earthwork. Although the actual work may not be affected, however, the requirement that embankment material is to be placed at or near the optimum moisture content may not be met during hot, dry periods because of rapid moisture loss. This can cause problems when the addition of moisture at some later date causes uncontrolled swelling of subgrade soils and of structure backfill.

Hot or prolonged dry periods are seldom a problem in areas where the source of water is adequate for maintaining the optimum moisture content in embankment materials. The addition of water at the point of excavation has proved economical in some situations.

Dust also may be a problem during dry periods. Most complaints from adjacent businesses and residents are about dust caused by poorly maintained haul roads. The addition of a small amount of asphalt emulsion to the sprinkling water may prove helpful.

Construction inspectors need to monitor the moisture content of highly plastic soils and take the necessary action to keep it at or near optimum during hot, dry weather. The subgrade in particular should be maintained at a uniform level to avoid pavement irregularities.

Summation

Except where rock excavation or clean gravels are involved, grading in cold or wet weather is difficult and often impossible from a practical standpoint. Particularly during wet weather, the quality of the work is the controlling factor, because most soils can not be placed in embankments satisfactorily when excess moisture is present.

When grading work is warranted during adverse weather, designers should consider the degree to which standard moisture-density requirements can be reduced by reasonable increases in base and pavement thicknesses or the use of granular drainage layers, soil mixing, or chemical additives such as hydrated lime.

SUBGRADES AND BASES

General

Winter weather has a pronounced effect on roadway subgrade work and severely limits finishing operations. It is common practice in the northern states to discontinue subgrade work during the winter months, except where the top of the embankment and subgrade can be constructed with rock or gravel materials. Some agencies in areas with moderate winters do permit subgrade work; however, they provide close inspection to prevent the use of frozen materials. Many of the additives or treatments that improve subgrade stability depend on warm temperatures and are difficult to use during the winter months. The beneficial reactions in lime and cement cease as temperatures drop to freezing. Research has indicated that although the curing of lime-treated sections is halted by cold weather, it resumes with the arrival of warm weather (*8*).

The base courses most commonly used are bituminous-treated, cement-treated, and mineral-aggregate. Each has limitations that affect construction during the winter months.

Bituminous-Treated

During the past few years there has been increasing interest in cold-weather base construction with hot plant-mixed bituminous mixes. In some cases the bituminous base is a part of a full-depth pavement. Although many specifications do not permit the placing of hot bituminous base courses at temperatures lower than 40 F (4 C), it is being increasingly accepted that thicker bases can be placed at much lower temperatures. The factors to be considered for adverse-weather construction are discussed in the "Bituminous Construction" section of this chapter.

Some agencies have adopted the use of bituminous-treated bases for the specific purpose of protecting completed subgrades during winter shutdown. In the spring, work often can proceed several weeks or even months ahead of projects in which subgrades were unprotected and thus became saturated. Further, these base courses usually will support medium-weight construction traffic, which greatly facilitates drainage maintenance and gives good access to structural or other work continued through the winter months. The structural value of such bases is accounted for in the surfacing design, and this tends to minimize extra costs.

Cement-Treated

The use of both soil-cement and cement-treated-aggregate bases during the winter months is severely limited by most agency specifications, primarily because of curing problems. Generally this work is limited to periods when the subgrade is not frozen and the air temperature is above 40 F (4 C) and rising. Also, there is commonly a requirement for providing a bituminous seal coat over the soil-cement treatments; in some cases this may be difficult for late-season work. A further requirement for soil cement is that it be covered by the next course during the same construction season. Because the curing action of the cement stops when temperatures drop to 32 F (0 C), there is fear that the treated base may be damaged. Heating long stretches of base is not practical.

Mineral-Aggregate

Highway agencies vary in specifying limitations on placing mineral-aggregate bases during cold weather. A few do not permit mineral-aggregate bases to be placed at temperatures below 40 F (4 C). Many do not permit the placement of this material on frozen subgrade or frozen layers of base. In practice, however, mineral-aggregate bases often are placed at temperatures well below freezing by the use of unfrozen material from stockpiles or directly from crushing plants. Some agencies and most contractors would rather get a course of base placed, even under adverse conditions, than have an unprotected subgrade through the winter months. Extreme caution must be used, however, if the subgrade is composed of silty or other moisture-sensitive soil. An unsealed granular base will hold free water on the grade for extended periods, increasing the chance that a soft, unstable grade will develop. Extensive reworking may be required. Mineral-aggregate bases placed at the beginning of a wet season should be protected with at least the first lift of bituminous pavement or sealed to prevent excessive moisture penetration.

It is common practice to halt all base placement work as soon as possible after rainfall commences. The compaction effort should be completed immediately after work has been halted. If rainfall appears imminent, the rolling operation should be closed up as near as possible to the laydown equipment, and a seal should be applied if extended shutdown is anticipated.

The moisture content of mineral-aggregate bases usually is increased during hot weather, particularly if the humidity is low. Bituminous emulsion frequently is added to sprinkling water to help maintain compaction and grade.

Summation

Bituminous bases offer the best chance of extending base work into adverse weather. For any base material, however, it is essential that a stable subgrade exist. Small, soft subgrade areas can be corrected prior to placement of base material by removal and replacement, by the addition of hydrated lime or portland cement, or by removal and replacement with base material.

Base material should not be placed over moisture-sensitive subgrades when extended rainfall is imminent, unless the base will seal itself against rapid moisture penetration (treated bases) or will be sealed by paving or special seal treatment.

PAVEMENTS

Highway pavements fall into two major categories: those using bituminous materials for the bonding agent and those using portland cement for the bonding agent. Other materials, such as tar and natural cement, have been used to a minor degree; adverse weather affects such materials in much the same way as it affects the two major materials.

Although hot plant-mixed asphalt concrete generally is defined as bituminous pavement, the following section on "Bituminous Construction" deals with other bituminous roadway surface treatments (e.g., seal coats, light bituminous surface treatments, and road mixes) as well as asphalt concrete.

Mixing, handling, and placing of portland cement concrete pavements in adverse weather are controlled by the physical and chemical properties of the material and by other principal characteristics affecting all types of portland cement construction; they are therefore discussed in the "Portland Cement Concrete Construction" section of this chapter.

BITUMINOUS CONSTRUCTION

General

Highway agency specifications generally are explicit in setting temperature or calendar limits on bituminous work. In practice, however, these specification limits are not always rigidly enforced, particularly when projects are nearing completion late in the construction season. There is a prevalent feeling that plant-mixed and machine-placed bituminous construction can be performed satisfactorily at temperatures somewhat lower than many specifications permit, and many agencies are in the process of revising specifications to eliminate calendar date restrictions and allow use of ambient temperatures and ground temperatures for control. Recognition is being given to recently developed data verifying that thicker lifts can be placed successfully at lower temperatures. An example of this trend is illustrated in the following excerpt from the 1974 Washington Standard Specifications:

5-04.3(16) Weather Limitations.

> Asphalt for "Prime Coat" shall not be applied when the ground temperature is lower than fifty (50) degrees F., without written permission of the Engineer.
>
> Asphalt concrete shall not be placed on any wet surface, or when the average surface temperatures are less than those specified in [Table 1], or when weather conditions otherwise prevent the proper handling or finishing of the bituminous mixtures.

The availability of improved vibratory compaction equipment and recognition of the advantages of pneumatic roller compaction immediately behind the laydown machine have made it practical to compact thicker lifts at temperatures near freezing or below.

Spray applications and road mixes involving paving-grade asphalts, cutbacks, or emulsions are seriously affected by cold or wet weather; this is why agencies resist changes from past practices.

Prime Coats

Most agencies do not permit the application of primes during cold weather. However, there is considerable variance in the specifications as to the lowest temperature and the starting and stopping dates for prime work. Surveys have found that most agencies use 50 or 60 F (10 or 16 C) as the starting or stopping temperature. In addition, many specifications list cutoff and start-up dates.

The critical factor in late-season prime application is the curing time available before the prime is covered with other construction. If cool weather prevents the prime from curing, it could flush into upper layers the following summer. For this reason faster-curing primes are selected for late fall or early spring work. It is the surface temperature rather than the ambient temperature that should be considered, inasmuch as the surface temperature may be several degrees lower than the air temperature directly above.

Some agencies permit the project engineer to omit the application of the prime coat if the surface of the grade to be paved can be maintained in a tight, stable condition during paving operations. Coupled with the use of thicker lifts of bituminous paving materials, this action often extends the paving season.

Tack Coats

The comments on temperature and calendar limits discussed above for the application of primes generally are applicable to tack application. However, because tacks are applied at such low rates, usually 0.05 gal/yd^2 (0.2 litre/m^2), curing is a lesser problem. In some cases the tack coat is omitted in late-season construction to facilitate progress, but this should be permitted only when good bond can be achieved without the tack coat.

Seal Coats

The success of seal coat (or light bituminous surface treatment) construction depends on the cover stone being adequately bedded in the bituminous material. This becomes more difficult to accomplish if the roadway surface is cold, if the air temperature is low, or if temperature conditions are marginal and it is windy. When the weather is cool, the cover stone must be placed immediately behind the spray application. In some cases 15 to 30 seconds is the maximum time before the cover should be placed. Heating and precoating seal-coat aggregates have been beneficial for cool-weather work. Temperature and calendar restrictions are similar to those discussed above for primes. Some specifications permit late-season seal-coat work if the temperature has reached 60 F (16 C) on three consecutive days, has not been below 40 F (4 C), and is 60 F in the shade at time of application.

TABLE 1

SURFACE TEMPERATURE LIMITATIONS FOR ASPHALT CONCRETE PAVING (WASHINGTON)

Compacted thickness	Surface course	Subsurface courses
Less than 0.10'	55 F	55 F
0.10' to 0.20'	45 F	35 F
0.21' to 0.35'	35 F	35 F
More than 0.35'	D.N.A.	25 F*

*Only on dry subgrade, not frozen, and when air temperature is rising.

Road Mix and Traveling Plant Mix

The mixing and placing of either in-place (road mix) or added materials (traveling plant mix) on the roadway is much more risky late in the construction season. The aggregate is more difficult to dry during cool weather, and mixing and curing also are affected. The use of emulsion in these processes increases the risk of failure because of slow curing and drying and, consequently, the greater likelihood of rainfall. The temperature and calendar limits usually are more restrictive than those for prime application.

