NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **127**

SNOW REMOVAL AND ICE CONTROL TECHNIQUES AT INTERCHANGES

HIGHWAY RESEARCH BOARD

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NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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SNOW REMOVAL AND ICE CONTROL TECHNIQUES AT INTERCHANGES

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

AREAS OF INTEREST:
HIGHWAY DESIGN
MAINTENANCE, GENERAL

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1971

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 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 Highway Research Board of the National Academy of Sciences-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 departments and by committees of AASHO. 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 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 Highway 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.

NCHRP Report 127

Project 6-10 FY '68
ISBN 0-309-02007-7
L. C. Catalog Card No. 74-185692

Price $5.20

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the Federal Highway Administration. Individual fiscal agreements are executed annually by the Academy-Research Council, the Federal Highway Administration, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of effective dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

The opinions and conclusions expressed or implied in these reports are those of the research agencies that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway Officials, nor of the individual states participating in the Program.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

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FOREWORD

By Staff
Highway Research Board

This report identifies problems associated with snow removal and ice control at interchanges and describes both design considerations and maintenance operation procedures that can be used to alleviate the problems. It also contains recommended procedures and forms for evaluating the design of interchanges and current winter maintenance practices. Application of the evaluation procedures and the identified desirable design and maintenance operation techniques should result in improvements in efficiency and safety during snow removal and ice control activities at interchanges in localities subjected to substantial snowfall. In view of the fact that a combined effort by design and maintenance disciplines is suggested to bring about desired improvements, both highway design and maintenance engineers in areas that experience significant snowfall should find the report useful.

Interchange areas on limited-access highways in snow-belt states are the source of a number of unique problems for maintenance personnel responsible for the removal of snow and ice from the roadways. The slower speeds and heavier traffic congestion on the ramps associated with interchanges hamper the efficiency of the maintenance vehicles. Limited snow storage, drifting, and the freezing of snowmelt as it flows across superelevated ramps also contribute to the problem. There is little question that techniques for eliminating or reducing the extent of these problems can contribute to the safety of the traveling public and maintenance personnel as well as the convenience of motorists and the efficiency of maintenance operations.

The investigation undertaken by the Bertram D. Tallamy Associates firm (subsequently known as Tallamy, Byrd, Tallamy & MacDonald, and now as Byrd, Tallamy, MacDonald & Lewis) consisted initially of a literature search, a nationwide questionnaire survey, interviews with highway administrators and maintenance engineers, and field observations of winter maintenance activities at interchanges in nine states. The identified problems were divided into two categories: (1) those associated with physical factors of the interchange, such as roadway and ramp geometrics, appurtenances, and drainage; and (2) those associated with maintenance operations, such as plowing and spreading routes, equipment assignments, materials storage, and personnel training. Suggested methods for alleviating snow and ice control problems at interchanges are also grouped in the report into the same categories under the chapter headings, "Application of Findings—Guidelines for Design of Interchanges to Accommodate Snow and Ice Control" and "Application of Findings—Operational Plans for Interchange Snow and Ice Control."

During the conduct of the study the researcher accumulated a photographic record of many problems associated with snow and ice control at interchanges and some of the techniques used by highway agencies to alleviate the problems. A photographic manual covering both interchange design and maintenance operations was prepared during the study and is included in this report. Copies of the photographic manual are available in limited quantities by request to the Program Director, NCHRP, Highway Research Board, 2101 Constitution Avenue, Washington, D.C. 20418. A set of 35-mm slides covering significant portions of the manual is also available on a loan basis from the same office.

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PART II

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 6-10 by Byrd, Tallamy, MacDonald & Lewis. At the initiation of work on the project the firm name was Bertram D. Tallamy Associates, later changed to Tallamy, Byrd, Tallamy & MacDonald, then to the current listing. L. G. Byrd served as Principal Investigator throughout the conduct of the research.

Appreciation is expressed to all of the individuals, organizations, agencies, associations, and State highway departments that participated in the interviews and conferences or otherwise contributed the valuable information and suggestions by which this project benefited.

Also appreciated are the cooperation and assistance provided by many individuals during the field observations.

SNOW REMOVAL AND ICE CONTROL TECHNIQUES AT INTERCHANGES

SUMMARY

Maintenance engineers have long recognized that highway interchanges create certain problems of snow removal and ice control, particularly in urban areas with high average daily traffic. However, limited research has been done in the fields of snow removal organization and equipment as they affect interchanges.

National Cooperative Highway Research Program Project 6-10, "Snow Removal and Ice Control Techniques at Interchanges," was undertaken to identify the factors affecting snow removal, to study the problems and current procedures for solution of these problems, and to suggest improved techniques for snow removal and ice control in interchange areas. This report is the product of that study; it includes recommendations and guidelines for establishing policies and procedures for maintenance operations and design of interchanges.

Project study procedures included a review of pertinent literature on the subject of snow and ice. To identify the specific problems encountered at interchanges, a broad interview program was undertaken of highway administrators, maintenance engineers, and superintendents. Field observations of interchanges in nine U.S. snow-belt states were conducted to reveal the many difficulties with, and current techniques for, interchange maintenance during the winter season. Several conferences were held with maintenance personnel and the exchange of information proved especially valuable.

Although the problems of snow removal and ice control on interchanges are basically similar to those on the main line, there are certain special considerations. These include: (1) a variation of emphasis (i.e., with greater average daily traffic on ramps, more attention must be paid to snow removal), (2) a wide variation in interchange design and operating characteristics not found on the main line, and (3) a concentration of structural and geometric features in a confined land area which may cause snow storage problems.

The factors, problems, and techniques influencing the efficiency of snow removal and ice control are summarized in two categories, (1) physical and (2) operational, as follows:

Physical Factors

A. Appurtenances

1. Problems
   a. Pavement obstructions (rumble strips, curbs, delineators, buttons, joints, covers)
      (1) Slowing of plow operators to maneuver around obstructions
      (2) Damage to equipment by concealed obstructions
      (3) Damage to the pavement appurtenances by equipment

b. Wind obstructions (guardrail, bridge rail, plantings, abrupt side slopes, windrowed snow)
   (1) Drifting across pavement areas
   (2) Swirling snow obscuring vision of equipment operators and highway users

2. Current Techniques
   a. For pavement obstructions
      (1) Use of special marking devices to warn plow operators of special obstructions
      (2) Use of rubber plow blades to yield to obstructions without damage
      (3) Trip-release mechanisms on snowplow blades
   b. For wind obstructions
      (1) Prompt removal of snow windrows adjacent to pavement
      (2) Strategic placement of mechanical snow fence or snow fence plantings to interrupt wind currents
      (3) Careful maintenance of roadside vegetation and height of cut
3. Design Alternatives
   a. For pavement obstructions
      (1) Use of flush or recessed delineator markings
      (2) Elimination of curbs and gutters through alternative shallow side ditches
   b. For wind obstructions
      (1) Selection of open-type guardrail and bridge rail design
      (2) Proper consideration of wind direction in making plantings
      (3) Flattened slopes (4:1 fills; 6½:1 cuts)

B. Turnarounds, Crossovers, or Connections for Equipment Routes
1. Problems
   a. Deadheading
   b. Unsafe maneuvers
   c. Special equipment requirements for size and/or maneuverability
2. Current Techniques
   a. Median crossovers
   b. Special overpass or underpass roadways
   c. Travel to adjacent interchanges
3. Design Alternatives
   a. Use of maintenance crossovers on or under structures required for other purposes

C. Snow Storage Areas
1. Problems
   a. High windrows blocking sight distances, ramp openings
   b. Windrows creating drifts
   c. Need for removal of stored snow from inadequate areas
   d. Casting snow onto adjacent roadways or properties from inadequate storage areas
   e. Snowmelt drainage across roadway from superelevated shoulders, gore areas, and narrow paved medians
2. Current Techniques
   a. Hauling and dumping
   b. Portable or stationary snowmelters

   c. Blowers to cast windrowed snow into other storage areas
   d. Temporary baffles to retain windrowed snow adjacent to bridge rails
   e. Temporary use of one traffic lane as storage area
   f. Special delineation (for plow operators) of areas where plow cast should be reduced or controlled
3. Design Alternatives
   a. Reversal of high shoulder slopes on superelevated sections
   b. Provision of adequate drains in gore areas, medians, etc., to handle snow-melt
   c. Adequate shoulder areas carried across bridge decks
   d. Bridge railing designed to retain snow where required

D. Adjacent Development

1. Problems
   a. Lack of snow storage for cast, blown, and handled snow
   b. Lack of storage sites for chemicals
2. Current Techniques
   a. Employ portable snowmelters
   b. Haul and dump elsewhere
3. Design Alternatives
   a. Provide sufficient area

Operational Factors

A. Organization and Training

1. Problems
   a. Determining most efficient mix of men and equipment
   b. Development of adequate training program
2. Current Techniques
   a. Separate crews for each interchange
   b. Incorporate interchange in workload of main-line crew
   c. Periodic training program to develop individual operator skills, crew coordination, cooperation, and assignment responsibilities
3. Design Alternatives—Inapplicable

B. Maintenance Yard Location

1. Problems
   a. Deadheading of equipment for reloading, refueling, or repairs
2. Current Techniques
   a. Use of special, conveniently located material yards with refueling facilities
   b. Use of special mechanic's repair trucks for field servicing of equipment
   c. Use of straight chemical snowmelting materials to extend coverage capacity per truckload
3. Design Alternatives
   a. Include maintenance yard location within interchange area

C. Procedures

1. Problems
   a. Selections of appropriate or even best procedures and techniques
2. Current Techniques
   a. Spread chemicals first, particularly just prior to snowfall
   b. Plow and spread simultaneously

c. Ride plow on pavement
d. Raise plow ¼ in. to 1 in.
e. Spreading rate varies by jurisdiction, by climate
f. Mixtures of chemicals and abrasives
g. Spread chemicals in bulk at ramp entrance to permit traffic distribution of chemicals
h. Spread chemicals on high side of pavement permitting brine to run over pavement