Plant Mix

Local, state, and federal highway agencies have been considerably interested in cool- or cold-weather construction with plant-mix material. The World War II pressures for new roads, streets, and airfields generated early interest in cold-weather bituminous paving. It was found that much of this construction done during cold weather did not perform very differently from work completed during warm weather. When there was a "need" after World War II, many agencies extended the construction season beyond specification limits by permitting work during adverse weather, but there was little public notice of this action until the Public Works Director of Woodbridge, New Jersey, started what amounted to year-round bituminous construction (*9*).

Efforts to estimate heat loss and cooling time during cold weather have been attempted through a consideration of mix temperature, location, cloud cover, time of day, wind, and surface and air temperature (*10, 11, 12*). The FHWA Region 15 Demonstration Projects Division has conducted field research and demonstrated cold-weather paving (*13*). Plant-mix bituminous pavement has been constructed on clean, dry surfaces at temperatures much lower than the 40 F (4 C) that is widely specified. The controlling factor is the pavement's ability to compact to the desired density before the material cools (Fig. 8). The National Asphalt Pavement Association's Quality Improvement Committee has suggested that the breakdown rolling should be obtained before the mat temperature drops below 175 F (79 C) (Fig. 9) (*11*). Conditions that may affect the amount of time available for breakdown rolling are laydown temperature, mat thickness, temperature of surface when mat is placed, air temperature, wind, and solar flux (heat from sun). The laydown temperature and mat thickness have more effect than the other conditions on the time it takes the mat to cool (*10*). In some cases insulated truck beds may be required to maintain the temperature of the mixed material. Excessive heating of aggregates and bituminous material to increase laydown temperature should never be permitted, because this will damage the binder.

The placement and compaction of bituminous material become more critical during cold weather. Plant production, haul-unit capacity, and spreading capability should be balanced. Material should not be kept in trucks for extensive periods, nor should the paving machine spend time waiting for material. Ideally, the paver should finish spreading the last load just as the next load arrives. The breakdown roller should work as close to the paving machine as possible.

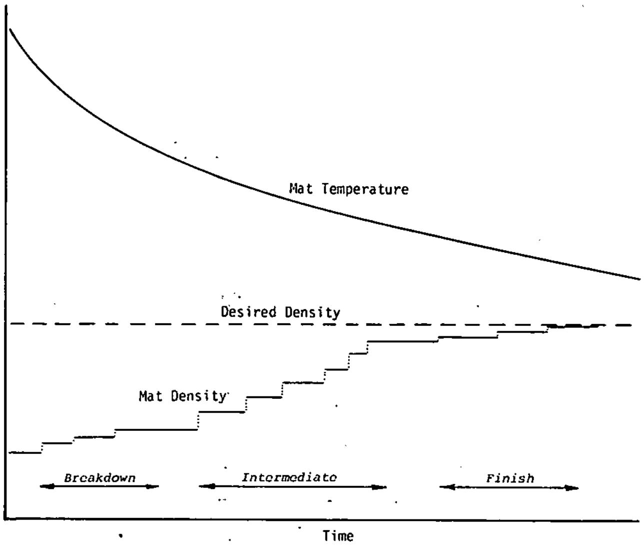


Figure 8. Relationship between compaction, density, temperature, and time for bituminous mat.

The total energy requirement for bituminous paving in cold weather is greater than that for warm conditions. This must be considered along with the other disadvantages and the advantages associated with cold-weather paving. The increased energy demand is greatest in heating and drying aggregates. Minor additional energy use occurs in equipment operation and increased compaction effort.

Hot weather normally causes little problem, except perhaps delay of finish rolling due to slow cooling and inefficiency due to worker discomfort.

Rain during either hot or cold weather causes problems for bituminous construction, although light rain can be tolerated to some degree when the paving is done with hot plant-mix material. Heavier rainfall usually stops all operations.

Summation

Bituminous construction of all types except plant-mix construction is affected seriously by cold or wet weather and normally should not be attempted. Plant-mix construction can be continued in temperatures approaching freezing

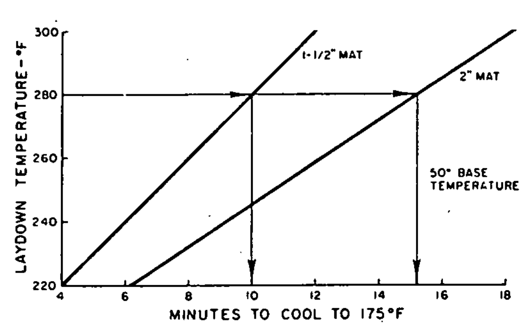


Figure 9. Effect of mat thickness (11).

and below, provided thick lifts are used and construction procedures are accelerated so that compaction can be achieved before the mix cools. Wet weather usually stops bituminous work. The following techniques are recommended for bituminous construction.

- Schedule prime and seal work to be completed in early fall or late spring to take advantage of any available good weather.
- Permit omission of the prime when weather does not favor curing if a tight, stable grade can be maintained ahead of paving.
- Make sure that a prime, if used, cures before covering it with bituminous paving materials.
- Place seal-coat aggregate immediately behind the distributor.
- Consider heating and precoating aggregates.
- Use as little tack as possible to avoid any curing delay.
- If rain is likely, place road-mix material in windrows to minimize moisture accumulation.
- When rainfall starts or appears imminent, stop plant production and complete rolling as soon as possible.
- During cold weather, use thicker lifts whenever possible to increase the time available for rolling.
- With asphalt cements, increase mixing temperature, but do not overheat; stay under 325 F (163 C).
- Be aware that in some areas cold-mixed emulsions may not cure when laid during cold weather.
- Complete breakdown rolling for hot asphalt mixes before the temperature cools to 175 to 200 F (79 to 93 C).
- Balance plant production with haul-unit capacity and paver capability.

PORTLAND CEMENT CONCRETE CONSTRUCTION

General

Portland cement concrete construction can be accomplished in adverse weather, provided it can be protected from damage by the elements during the curing period. Because structure work has forms on most surfaces and usually is confined to relatively small areas, structure work has a much greater potential for adverse-weather work than roadway paving does.

Most highway agencies have long recognized that quality concrete can be placed during winter months. Bridges were constructed during severe winters in Canada, one as early as 1826 and another in 1932, and are still in service, indicating that the quality of work is satisfactory. More recently, during construction on the Campodazzo Viaduct in Italy, heated enclosures were constructed to keep the project on schedule at temperatures down to −49 F (−45 C).

Paving involves large areas of fresh concrete exposed to the elements, and the difficulty and attendant high cost of protecting these large areas from rainfall or freezing temperatures usually preclude extensive paving during such weather. When paving during adverse weather is necessary, straw cover, blankets, plastic covers, or earth cover are used for protection. Criteria for mixing, handling, and placing are similar for all types of portland cement concrete construction.

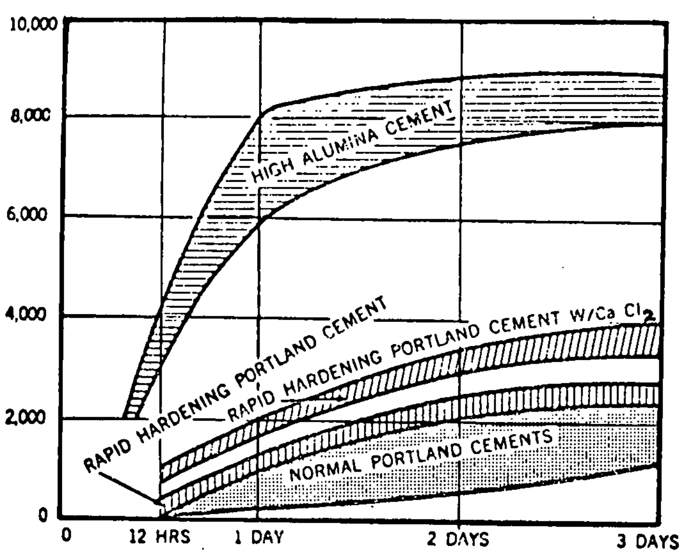


Figure 10. Comparison of compressive strengths (Portland Cement Association).

Cold Weather

Specifications and procedures have been developed to control the mixing, placing, and protection of concrete during cold weather. The American Concrete Institute's "Recommended Practice for Cold Weather Concreting" (ACI 306-66) is used as a standard reference by many U.S. agencies (*14*).

When the temperature is below 40 F (4 C), one or more of the following extra steps or precautions are taken to ensure durable, high-strength concrete:

- Increase cement content.
- Change type of cement.
- Heat mixing water.
- Heat aggregate.
- Insulate concrete in forms to prevent heat loss.
- Provide external heat and cover during early curing.

Detailed planning and prior approval are required to implement any of the above steps. Special equipment is needed to heat water or aggregate, and enclosures may be required for the protection of fresh concrete. The volume of concrete placed, the section thickness, and the surface area exposed are also factors that should be considered.

Materials

The hydration heat released by the cement gives limited protection against cool temperatures. The concretes made with fine-grind cements and other fast- or rapid-setting cements attain high early strength and are used for concrete that is placed during cold weather (Fig. 10).

Calcium chloride (1 to 2 percent) is used to accelerate set and obtain high early strength; however, it should not be used for reinforced concrete where corrosion of the steel might occur and should not be used in conjunction with aluminum.

Water-reducing agents are used to improve the work-ability of the mix, thus keeping the water content low and lessening damage to the concrete surface from freeze-thaw cycles. Entrained air has the same effect.

So-called antifreeze chemicals that are now available are not recommended for use in concrete (*15*).

Mixing

The temperature of the concrete during mixing is critical in cold weather and must be maintained between specific limits, usually 40 to 60 F (4 to 16 C) (Table 2). Most highway agencies do not require that water or aggregates be heated when the air temperature is above 40 F. Most agencies specify that when the air temperature is between 30 and 40 F (−1 and 4 C) the water be heated enough to bring the mix temperature to the desired level (50 to 60 F—10 to 16 C). However, the high specific heat of the aggregate causes a time lag in mix temperature stabilization. Some specifications require that heated water be added to cold aggregates well in advance of final mixing. If the air temperature is below 30 F, the fine aggregate is heated. Figure 11 shows the relationship between the temperature of the aggregate, and water, and the concrete mix. Neither the mixing water nor the aggregate should ever be hotter than 180 F (82 C). (Some specifications limit this to 150 F—66 C). To permit temperature stabilization, water and aggregate should be well mixed before cement is added. Mix temperatures should not exceed 70 to 80 F (21 to 27 C).

Mixing water is heated by gas, electricity, or steam pipes. Stockpiled aggregates are heated with live steam, by metal pipes containing gas-heating devices, in drum driers, or under canvas cover with space heaters.

Placement

Forms and reinforcement should be free of ice and frost before concrete is placed. All form surfaces that will be in contact with the concrete must be oiled. During the winter months, wood forms must be coated with oil before the wood becomes saturated with moisture.

The minimum temperature for placing fresh concrete ranges from 40 F (4 C) for mass sections to 55 F (12 C) for thin sections. ACI recommends that concrete be placed near the minimum temperature and not at high temperatures (Table 2).

Protection

The unhardened concrete must never be permitted to freeze. If the surface or edges are frozen, permanent damage to the concrete occurs. The hydration heat, when contained by adequate insulation, keeps the concrete at the desired temperature during moderately cold weather (Fig. 12). The materials most often used as insulation for forms are fiberglass, rock wool, balsam wool, and polystyrene. The R values for a 1-in. (25-mm) thickness of these materials vary from 3 to 5 (0.5 to 0.9 m²K/W) (Fig. 13). The 1969 Wisconsin Standard Specifications require an R value of not less than 7.0 (1.2 m²K/W) if the pour thickness is 24 in. (610 mm) or less and of not less than 5.0 if the pour thickness is more than 24 in. The 1967 Michigan Standard Specifications requirement is shown in Figure 14.

Several agencies require that the ambient temperature and the temperature at the surface of the concrete be recorded at frequent intervals (4 to 6 h) for the first 3 to 5 days. The surface temperature is measured at edges, corners, and other points when lower temperatures are anticipated.

The practices followed by highway agencies to protect concrete during the first few days are reasonably consistent. The two critical factors are the number of days that protec-

TABLE 2

RECOMMENDED CONCRETE TEMPERATURES FOR COLD-WEATHER CONSTRUCTION (after ACI 306-66).

Weather Condition	Minimum Mixing Temperature		
	Thin Sections (4"-8") (100 to 200 mm)	Moderate Sections (8"-24") (200 to 600 mm)	Mass Sections (>24") (>600 mm)
30°F to 40°F -1°C to 4°C	60°F 16°C	55°F 13°C	50°F 10°C
0°F to 30°F -18°C to -1°C	65°F 18°C	60°F 16°C	55°F 13°C
Below 0°F Below -18°C	70°F 21°C	65°F 18°C	60°F 16°C

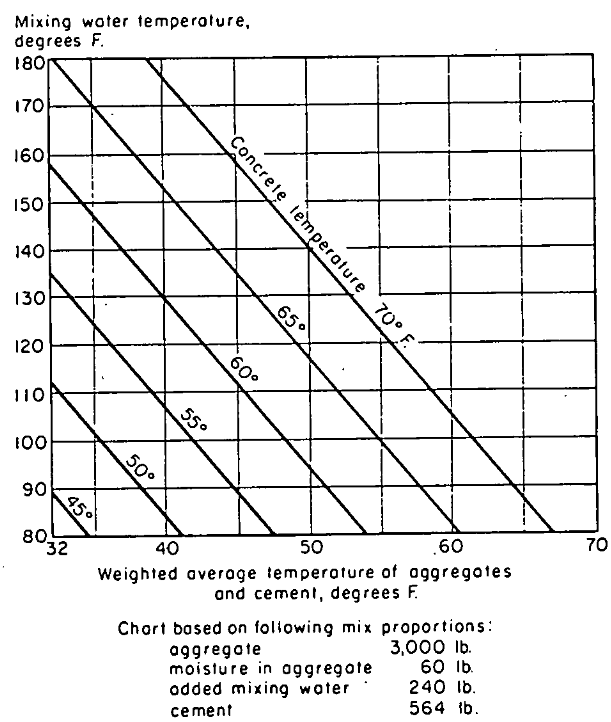
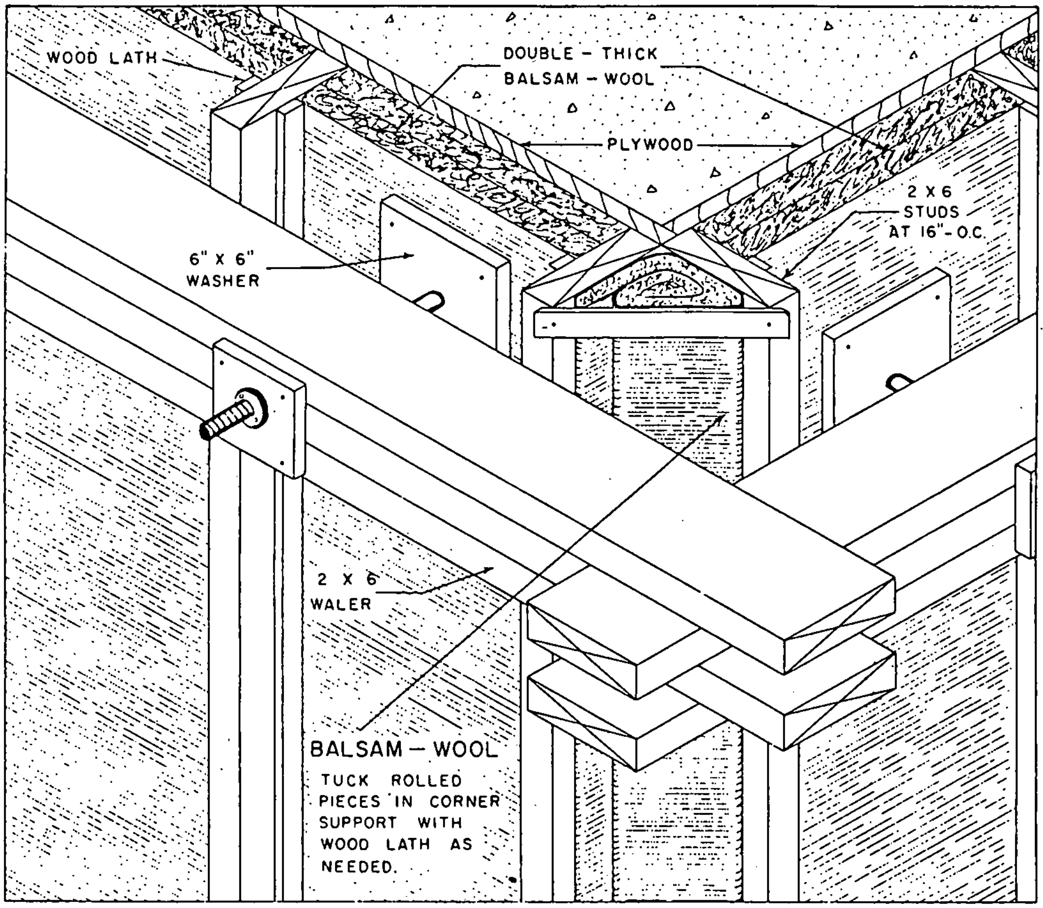
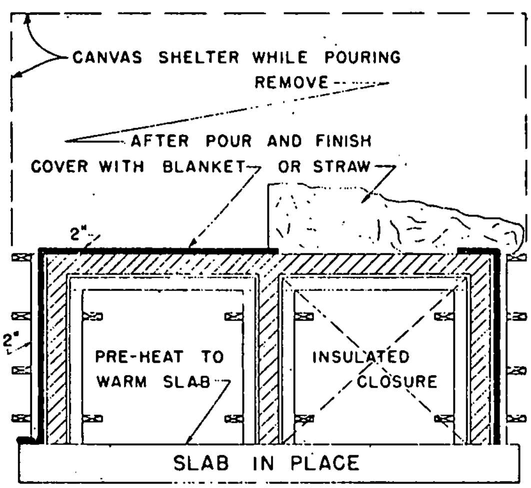


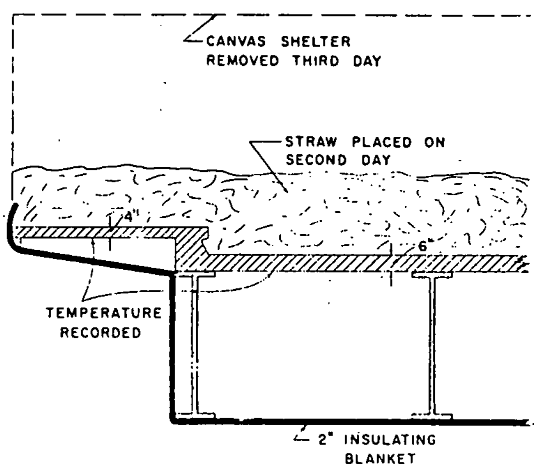
Figure 11. Temperature of mixing water needed to produce heated concrete of required temperature (15). *(Although this chart is based on the mixture shown, it is reasonably accurate for other typical mixtures.)*



Method of applying insulation to mass concrete forms.



Method of protecting new concrete in concrete box culvert from freezing outside temperatures.



Method of insulating concrete slab poured on steel girders; Bad River bridge, Ft. Pierre, South Dakota.

Figure 12. Protection of fresh concrete from cold temperatures (16).

tion is provided and the temperature level maintained during this period. A few agencies require protection for as few as 3 days, but most specify 5 to 7 days. Several agencies that formerly required 10 days have lowered their requirement to 7 days. Nearly all agencies specify that the temperature be kept at or above 50 F (10 C) during the protection period. Several limit the maximum temperature to 100 F (38 C). Heat sources should be kept a safe distance from oiled wood forms and other flammable protection materials (*16*). The heated enclosure should be protected from winds and have sufficient heaters in use to provide uniform heat to the entire structure.

Plastic and canvas tarpaulins are widely used as heat enclosures for protecting fresh concrete. Straw, hay, and other materials have been used to insulate concrete bridge slabs and pavements.

The effect of curing temperature on the compressive strength of test cylinders is shown in Figure 15. Figure 16 shows the superiority in strength gain of Type III cement over that of Type I cement for curing conditions of 55 F (12 C) and 40 F (4 C). These effects must be considered before load supporting forms are removed. Some agencies do not count any curing day during which the ambient temperature drops below a prescribed minimum (usually 40 F) in determining when forms can be removed or a structure can be loaded or opened to traffic. Compression tests on cylinders cured with the structure sometimes are used to determine when forms can be removed.

Deicing chemicals, particularly salts, are not suggested for use on fresh concrete. It is generally accepted that salts are potentially harmful to concrete during the first winter.