3. Design or Research Alternatives
   a. Current research to determine most appropriate techniques

D. Equipment

1. Problems
   a. Inappropriate equipment
   b. Outmoded equipment
   c. Multiplicity of makes and models
   d. Inadequate communications
2. Current Techniques
   a. For interchanges, cab-reversible highly maneuverable plows and cab-controlled chemical handling equipment and snow melters
   b. Standardize by division or district
   c. Install two-way radio in equipment operating individually and in the control vehicles of a group operating together
3. Design and Development Alternatives—Development of snow and ice control equipment for interchanges

E. Materials

1. Problems
   a. Insufficient storage
   b. Inadequate storage
   c. Materials handling
   d. Deleterious effect on groundwater and vegetation
2. Current Techniques
   a. Satellite storage near interchanges
   b. Covered storage from tarpaulins to silos
   c. Appropriate material-handling equipment such as front-end loaders, chain-bucket loaders, endless belts, vacuum loaders, and blowers
3. Design or Research Alternatives
   a. Research new chemicals, storage and handling equipment and facilities

F. Traffic

1. Problems
   a. Diminished casting capability of snowplows
   b. Increased probability of stalled vehicles
2. Current Techniques
   a. Greater frequency of coverage of interchange
   b. Separate crews for interchange
   c. Contracted towing service for stalled vehicles
3. Design or Development Alternatives
   a. Special highly maneuverable equipment for interchanges

G. Jurisdictional Boundaries

1. Problems
   a. Inappropriate boundaries
   b. Turnaround requirements in other than own jurisdictions
   c. Plow up or down in passing through neighboring jurisdictions?
   d. Devious return routes to interchanges in heavy city traffic
2. Current Techniques
   a. Mutual agreements between jurisdictions
3. Design Alternatives—Consider impact of jurisdictional boundaries during design

H. Climatic Conditions (quantity and intensity of snowfall, temperature, and wind)

1. Problems
   a. Staffing and equipping for unknown or unpredictable requirements
   b. Stockpiling materials for unpredictable requirements
2. Current Techniques
   a. Staff and equip to handle storms of specific frequencies (i.e., one, two, or five years)
   b. Contract for assistance above certain requirement level
   c. Special crews for interchanges
   d. Stockpile materials for various alternatives; i.e., ¼ or ½ seasonal requirement, relying on timely deliveries for the rest
3. Design Alternatives—Inapplicable

The solutions to the foregoing interchange snow and ice control problems lie in a combined effort by the maintenance and design engineers (1) to determine what is or may be causing the problem, and (2) to take appropriate corrective action. When operational problems exist, such as insufficient plow coverage within the interchange, reassignment of men and equipment, or perhaps the assignment of a separate plow to the interchange, may be warranted.

Where problems originate with design, a reassessment of design criteria may be in order. The snow and ice control function should be seriously considered during interchange design. Coordination between maintenance and design personnel can often present significant benefits of increased efficiency, user and crew safety, and reduced expenditures during winter interchange maintenance operations.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

For some years maintenance engineers have been aware that interchanges are causing or amplifying problems in snow removal and ice control. In particular, this concern was felt by maintenance engineers responsible for interchanges located in urban areas. National Cooperative Highway Research Program Project 6-10, "Snow Removal and Ice Control Techniques at Interchanges," was developed to respond to these concerns.

The project statement says:

> The variety of geometrical shapes of interchange

ramps with associated structures and their urban or rural locations invariably create problems with respect to optimum snow removal and ice control techniques in the interchange areas. Alternate freezing and thawing of plowed or unplowed snow across superelevated ramps contributes to problems of snow and ice control. Drifting may further aggravate this problem. Improved snow removal and ice control techniques in interchange areas are vital to the safety of highway traffic.

The project was undertaken to identify, study, and develop solutions to these varied problems. This report is the product of that study. The report is divided into two parts. Part I is directed to the engineering administrator and researcher. It outlines the factors that affect snow removal and ice control at interchanges, and discusses the problems that accompany these factors and the techniques currently being used to overcome the problems. Further, it presents recommendations that can serve as guidelines for establishing policies and procedures concerning the design of interchanges and the conduct of maintenance operations.

Part II of the report is an appendix including procedures and forms for evaluating the physical design and the snow removal operations at particular interchanges. Also included is a *Maintenance and Design Manual* (Appendix J) for design and maintenance engineers and superintendents. The manual discusses the factors and problems of snow and ice control at interchanges that must be considered daily by maintenance personnel during the snow season and by the design engineers when they are planning interchanges. Suggestions and practical ideas are presented that can simplify snow removal and ice control operations. Some are simple and can be incorporated without much effort. Others may conflict with economic or other operating considerations that must be taken into account. Some may not be economically feasible and will have to be discarded. Photographs are used extensively in presenting the information.