Precast concrete beams are easily formed, cast, and cured in shelters and can be placed whenever the weather is satisfactory. Other concrete members and shapes also may be precast. The cost of precasting may be lower than the cost of protecting fresh and uncured concrete from freezing temperatures.

The following practices are suggested for cold-weather concrete work.

- Plan and schedule work to take advantage of any available warm periods.
- Determine the minimum temperatures at which various types of concrete structure can be placed and protected.
- Inform and instruct inspectors and contractor personnel on the correct procedures and techniques to be used.
- Do not overheat aggregate or water.
- Provide heat, insulation, and cover as necessary to protect fresh concrete.
- Adjust form and support removal date for cold days.
- When construction during cold weather is anticipated, consider precast concrete construction for structures.

Hot Weather

Construction problems with portland cement concrete are not limited to cold temperatures. Hot weather (90 F; 32 C) creates problems in mixing, placing, finishing, and curing concrete. ACI Standard 305-72, "Recommended Practice for Hot Weather Concreting" (*14*), reports that

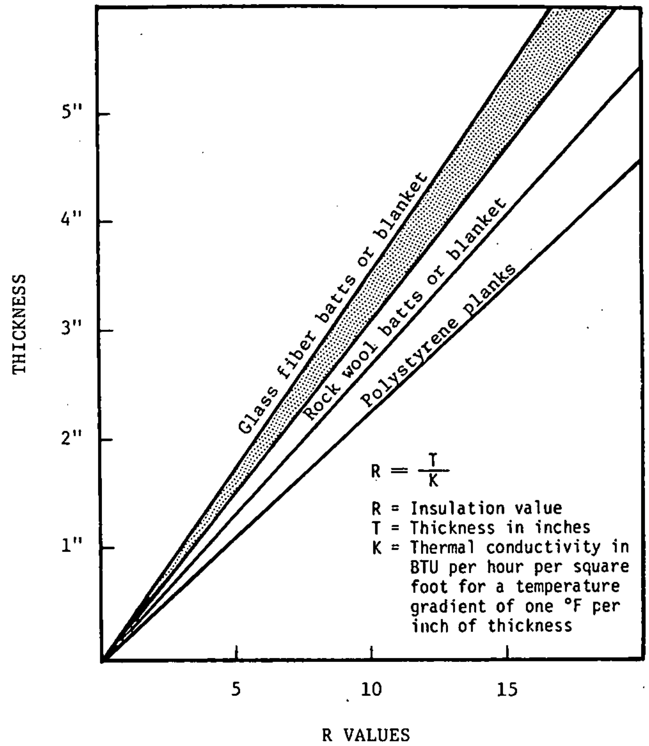


Figure 13. R values versus thickness for insulation materials.

high temperatures cause more rapid hydration of cement, increased evaporation of mixing water (and thus the need for greater amounts of mixing water), reduced strengths, and larger volume changes. Also, cements currently in use are finely ground and thus set more rapidly.

Highway agencies and others have developed practices for concrete construction during hot weather. These practices have been directed to (a) keeping the temperature of the concrete below 90 F (32 C) during mixing, transporting, and placing and (b) protecting the concrete during the early curing period.

Mix Design

ACI suggests that for hot-weather work the cement content be kept at the minimum that will meet strength requirements. Water-reducing retarders may be specified to help prevent rapid setting.

Thickness of Pour (Inches)	Thickness of Insulation Material	
	For Unlined Steel Forms (Inches)	For Wood-Lined Steel or Wood Forms (Inches)
12 or less	2	2
Over 12 to 24	2	1½
More than 24	1½	1

Figure 14. Specification requirements for form insulation (Michigan 1967).

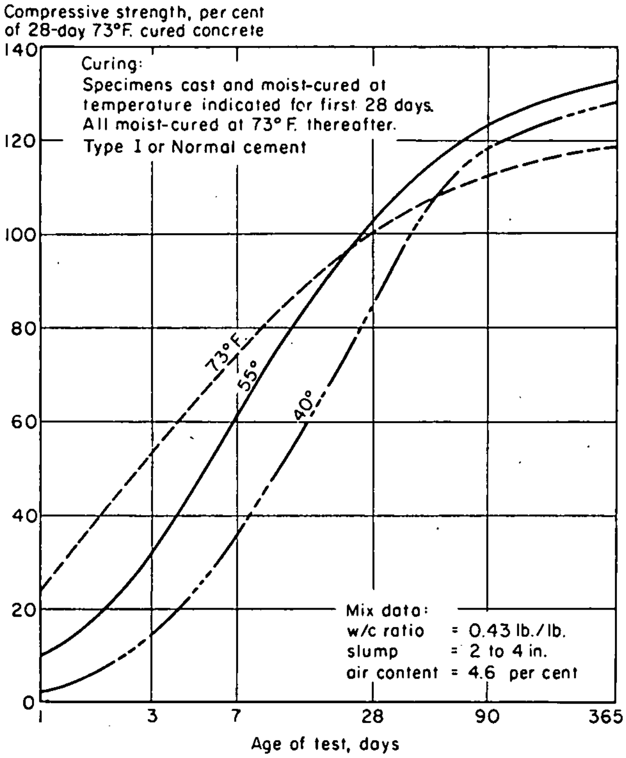


Figure 15. Effect of temperatures on concrete compressive strength at various ages (9).

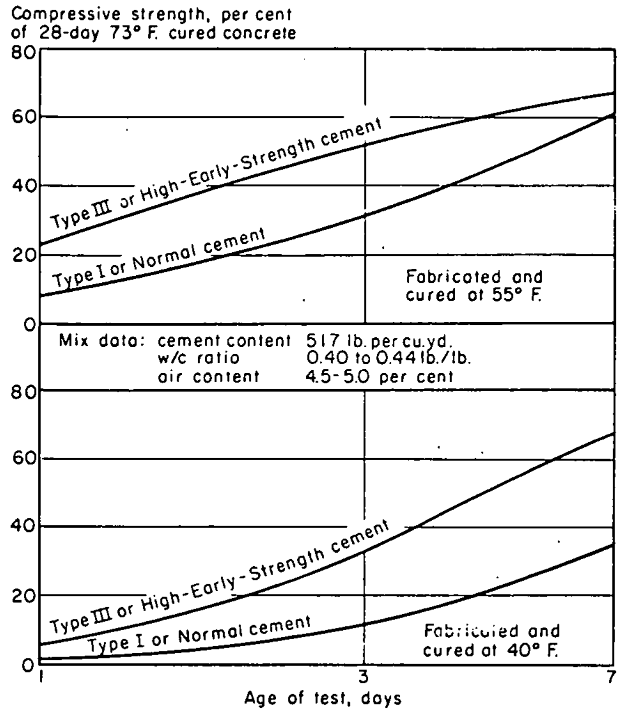


Figure 16. Early compressive strength relationships involving portland cement types and curing temperatures (9).

Mixing

The temperature of the fresh concrete should never exceed 90 F (32 C) (some agencies specify 85 F—29 C) during mixing, transporting, and placing. The temperature of the aggregates affects the mix temperature more than the water or cement temperature does. Providing shade for stockpiles or using aggregate from the side of the pile away from the sun can help keep mix temperatures down. Sprinkling the aggregates with cold water is also helpful. Cool or cold mixing water can help reduce mix temperature. Pipelines and storage tanks for mixing water can be painted, shaded, insulated, or buried to help keep water cool. Ice can be used in the mixing water to lower the temperature, in which case all the ice should be melted before mixing is completed. Mixing should be limited to the minimum that will produce uniformly mixed concrete.

Hauling

Scheduling hauling capacity to meet batch mixing and placing capability becomes more important during hot weather. Mixed concrete should not remain in the drum after mixing, because this may create problems with transit-mix units. Dispatching of these units should just meet the placing capability.

Placing

There is less time available for placing the fresh concrete during hot weather, because it becomes stiff sooner and is more difficult to consolidate. The forms can be cooled by sprinkling, except where ponding might occur. If the concrete is being placed on grade, the surface should be sprinkled immediately before the concrete is dumped.

Finishing

Most often it is the finisher that feels the full effect of hot weather on fresh concrete. Even moderately hot weather, when combined with a little wind or low humidity, can cause finishing to be difficult. Retarders or water-reducing admixtures have been used to extend the time available for finishing. Surface water should not be added; instead, the speed of the finishing operation should be increased and moved closer to the placing operation. The addition of moisture during finishing is not recommended; however, if moisture must be added to the surface to facilitate finishing, it should be added as a mist or fog and not with a whitewash brush. Revibration has been used to prevent plastic shrinkage cracks and the trapping of moisture under a surface crust.

Wind screens or barriers have been used to protect slabs and decks when the wind-humidity combination would cause rapid surface drying and plastic shrinkage cracks.

Curing

In hot weather, protection of the concrete during curing is most critical in the first few hours, and protection should be placed as soon as possible without damaging the surface. Two effective methods are wet curing (with burlap, soaking hoses, etc.) and covering (with a white-pigmented curing compound or plastic sheets). Cool or cold water should not be applied to a hot surface because of the possibility of cracks from temperature-change stresses.

Wet Weather

Rain has an adverse effect on all portland cement construction. Mix control is difficult because of the changing moisture content of stockpiled aggregates; placing is difficult because of ponding of water in formed areas or on subgrades and possible increases in water content of the mix; and finishing of exposed surfaces is difficult because of surface wash and excess surface water. All this work should be attempted only when the fresh concrete can be protected during placing and finishing operations and the finished surface can be protected until set.

Summation

It generally is not practical to perform portland cement concrete paving during adverse weather because of the large amount of exposed surface that must be protected from freezing temperatures, high heat and wind, and rainfall. When adverse-weather paving is essential, the principles of protection applicable to structure work must be adhered to.

Structure work frequently is continued during adverse weather. The small amount of exposed surface requiring protection and the limited work area affected make protection practical, and the extra cost involved often can be offset by benefits. Alternate use of precasting techniques may be warranted when weather is severe.

STEEL STRUCTURES

General

Steel members for bridge substructures and superstructures are not affected to any great extent by cold weather. The limiting factor is the ability of workers and equipment to perform safely and efficiently. The increased frequency of wind, rain, sleet, and snow that usually occurs during winter months is more of a deterrent than the cold weather.

Final connection of steel structures erected from both abutments may be more difficult in winter than in summer. In either season special connection techniques may be required to adjust for expansion and contraction characteristics of metal.

Below are listed several valid reasons for continuing structure work during cold weather.

- Structural steel, reinforcing bars, and concrete forms can be fabricated at protected work sites on or off the project.
- Protection at the structure site can be provided.
- Work on structures often extends over several months, justifying special protection.
- It is difficult to accelerate structure work during warm weather (because foundations must precede piers, etc.)
- Other project work depends on the timely completion of structures.
- Necessary interrelated portland cement concrete work such as foundations and piers can be constructed during adverse weather.

Icy conditions, snow, rainfall, and high winds can seriously affect safety, worker comfort, and worker efficiency and must be offset. Means for accomplishing this are discussed later in this chapter in the section on "Work Protection and Worker Comfort."

The handling and assembly of steel structural members are the critical work items during winter weather. Steel structural members of bridges are fastened by bolting, riveting, or shop- or field-welding. Bolting operations can be carried out during any weather that workers can endure. Extremely cold temperatures will cause faster cooling of rivets. Welding is weather-sensitive to such an extent that some agencies specify limits and procedures.

Weather Considerations for Welded Structures

Welding practice varies among agencies; some set their own specifications, and others refer to the recommendations of the American Welding Society (AWS). The following excerpts from different specifications indicate the range of practices.

Connecticut Standard Specifications for Roads, Bridges and Incidental Construction (1969), pp. 255–256:

> (b) Weather Conditions: Welding, either in the shop or field will not be permitted when the air temperature is below 35 degrees F. except with the special permission of the Engineer, and in no case will welding be permitted when the air temperature is below 25 degrees F.; or when surfaces to be welded are wet from condensation, rain, snow or ice; when rain or snow is falling on the surfaces to be welded; or during periods of high wind unless the welding operator and the work are properly protected. At temperatures between 45 degrees F. and the lowest temperature at which welding is permitted, the surface within 4 inches of the point where the weld is to be started shall be heated with a gas torch to a temperature warm to the hand, or about 100 degrees F., before the weld is started and this temperature shall be maintained as a minimum about the weld area until the bead is completed.

Washington Standard Specifications for Road and Bridge Construction (1969), p. 247:

> No welding will be permitted when the ambient temperature is below 20° F.

Minnesota Standard Specifications for Highway Construction (1972), p. 428:

> Welding shall not be done when the temperature of the base metal is less than 50° F. In case of rain, snow, high wind or low temperature, the working area shall be protected by suitable shelters or windbreaks.
>
> During moderately cold weather the use of small movable shelters and preheating the metal by means of blow torches will in general be satisfactory.
>
> When the temperature is below 15° F, the span or portion of the structure involved must be entirely housed in and heated to a minimum of 50° F. The use of open salamanders for such heating will not be permitted.

AWS Structural Welding Code (1972), p. 16:

> Welding shall not be done when the ambient temperature is lower than zero F, when surfaces are wet or exposed to rain, snow, or high wind nor when welders are exposed to inclement conditions.

AASHTO Standard Specifications for Welding of Structural Steel Highway Bridges (1974), p. 9:

> (1) Welding shall not be done when the ambient temperature is lower than zero F. When the base metal is below the temperature listed for the welding process being used and the thickness of material being welded, it shall be preheated (except as otherwise provided) in such manner that the surfaces of the parts on which weld metal is being deposited are at or above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 inches both laterally and in advance of the welding. Preheat and interpass temperatures must be sufficient to prevent crack formation. Temperature above the minimum shown may be required for highly restrained welds. For *ASTM A514/A517* steel the maximum preheat and interpass temperature shall not exceed 400 F. for thicknesses up to 1½ inches, inclusive, and 450 F. for greater thicknesses. Heat input when welding *ASTM A514/A517* steel shall not exceed the steel producer's recommendation. *Welding shall be carried continuously to completion or to a point that will insure freedom from cracking before the joint is allowed to cool below the minimum specified preheat and interpass temperature.*
>
> (2) *For A36 steel to one-inch thickness, inclusive, when welded with other than low-hydrogen electrodes, the minimum preheat and interpass temperature shall be 150 F.*
>
> (3) In joints involving combinations of base metals, preheat shall be as specified for the higher strength steel being welded.

Contractors use canvas, plastic, plywood, and roof sheeting to protect welders and conserve heat during cold or wet weather. There have been reports of acceptable welding at low temperatures (*17*), but caution should be observed at temperatures below 32 F (0 C) and welding should be discontinued at temperatures below 0 F (−18 C). Suitable protective structures could extend these work ranges in the field.

Welding, except when suitably protected, ceases during rainstorms. Hot weather has little if any effect on welding work, but the protective clothing required for the welder is uncomfortable during warm to hot weather and may cause heat exhaustion.

Radiographic-quality welds can be made in the field under adverse weather conditions only if very exacting and demanding procedures are followed. Contractors should not attempt such welding unless they are prepared to maintain strict adherence to these procedures. There is no room for short cuts. Runoff tabs, drying ovens, carbon arc and grinding equipment, and complete housing of the welder and the joint to be welded are musts. In addition, a welding sequence must be followed.

Summation

Steel structure work frequently is extended into or scheduled for off-season work.

The prime factors to be considered are worker safety and comfort, inasmuch as the material is virtually weather-insensitive.

Special procedures are necessary for welded structures. Strict adherence to the procedures must be emphasized, especially for radiographic-quality work.

MASONRY STRUCTURES

Masonry work (brick, stone, etc.) usually is a relatively minor part of a highway contract. Special walls, manholes, grouted or sacked-sand riprap, and tree wells are a few examples of masonry work. Often it is desirable to schedule such work to be performed during favorable weather. If this is not practical, some masonry work may be completed in heated enclosures during cold weather. The work site is sheltered so that curing temperatures of at least 40 F (4 C) can be maintained until the mortar gains the desired strength—usually three to seven days (*4*).

Limited studies indicate that masonry construction is less sensitive to cold temperatures than is concrete construction (*4*). In most applications masonry work does not carry critical loadings and bond strength is more important than compressive strength.

Some of the practices to be followed for cold-weather masonry work are listed below.

- Increase cement content of mortar.
- Cover completed work to prevent moisture penetration and to protect the work from cooling too rapidly.
- Avoid use of moisture-saturated brick, blocks, and so on.
- Construct plastic or tarpaulin enclosure when temperature is below 32 F (0 C).
- Permit use of approved additives.

In hot weather it may be necessary to provide temporary cover to prevent rapid loss of moisture from the mortar. Pre-wetting masonry blocks or bricks just prior to use is common practice. Worker comfort and efficiency become important because of the relatively high skills involved.

It is not common practice to continue masonry work during rainstorms unless protection has been provided. Freshly placed work should be covered to prevent staining and the loss of mortar, and temporary shelters may be necessary to permit proper placement without damage to mortar.

MISCELLANEOUS CONSTRUCTION

General

Most miscellaneous work items that are a part of highway construction are affected by adverse weather conditions. Many of these items can be completed during the winter if planning and protection are adequate. In most cases work must be halted during rainfall. Hot weather may seriously affect the efficiency of laborers.

Pile Driving

There are few restrictions on pile driving during cold weather. If the surface of the ground or the water is frozen, the frozen materials are usually removed before an attempt is made to start the pile. In high winter winds a heavier crane may be required to maintain pile alignment. Rough water is a factor that must be considered when piles are driven from anchored barges.

Painting

The accumulation of moisture on the surface of cold metal severely limits the amount of painting that can be done outside during cold weather. Most highway agencies do not permit painting of exposed structural steel when the temperature is below 40 F (4 C) or when the temperature of the metal might drop below this level before the paint is dry. Some agencies prohibit painting if the humidity is above 85 percent or if the metal is so hot that blistering might occur. Increased drying time between applications is required when coats are applied at low temperatures. It is possible to provide heated enclosures for painting, but this may be dangerous if turpentine or acetone thinners are used without adequate ventilation. Rainfall stops exterior painting.

Guardrail

The installation of guardrail posts and rails can proceed at temperatures below freezing. Hand or pneumatic digging tools may be required to dig starting holes for posts.

Fencing

Most work required for fence-building can be performed during cold weather. Holes can be dug with some increased effort. If the posts are to be set in concrete, some type of cover should be provided to prevent the top section from freezing. Plain earth often is adequate. Fence wire is brittle at very low temperatures and may break easily during stretching. Access to the fence location is a problem after rain or snow. Attempts to perform work at this time may damage areas that should not be disturbed.

Small Drainage

In states that experience a limited amount of cold weather it is common practice to install both large and small cross-drains during cold weather. If cement mortar is used to grout joints on concrete pipe, this work may be delayed until the temperature rises or protective measures are used.

Signing and Lighting

The only problem involved in cold-weather installation of signing and lighting is the need for protection of concrete footings. For structural members requiring a paint coat, the shop coat usually can be used for protection until warmer temperatures permit the application of the field coats.

Seeding, Sodding, and Planting

Much landscape planting is specified for completion during late winter and early spring, while plants are dormant. Seeding can be done, but it is not good practice to seed when there is some chance that the seeds might sprout during a warm spell and not be able to survive later cold weather. During winter months it is difficult to complete grading and to place topsoil for seeding or sodding. Extended wet periods delay preparation of seed beds and may cause loss of topsoil and seeding through erosion. Many agencies now incorporate seeding and requirements for such items as mulch and mats into the erosion-control plan, which requires that seeding and sodding be completed as construction progresses.

Seeding and planting before or during extended hot spells usually are prohibited unless an adequate water supply is available for frequent sprinkling or irrigation.

WORK PROTECTION AND WORKER COMFORT

Plywood sheets, plastic, or canvas are used to protect workers, equipment, and materials from rain, snow, and wind. Some of these protective shelters for small work sites are:

1. Scaffolding enclosures.
2. Air-supported structures.
3. Drapes and windbreaks.
4. Tents.
5. Prefab or temporary buildings.

The selection of adequate clothing for the temperature range anticipated is important. Wearing several layers of lightweight insulation is better than wearing a single heavy garment, because the several layers permit rapid adjustment to meet activity or temperature changes. Perspiration fills the air spaces in clothing with moisture, and the evaporation of the moisture lowers body temperature. Ventilation can be regulated through the neck, sleeve, and ankle openings in the outer garments or through special vents provided in clothing specifically designed for wear in hot weather. Although clothing selection is an individual responsibility, the agency and the contractor can provide guidance and may supply special protective outer garments, gloves, and footgear for exposed workers.