RESEARCH OBJECTIVES

The original objectives of this study were:

1. To identify and evaluate the factors that influence the efficiency of snow removal and ice control operations at interchanges; for example, circuitousness of travel, limited storage area, equipment operational difficulties, kind of interchanges, traffic volumes, drainage, lower traffic lanes, etc.

2. To develop operational systems that will provide for efficient snow removal and ice control procedures on interchange roadways with associated structures in both rural and urban locations. Primary emphasis is to be placed on the maintenance problems attendant to existing facilities and equipment and their recommended solutions. Consideration shall also be given to design innovations that will minimize future maintenance problems.

The approved research plan divided the project into two phases. The initial phase responded to the requirements of the first objective and was designed to pinpoint the problems of snow removal and ice control at interchanges and the factors contributing to the problems. The results of the investigation developed under Phase 1 were initially presented in the 1968 *Interim Report.*

On completion of Phase 1 the second objective was revised to emphasize the evaluation of operations and design and allow the preparation of a procedural manual. The revised second objective directs the researchers to:

> Evaluate improved operational procedures and techniques and potential design improvements for specific snow removal and ice control problems associated under Objective # 1 and prepare a procedural manual based on the evaluations. Primary emphasis is to be placed on the maintenance problems attendant to existing facilities and equipment and their recommended solutions. Consideration shall also be given to design innovations that will minimize future maintenance problems.

The various factors and problems that were found to

Figure 1. Cross-pavement drainage of snowmelt.

influence snow removal and ice control are discussed in Chapter Two of this report, including methods used by different agencies to simplify the problems. Areas of potential improvement and guidelines for interchange design to accommodate snow removal and ice control are discussed in Chapter Three. Procedures to evaluate interchange operations are included in Chapter Four. Chapter Five contains conclusions and recommendations for further study of snow removal and ice control methods.

LITERATURE REVIEW

The attack on the interchange snow and ice problem was initiated by reviewing pertinent and available literature on the subject. The review revealed many articles on the general problem of snow removal and ice control but almost no literature specifically dealing with interchange operations. The more important literature sources used in this project were as follows.

CRREL

The U.S. Army Cold Region Research and Engineering Laboratory at Hanover, N.H., has published many technical documents and papers on the basic properties of snow and ice, their behavior, and engineering applications. *Snow Removal and Ice Control* by Malcolm Mellor is an excellent handbook of the basic scientific and engineering problems involved and gives a summary of current ideas and practices in snow removal and ice control as they affect means of transportation. An excellent compendium on snowdrift control is a draft mimeograph prepared by L. D. Minsk.

NCHRP

The National Cooperative Highway Research Program has published a number of reports that are applicable to the subject. *NCHRP Report 1,* "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures," is primarily concerned with repairing concrete in structures affected by deicing chemicals. *NCHRP Report 4,* "Non-Chemical Methods of Snow and Ice Control on Highway Structures," is an excellent reference on the subject.

HRB

There are many Highway Research Board publications on the chemical control of snow and ice. Among them are *HRB Bull. 252,* "Snow and Ice Control with Chemicals and Abrasives." *Hwy. Res. Record No. 193* contains five papers on the effects of deicing chemicals on vegetation and groundwater supplies.

BPR

An article entitled "Snowdrift Control Through Highway Design" by Frederick W. Cron in *Public Roads* (Dec. 1967) is a fine summary of the causes of snow drifting on highways. It brings up to date the basic work done by Finney in the 1930's. An illustration from this text is shown in Figure 2.

Summary

The literature search indicated that only limited research and development work is being accomplished on snow removal equipment, with the exception of tests on different plow blades. Because a review of current publications produced little information directed specifically to the problem of snow removal and ice control at interchanges, it appears that interchanges have not been treated as a separate problem in previous snow removal studies.

The documents reviewed are listed in Appendix A.

RESEARCH METHODOLOGY

A number of lines of attack were considered in attempting to pinpoint the problem of snow removal and ice control at interchanges.

Time and Motion Study

It was determined that the use of time and motion techniques on this research project would be ineffective. Because this study required a comprehensive look at the whole system of snow and ice control at interchanges, any attempt at incremental refinement of existing procedures, most of which are unique to a given interchange, was considered inappropriate.

Data Collection and Statistical Analysis

A second technique given consideration was that of statistical analysis of performance and cost data. Insofar as could be ascertained, highway departments do not keep separate costs on snow removal and ice control at interchanges. If this approach were to be used, original cost and performance data would have to be gathered by a considerable expenditure of time and project funds. It was determined that even if the data were obtained, an analysis would be of little benefit because this method would not be likely to highlight the inherent problems or indicate their solutions.