Most modern-day equipment can be furnished with cabs that include heat or air-conditioning.

CONSTRUCTION STAKING

When winter construction work is anticipated or scheduled, the field party responsible for construction control usually establishes an adequate system of control before the onset of cold weather. It is easy enough to set many extra stakes or hubs during warm weather and thus avoid the risk of having to set a few in cold weather. If construction progress does not permit all the necessary controls to be established, supplemental stakes and offset lines are provided to lessen the amount of work required later. All control and reference points are guarded or protected and are described in the project field books or on the construction plans and stakeout sheets. Paint is sometimes used instead of crayon to mark stakes if they must go through a winter season. Reference stakes should be located so as to minimize the chance of damage from heavy equipment or traffic. During periods of alternate freezing and thawing, short stakes, hubs, or pins may be partially ejected from the ground unless they extend well below the frost or freeze depth. Bench marks can be placed on power poles, foundations of major structures, or small notches cut near the ground line in tree trunks. All reference and alignment stakes for structures should be checked during the winter and after the spring thaw. Reference stakes also should be checked after floods or high water.

Survey parties and inspection crews are somewhat reluctant to perform field engineering and construction staking during cold weather. It is more difficult for a person to operate most engineering equipment (transits, levels, tapes) while wearing gloves or mittens. Placing control stakes in frozen ground often requires an increased effort and special tools or steel pins. Recording data in field notebooks is also difficult in cold weather.

Highway agencies usually do not assume any responsibility for the protective clothing that may be required for field engineering crews. In past years much use was made of surplus military service items available through numerous outlets at reduced prices. At present many people use the newer, lightweight insulated ski and mountain gear developed for sportsmen. The party chief can use a hunter's hand-warmer to keep the fingers warm while recording field notes; gloves or mittens with a trigger finger serve the same purpose. A few individuals use electrically heated socks. Special cushions that are available provide heat when used for seats. The instrument man can be made considerably more comfortable during cold weather with the addition of a windbreak. If the setup is for several hours, a heat source such as a charcoal bucket or tent heater may be added.

Several agencies have purchased small, enclosed work trailers for the use of field parties during cold weather. They also are used to store stakes, hubs, tripods, plans, and the like, and to serve as a field office.

Most steel tapes are calibrated at 68 F (20 C). If precise measurements are made at lower temperatures, the tape is recalibrated or corrections are made to obtain accurate measurements. This is most important when measuring base lines for triangulation or setting abutment or pier reference points for bridge structures.

Protecting survey instruments from direct sun heat is essential for maintaining accuracy in project layout. An umbrella or a similar light screen usually is used for protection. Steel tapes that have been calibrated at lower temperatures should be recalibrated, or corrections should be made for higher temperatures.

Construction staking is usually halted during periods of rain or snow. If alignment or elevations are needed during periods of precipitation, plastic or canvas materials can be used to construct adequate covers. Steel or metallic tape should not be used during electrical storms.

FIELD INSPECTION

Cold weather impedes construction inspection and field-testing. The loss of confidence in tests that are performed under winter conditions is one factor that causes some agencies to curtail or reduce work by setting calendar or temperature limits. Some suspect that those tests that can be made are not being performed as often as is necessary during cold weather. Management should be aware of adverse field conditions and rotate inspection personnel during cold weather.

Many contracts require field laboratories for the use of inspectors. In climates that are less severe, the heat from stoves used for drying samples may maintain a comfortable temperature. Use of a heating system and special construction or insulation can be justified for field labs that will be used during the winter months in climates that are more severe. Work trailers have been used to provide winter shelter at or adjacent to the work site. Wind shelters can be effective in reducing discomfort for inspectors in exposed areas. Before buildings that are on the right-of-way but not in the construction area are removed, they may be used by inspectors to perform tests and complete field records.

Inspectors in extremely cold areas may be relieved or rotated at short intervals. This requires additional personnel, but inspectors from operations that have been stopped because of adverse conditions may be available.

Construction inspection generally is not adversely affected by hot weather, although the effect of high temperatures on certain types of tests must be recognized. Shading shelters assist in moisture-test operations, soil-density testing, and field weighing tests.

A few control centers for production of bituminous or portland cement concrete mixtures are air-conditioned, but most construction inspection requires the inspector to work in open areas at ambient temperatures. The quality of this inspection work is seldom affected by hot weather.

EQUIPMENT OPERATION

General

Adverse weather affects the operation, efficiency, maintenance, and fuel requirements for much of the machinery used in highway construction. In some cases special equipment or construction techniques may be required so that work can continue.

Cold Weather

Cold weather and winter conditions cause additional wear and tear on construction equipment and also increase fuel and maintenance requirements. In some cases equipment that has been used during the summer with a minimum of maintenance is not capable of handling the increased stress of winter work.

Efficiency of both operator and equipment is reduced during severe cold weather. Traction loss on frozen or thawing surfaces lowers production. Difficulty in loading or moving frozen or wet materials also reduces the amount of work that can be performed. If operators are required to bundle up, wear gloves, or use closed cabs, additional reductions in output may occur, and in some cases operator or job safety may be impaired.

The increased costs of winter equipment operation are weighed against the cost of a nonproductive winter season. In many cases, if operation costs alone are considered, it is less costly to stop operations.

Hot Weather

Construction equipment engaged in highway work is not adversely affected by high temperatures; however, the dust that frequently accompanies hot weather can cause operation and maintenance problems. Most field supervisors keep haul roads and work sites free of excessive amounts of dust caused by construction equipment.

Wet Weather

Efficiency of earth-moving equipment is severely reduced during wet weather. Mud increases maintenance costs. The need for additional and repetitive drying of soils increases equipment use per unit of material handled. Extra pushing and towing equipment may be necessary. Rubber-tired equipment loses traction. Crushing-plant screens may clog. All these factors weigh heavily against the continuation of earth-handling operations during wet weather.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

It is evident from a study of reported practices that much highway construction work has been and is being done during adverse weather, both hot and cold. Heavy rain generally stops all exposed construction. Snowfall, high winds, and combinations of severe weather also frequently stop work. Because most construction work is scheduled for summer months, hot weather is readily accepted as construction weather; however, worker efficiency may be severely affected, and the quality of portland cement concrete may suffer unless special procedures are used. Not all items of highway construction are affected to the same degree by adverse weather. Good planning by agencies and contractors can enable more work to be done during the winter months.

Highway agencies must share responsibility with the construction industry for the lack of advancement in winter-work attempts. Specifications generally contain definite instructions for stopping and starting work in terms of either calendar date or temperature. Only a few contain instructions for performing work outside of or beyond the specified date or minimum condition.

Increased fuel consumption and the cost of heating the materials and work areas continue to be important factors in winter work. Energy shortages now make it even more essential that the total costs and benefits of winter work be considered. A primary consideration is the increased consumption of energy versus extended unemployment for the winter period, a choice that should not be considered lightly. A strong argument can be made for continued employment and less consumption of fuels for recreation and pleasure.

If an agency desires that work continue through the winter season, this requirement should be well noted and specifically pointed out to the bidding contractors. If the agency is interested in encouraging winter work on particular projects only, these projects should be scheduled so that all or much of the prerequisite nonwinter work can be completed before the onset of cold weather.

Field parties and inspectors should be briefed on the problems associated with cold-weather construction. *It should be understood by all parties that cold weather is not an excuse for producing or approving inferior work.*

When considering winter work, highway agencies should study carefully any historical weather data that is available. The contractors also should be familiar with this data. In addition, a reliable forecast of the local short- and long-range conditions is useful to both agency and contractor.

Because of the difficulty of soil compaction at or below freezing temperatures, earthwork operations are severely restricted in many states during the winter months. With adequate planning, however, it is possible to carry out limited embankment construction with blasted rock or granular materials. Subgrade work is even more difficult unless the top of the embankment is constructed of granular materials. In many areas the temperature permits mineral-aggregate bases to be placed during much of the winter. Where water-sensitive subgrades are involved, either the base course should be self-sealing (treated bases) or it should be sealed by paving or special seal treatment.

Cast-in-place concrete work can be performed at low temperatures, even below 32 F (0 C), but careful planning and preparation are necessary.

Spray application of bituminous materials and road mixing are not feasible during cold or even cool weather. Hot plant-mix bituminous paving can be completed at or below freezing temperatures.

Various items of miscellaneous construction can be continued during much of the winter; guardrail, fencing, lighting, signing, and structural work are the most common.

The economic impact of highway construction varies with each area and specific location. Some highway workers may find alternate employment during the winter season; others may find it necessary to request unemployment compensation. During long layoffs some may turn to welfare assistance and food stamps. Numerous states have exhausted their own funds for unemployment compensation. All these considerations must be evaluated before a final decision on winter work is made.

There has been increasing concern about the problems associated with mixing, placing, finishing, and curing structural concrete during hot weather. The temperature of the fresh concrete should be no higher than 85 F (29 C) during mixing or placing. This may require the use of chilled water or the addition of ice in lieu of a part of the water.

Finally, there are winter conditions so severe that highway construction can not be continued. It is not always low temperatures that limit work; snow, rain, and wind play a role. In areas where the advent of cold weather is certain, contractors can prepare for extended work under adverse conditions. In areas of changing winter temperatures contractors are generally inclined to take their chances and make little preparation for cold-weather work.

The following comments are applicable to highway construction during adverse weather conditions.

- All highway construction is affected to some degree by adverse weather.
- The most adverse conditions are created by rain or snow in combination with wind and/or cold temperatures.
- The worker is concerned with comfort, the contractor with cost, and the highway agency with completion dates and quality of work as well as cost.
- There is evidence that the problems of winter construction have been largely neglected.
- Recent developments in construction materials, equipment, and techniques have made it more practical to perform winter work.
- All costs of stopping work during winter months should be considered before a decision is reached.
- Innovative planning and scheduling enable much work to continue through the winter.
- Protective clothing that is available enables workers to be fairly comfortable at low temperatures.
- Much highway construction can be performed during the winter without appreciable loss of work quality.
- Hot weather creates problems of worker comfort and may affect the quality of concrete work.
- Increased energy requirements for off-season work must be considered.
- Agencies should consider specifications that will reduce the contractor's risk with off-season work.

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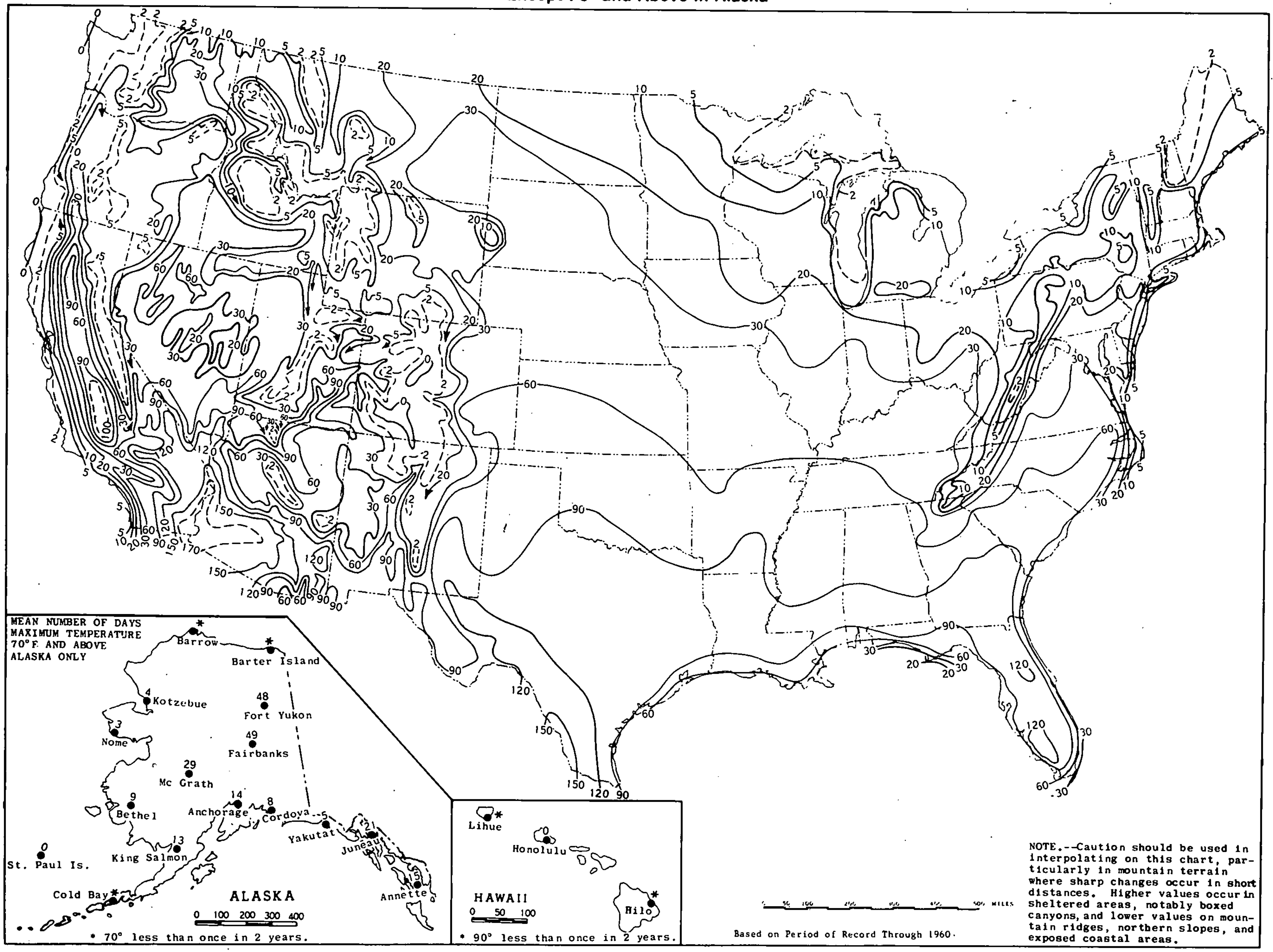
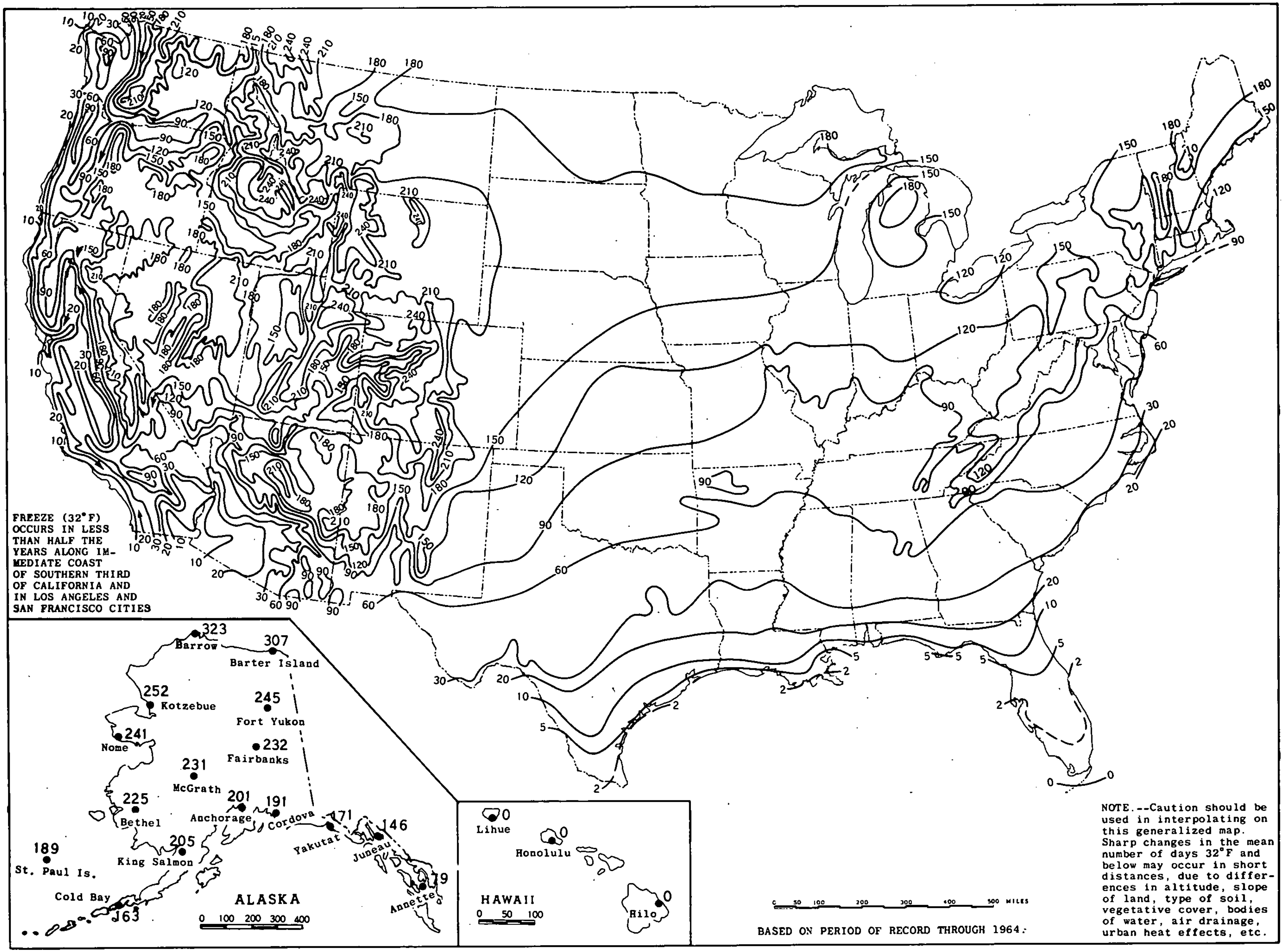
APPENDIX
CLIMATIC MAPS

Following are excerpts from the "Climatic Atlas of the United States," published in June 1968 by the Environmental Data Service, Environmental Science Services Administration, U.S. Dept. of Commerce, and reprinted by the National Oceanic and Atmospheric Administration in 1974.

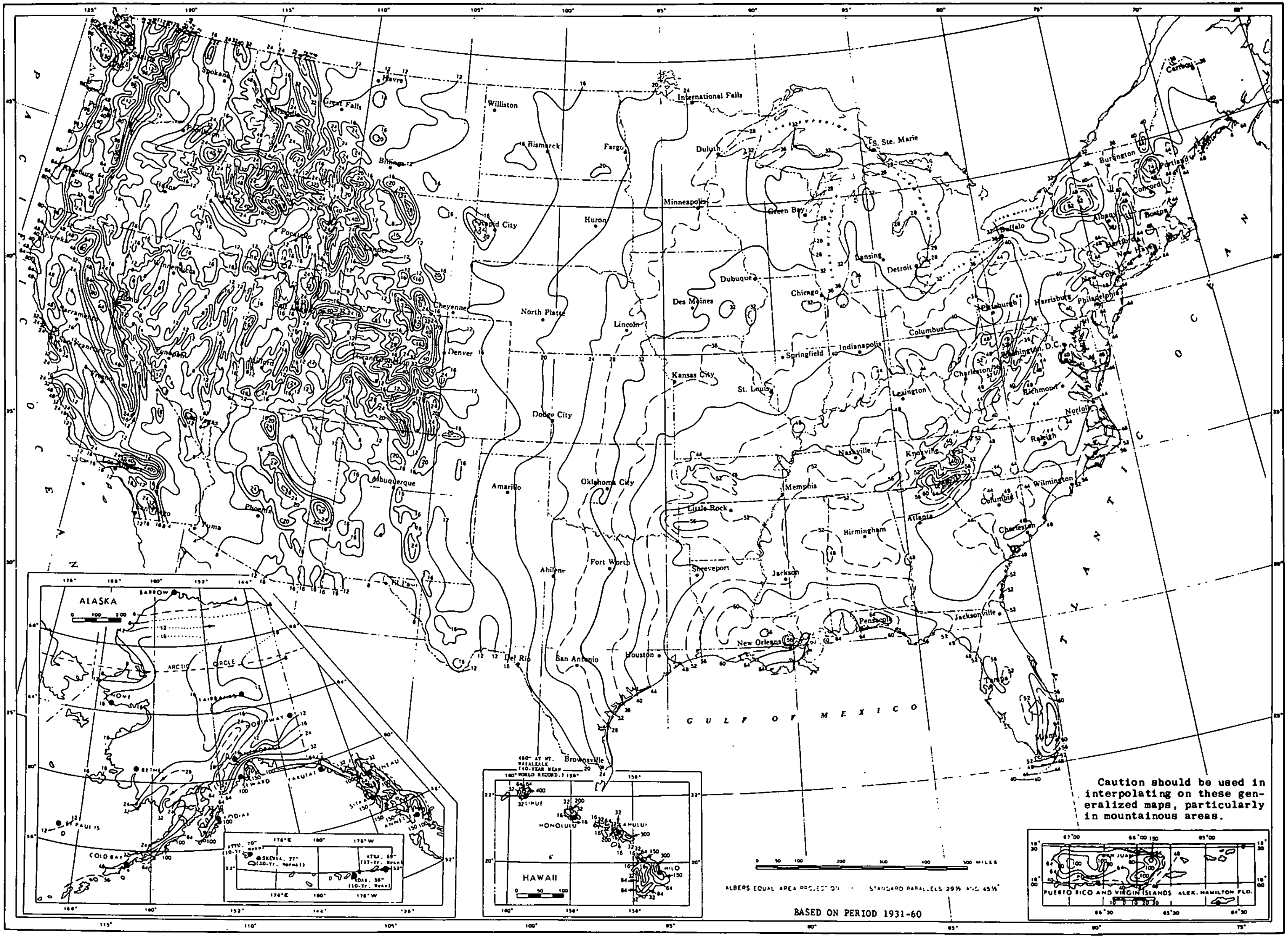
MEAN ANNUAL NUMBER OF DAYS MAXIMUM TEMPERATURE 90°F AND ABOVE
Except 70° and Above in Alaska