Selective Interviews and Observations

A third alternative was that of conducting selective interviews and observations following the literature search. Interviews of selected highway administrators, mainte-

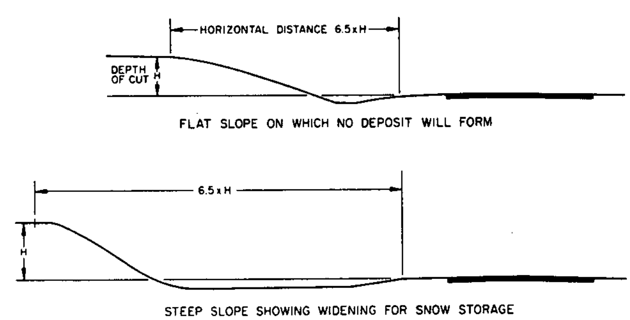


Figure 2. Typical highway cross sections for minimum snow deposits (Finney, 1939).

nance engineers, superintendents, and foremen would assist in determining the problems at interchanges and would develop ideas for solutions to the problems. In addition, field observation of snow removal operations at interchanges would corroborate the information obtained during the interviews and reveal the many difficulties that in summation make up a problem. The accumulated experience and knowledge of many individuals who are intimately involved on a daily basis with the snow problem during the winter season seemed to offer a broader overview and a greater potential toward accomplishing Phase 1 of the study than a detailed study at a limited number of observation points might produce.

Accordingly, the adopted plan of attack included interviews with knowledgeable individuals and field observation of snow and ice control operations at selected interchanges in nine snow-belt states.

INTERVIEW AND OBSERVATION PROGRAM

Interviews proved to be a fruitful source of information for the study. A comprehensive interview outline was prepared to ensure full coverage of the subject during the course of the discussions. Interviews were held with chief administrative officers as well as maintenance engineers, section superintendents, and foremen. Research and development scientists, involved in snow and ice research, and equipment manufacturers also were contacted. The various government agencies covered included state highway departments, toll road agencies, counties, municipalities, and port authorities.

The highway system under the responsibility of the individuals interviewed covered most variations in physical, operational, and environmental conditions found in the states having a snow and ice control program. Such variables as climate, terrain, traffic, geometrics, and locations were considered.

As shown in the following, 52 individuals representing 31 different organizations were interviewed.

State highway departments	12
Industries	3
Laboratories	4
Counties, cities, and other	12
Total, organizations	31
Total individuals	52

In many instances, the interviews involved a full day's discussion with field inspection of equipment, facilities, and representative interchanges included in the visit.

Table 1 gives the 17 states, the District of Columbia, and Canada, in which field visits were made, and the 9 states in which interchange observations were conducted. Figure 3 shows the geographical location of the latter states.

TABLE 1

LOCATION OF INTERVIEWS AND OBSERVATIONS

STATE OR COUNTRY	ORGANIZATIONS INTERVIEWED	INTERCHANGES UNDER OBSERVATION
California	2	4
Canada	3	0
Colorado	2	0
Connecticut	1	2
District of Columbia	1	0
Idaho	1	0
Illinois	1	4
Massachusetts	1	1
Michigan	1	1
Minnesota	3	13
Missouri	1	0
New Hampshire	1	0
New Jersey	1	0
New York	3	0
North Dakota	1	0
Ohio	3	3
Rhode Island	1	2
Virginia	2	0
Wisconsin	2	1
Total	31	31

Observations

A program of field observation during the 1967-68, 1968-69, and 1969-70 winter seasons of the procedures, equipment, and problems presently encountered in snow and ice control at specific interchange locations was conducted. Five regional groups of interchanges of varied terrain, climate, and traffic across the snow belt in the United States were selected for observations. The regions included New England, Great Lakes, Central Plains, North Central, and Western Mountains. The interchanges varied from complex urban to rural with high to low traffic densities on the ramps. To provide a broad coverage of highway agencies, most regions selected included more than one state. The location and number of interchanges are given in Table 1.

Two record forms were designated for use in the field. The "Data Form" provided information on the geometrics and other physical characteristics of an interchange (Fig. 4). The "Storm Observation Report Form" was designed to provide detailed information on snow removal operations during each storm at each interchange (Fig. 5).

The selection of field representatives to observe snow removal procedures and to gather and record the physical data was based on two criteria: (1) their proximity to the interchanges to be observed, and (2) their experience in the highway maintenance field. Each observer had more than 30 years of highway maintenance experience and was deeply interested in the study.

The initial information gathered from field observation was somewhat limited because of the lack of snow throughout the U.S. during the 1967-68 season. The information gathered by the observers, however, supplemented that developed from past experience of the project staff and from interviews and discussions with maintenance personnel.

During the winters of 1968-69 and 1969-70, extensive field observations and photographs of interchange conditions and snow removal operations were collected by the researchers and by the field representatives. Observations

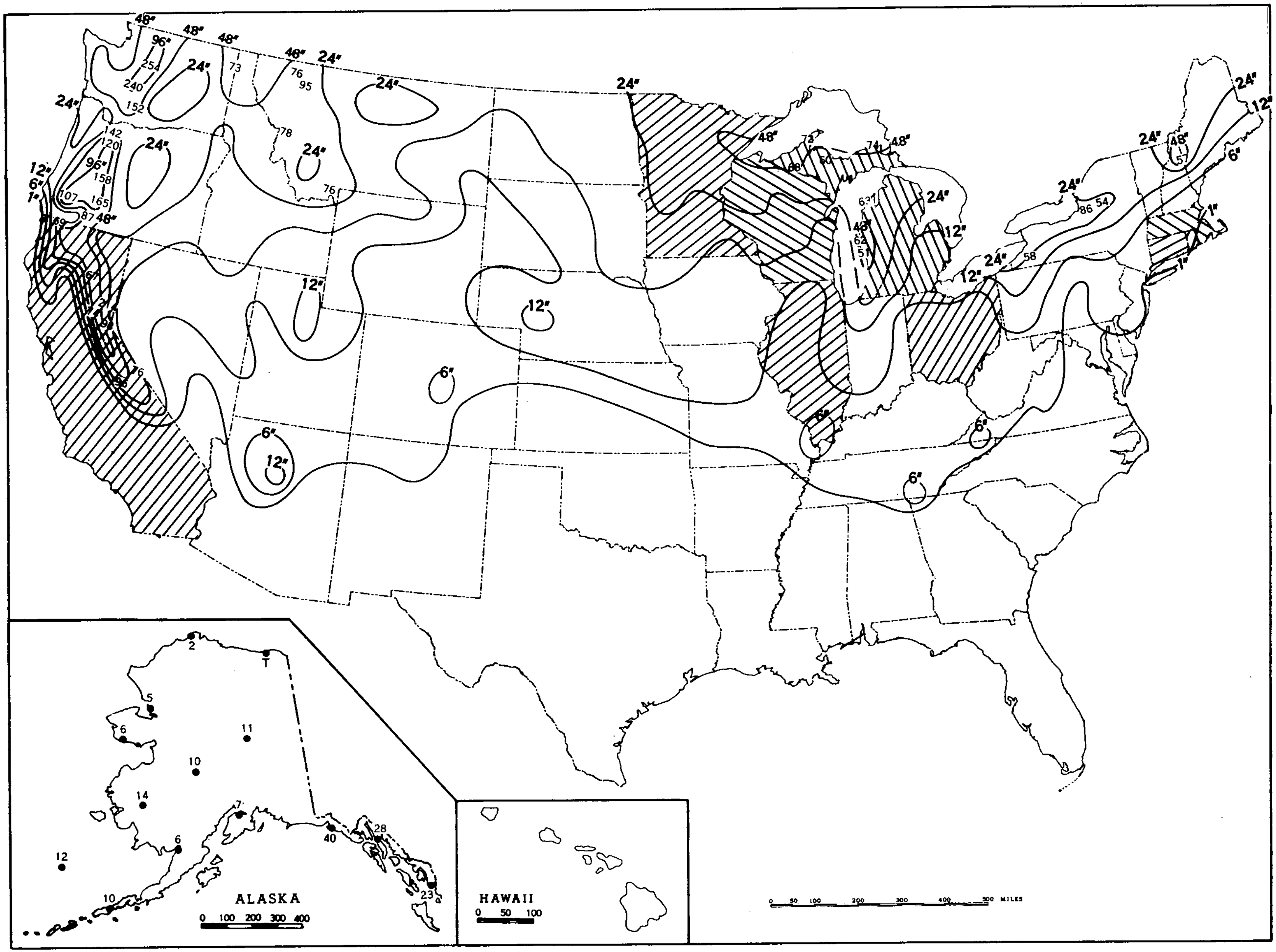


Figure 3. States in which interchanges were under observation. Superimposed on map showing total unmelted snowfall recorded during the month of January 1969 (U.S. Weather Bureau).

BERTRAM D TALLAMY ASSOCIATES

Snow Removal and Ice Control
Techniques at Interchanges
T/A 107-4 NCHRP 6-10

Data Form

Instructions: Gather required data and complete this form once for each interchange.

State ____ County ____

Highway ____ Interchange ____

Date ____ Observer ____

Average Weather

1 Average annual precipitation ____

2. Average annual snowfall ____

3. Average annual number of snow storms ____

4 What agencies are used to forecast the weather? ____

5 Which is the most reliable source? ____

General

	Yes	No
1. Is an attempt made to keep the interchange clear of ice and snow under all winter conditions (bare pavement)?		

2. How frequently can the interchange be covered under a severe storm condition? ____

Plowing ____

Spreading chemicals ____

Spreading abrasives ____

Mileage traveled to make one assigned round? ____

Lane miles per hour per piece of major equipment? ____

3. What constitutes the assignment of a crew for the interchange? ____

(a) this interchange only ____

(b) other assignment--describe ____

Facilities

Interchange

1. Obtain plan of interchange. On it spot items of particular interest to this study such as: drainage, nearest crossovers, snow storage areas, order and direction in which ramps and bridges are plowed, other items in snow removal plan, geometric problems, other problems, general wind direction, location of usual drifts, snow fence locations, melters.