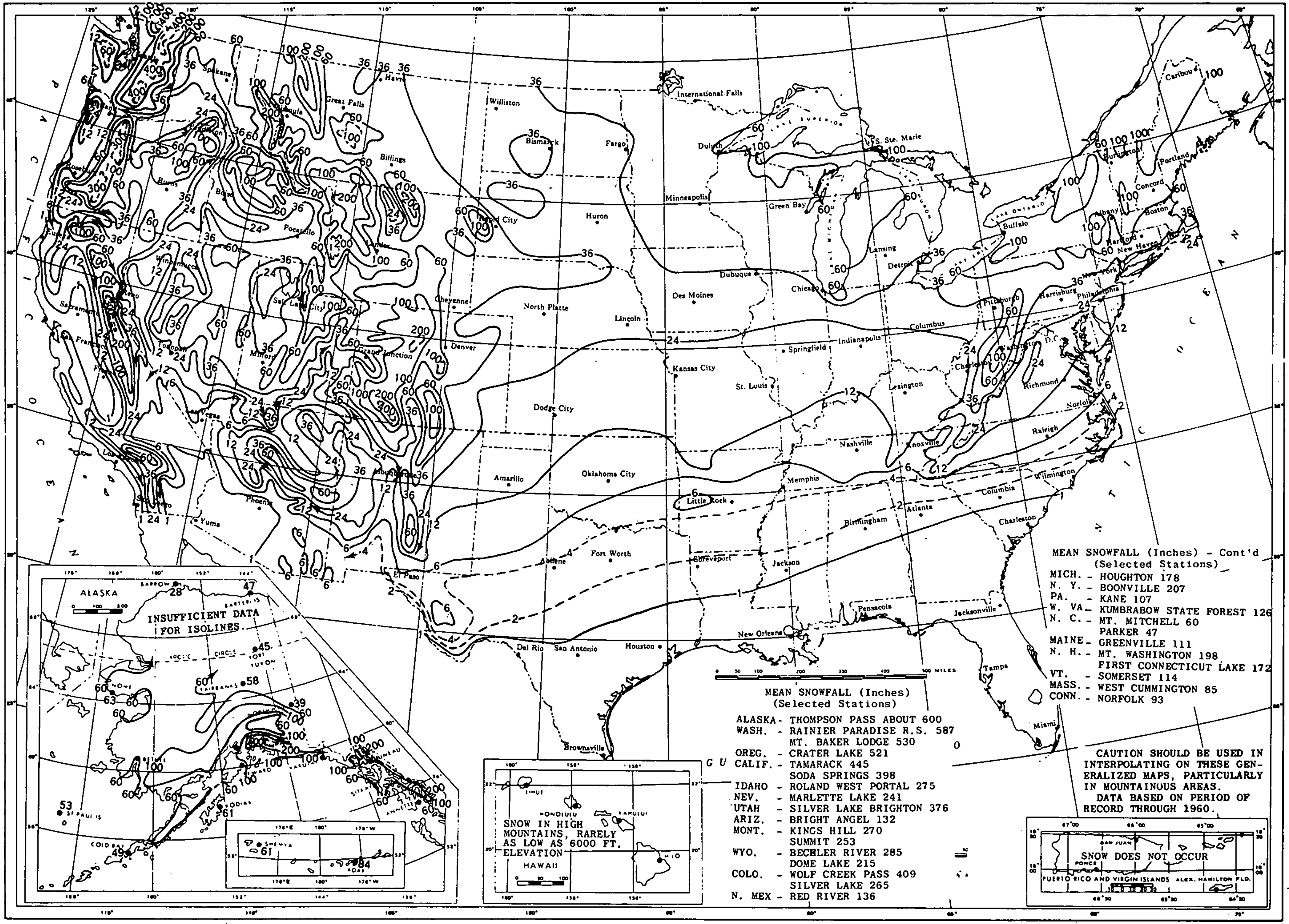
MEAN ANNUAL NUMBER OF DAYS MINIMUM TEMPERATURE 32°F AND BELOW

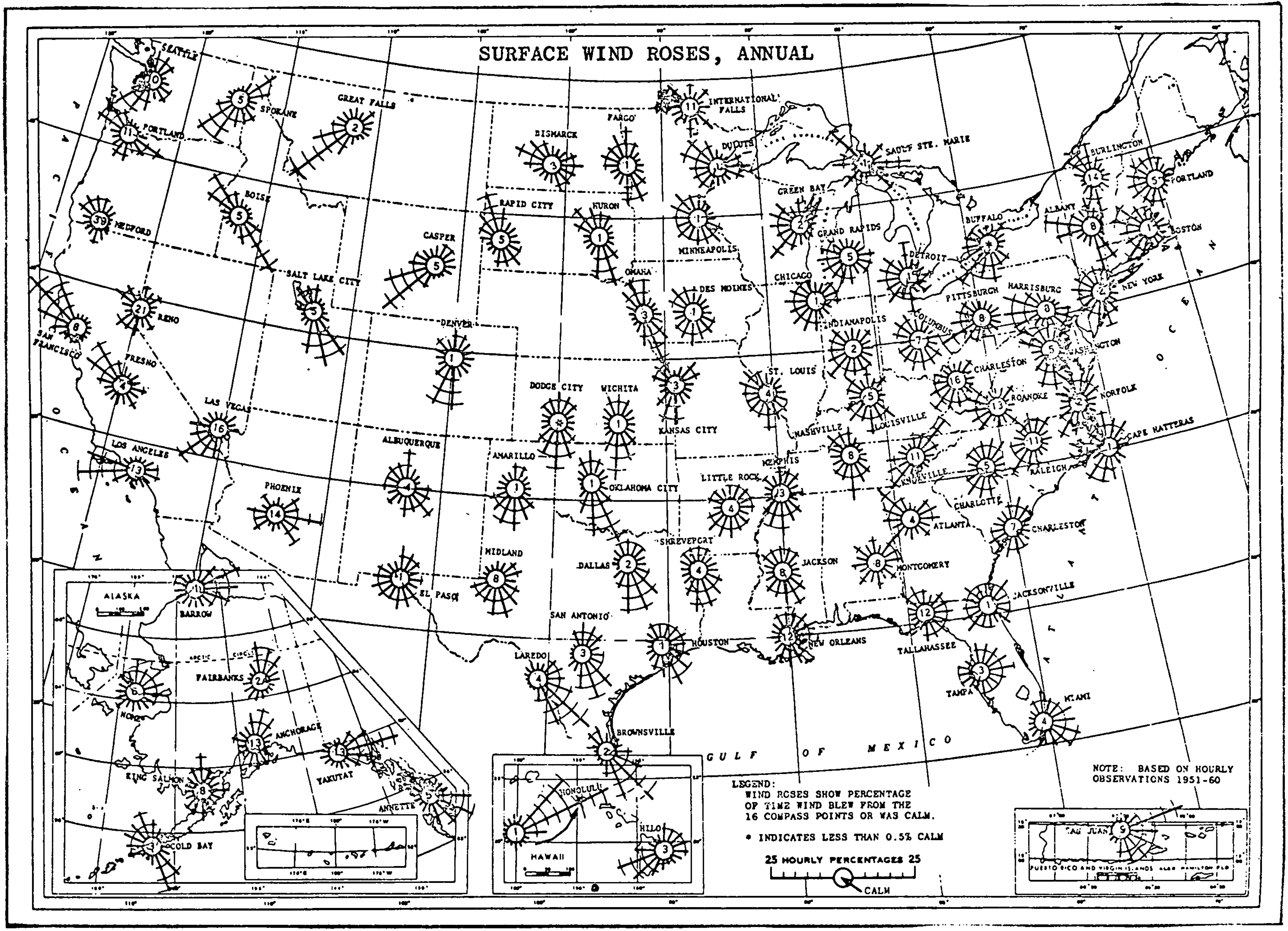


NORMAL ANNUAL TOTAL PRECIPITATION (Inches)



MEAN ANNUAL TOTAL SNOWFALL (Inches)




SURFACE WIND ROSES, ANNUAL
SEATTLE
SPOKANE
GREAT FALLS
PORTLAND
BISMARCK
FARGO
INTERNATIONAL FALLS
DULUTH
SAULT STE. MARIE
BURLINGTON
PORTLAND
BOISE
MEDFORD
RAPID CITY
HURON
MINNEAPOLIS
GREEN BAY
GRAND RAPIDS
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ALBANY
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FAIRBANKS
NOME
ANCHORAGE
YAKUTAT
KING SALMON
ANNETTE
COLD BAY
HONOLULU
HILO
HAWAII
SAN JUAN
PUERTO RICO AND VIRGIN ISLANDS
LEGEND:
WIND ROSES SHOW PERCENTAGE
OF TIME WIND BLEW FROM THE
16 COMPASS POINTS OR WAS CALM.
• INDICATES LESS THAN 0.5% CALM
25 HOURLY PERCENTAGES 25
CALM
NOTE: BASED ON HOURLY
OBSERVATIONS 1951-60

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