Maintenance

2. Obtain vicinity map and on it locate maintenance facility and interchanges which it serves.
3. Obtain maintenance facility plot plan. On it locate and describe: shops, equipment sheds, material storage facilities (salt, abrasives), materials handling equipment.

Labor

	Yes	No
1. Are crews given formal or informal training?	____	____
At what intervals? ____		
2. Do personnel know in advance what their responsibilities will be during storm operations?	____	____

3. What arrangements are used for alerting maintenance personnel of impending storms? ____

	Yes	No
How long does it take to put crew on the job? ____		
4. Is the length of shifts increased during storm periods?	____	____
How long are shifts? ____		
5. How many men work during each shift on this interchange? ____		
6. Are arrangements made to get additional men on the road during severe conditions?	____	____
How long does call-out take? ____		

7. What is the maximum number of hours personnel are permitted to work continuously? ____

8. Describe organization for snow removal. (Numbers and job description) ____

Equipment

1. How many plows are available for use during snow storms at this interchange?

Push plows ____ Wing ____

Rotaries ____ Reversibles ____

Turnovers ____

2. How many material spreader trucks are available for use during snow storms at this interchange?

No. of Trucks	Material Capacity	Type of Spreader

3. How are plow blades set relative to pavement:

Location		Replacement Frequency	
Above ____ inches		Shoes ____	
Flush ____		Casters ____	

4. Type of plow blades:

Mild steel ____

Carborundum ____

Rubber ____

5. How many vehicles, in train, are used to plow ramps and which direction does each vehicle plow the snow?

Number	Type Plow	Direction: Median	Direction: Shoulder

6. How many spare units of equipment (in event of breakdown) are available during a storm?

Equipment	Number	Owned/Rented
Trucks		
Plows		
Spreaders		
Loaders		
Melters		

7. What lag time would there be between notification of need and availability of rental equipment for use on road?

8. What type of equipment is used for loading materials into spreader trucks?

Figure 4. Data Form.

Equipment	Chemicals	Abrasives
Mechanical Loader		
Conveyor		
Hopper		
Manual Labor		

9. What is the normal plow truck speed?________mph

10. What is the normal spreader speed?________mph

11. Are there any suggestions for equipment changes, improved equipment or new equipment?

12. Describe communication equipment and its use.

13. Does pavement contain a snow-melting device: Yes ___ No ___

Materials

1. What materials are stored for use on interchanges?

	Abrasives (Capacity)	Bulk Chemicals (Capacity)	Bag Chemicals (Chapacity)
Open			
Bin			
Shed			
Hopper			
Other			

2. How accurately is the rate of application for materials controlled:

   Good________Fair________Poor________

3. What types of chemicals or combinations are used and under what conditions?

Chemicals - Rate	Condition: Temperature (Rising - Falling)	Condition: Other

4. Under what conditions are abrasives used on interchanges?

Abrasives - Type	Rate	Condition: Temperature (Rising - Falling)	Condition: Other

5. Any control over spreading rate of chemical based on temperature, depth of snow, density, etc.________

6. Describe the procedure used for mixing chemical or abrasives, if applicable.

7. Is there a spring cleaning program to remove abrasive material from the interchanges? Yes ___ No ___

   To what account is it charged?________

Techniques and Procedures

1. Forward a copy of instructions, operating plan, sketches or diagrams issued to personnel.

2. What is sequence of operations in treating this interchange? (Salting, abrasives, plowing, blowing, melting, widening, other).

3. Are special plowing assignments made for interchange area? Yes ___ No ___

   What?________

4. When is snow removed from the shoulder area?________

   With what?________

5. When are chemicals applied to road surface?________

6. What spreading patterns are used (width of spread) and what is the application rate?

Pattern	Rate	Material

7. Who patrols roads looking for hazardous conditions during winter months?

   State Police ________

   Foreman or Supervisor________

   Special Patrol Force ________

8. Are operational procedures and policies for bridge decks the same as the mainline: Yes ___ No ___

   If no, what do you do?________

Improvement Suggestions

Discuss snow removal and ice control at this interchange and suggest corrective action:

1. Work plan and technique.
2. Training program.
3. Personnel problems.
4. Equipment selection and features (power steering, snow blowing on windshields, etc.)
5. Equipment servicing and maintenance.
6. Housing facilities (repair facilities, material storage, test area).
7. Materials (methods of storage, loading, quantities available and replenishing).
8. Roadway and structure design features
   - Grades (traffic difficulties)
   - Curves (short radii, superelevation)
   - Guard fence placement (drifting)

Figure 4. (*Continued*).

were conducted in seven states during and after heavy snowfalls. Procedures included riding with and following snowplows to observe and document plowing problems and conditions. One aircraft flight was taken into the Northeast to make low-level aerial observations and take photographs after a severe, "paralyzing" snowstorm. Table 2 gives details of the interchanges that were observed.

Questionnaire

To assist in the derivation of maximum benefit from this research effort, a summary of the *Interim Report* and a brief questionnaire were sent to the Maintenance Engineer in each of the 50 states through the AASHO Committee on Maintenance and Equipment in June 1969 for review and comment.

The questionnaire included the following questions. Table 3 gives a summary of the responses. Many useful comments that were received are compiled in Appendix B.

1. Do you consider interchange snow and ice control to be a separate and significant problem area in your winter maintenance program?
2. Do you provide special equipment, materials, or procedures exclusively for interchanges?
3. Have you developed and adopted special design criteria for interchanges specifically related to snow and ice control (i.e., snow storage areas based on 10-, 25-, 50-, etc., year snowstorms, drainage inlets for snowmelt, bridge railing to permit or prevent snow cast, etc.)?
4. Does your formal plan review procedure for new highway interchange designs include a review for maintainability by knowledgeable maintenance engineers?
5. Do you maintain any separate records of manpower, materials, and/or equipment utilization in snowstorm operations in interchanges?
6. Are you currently conducting or have you recently conducted any study, research, or special analysis of snow and ice control at interchanges?
7. Do you know of any additional factors or problems

BERTRAM D. TALLAMY ASSOCIATES

Snow Removal and Ice Control Techniques at Interchanges
T/A 107-4 NCHRP 6-10

Storm Observation Report Form (Revised)

Instructions: Complete this report each time a storm is observed at an interchange.

A storm is defined as starting with the beginning of precipitation which necessitates corrective action by maintenance forces to provide a clear pavement. The storm has ended when precipitation ceases and that condition continues for a period sufficient for a clear, normal pavement surface to be restored.

Include data on interchange only, i.e., on structures, ramps, mainlines to turnarounds, or if no turnarounds then 100 yards beyond last ramp exit or entrance; and labor, equipment and material costs expended in the interchange area only.

State: ______ County: ______
Highway: ______ Interchange: ______
Date: ______ Observer: ______

1. Time

	(a.m./p.m.)	Day of Week	Mo.	Day	Year
Storm started:					
Storm ended:					
Pavement completely cleared:					

2. Description

Dry snow ___ Sleet ___ Freezing rain ___
Wet snow ___ Other (describe) ______
Temp. (°F.) . . . . Max.______ Min.______
Depth of snow . . . . . Aver. (in.)______ Drifts(ft.)______
Wind . . . . Direction______ Velocity(mph)______
Visibility: Good ___ Fair ___ Poor ___ Feet:______

3. Procedure

		Time	Time
Chemical	___	From______	To______
Plowing	___	From______	To______
Abrasive-Chemical	___	From______	To______

4. Results

	Excellent	Good	Poor	Ineffective	Remarks
Chemical					
Plowing					
Abrasive-Chemical					

5. Manpower

Number of men	Number of hours	Total Man hours	Total Direct Labor costs

6. Equipment

Type	Distance Traveled	Hours Used	Rental Rate	Total Cost

Total Equipment Cost ______

7. Materials

Type	Amount	Unit Cost	Total Cost

Total Material Costs ______

Total Direct Costs ______

8. Interchange Data

	Ramp #	Length	ADT
Mainline			
Secondary Road			
Total			

Distance required for one piece of equipment to cover the interchange
Productive distance ______
Deadhead distance ______
Total distance ______

Note: On the reverse side or elsewhere provide a sketch of the interchange with the above data included thereon. Plot the route taken by each piece of equipment taken during the storm and the number of times the route was covered.

9. Observations and Remarks: Comment on the effectiveness of the clearing operations, and on problems encountered. Make any suggestions that appear warranted for improving procedures, equipment, materials. Use reverse side of form or additional sheets if necessary.

Figure 5. Storm Observation Report Form.

TABLE 2

INTERCHANGES OBSERVED

STATE	INTERCHANGE	URBAN-U RURAL-R	TYPE [a]	ADT MAIN LINE	ADT RAMPS [b]
Calif.	I-80 & Calif. 89(S)	R	D	9,800	2,560
	I-80 & Calif. 20	R	Tm	10,400	1,250
	I-80 at Baxter	R	D	9,600	970
	I-80 at Crystal Springs	R	D		
Conn.	# 90 Conn. Turnpike	R	Y	3,800	1,800
	# 91 Conn. Turnpike	R	Y	5,400	3,200
Ill.	I-55 & US 54 Springfield	U	C	11,600	4,420
	I-55 & US 36 Springfield	U	C	14,300	5,300
	I-55 & Ill. 29 Springfield	U	C	12,800	4,100
	I-55 & Stevenson Dr. Springfield	U	Cmh	9,800	4,600
Mass.	I-195 & Mass. 138 Fall River	U Urban complex		21,000	
Mich.	I-75 at Erie	R	D		900
Minn.	# 74 on I-94	U (One large urban complex: #74–#43)	D		
	# 75 on I-94	U	Dm		22,000
	# 76 on I-94	U	Ym		6,100
	# 77 on I-94	U	Dm		21,000
	# 78 on I-94	U	Dm		13,200
	# 79 on I-94	U	Cmh		
	# 80 on I-94	U	YhDh		
	# 41 on I-35E	U	Dm		12,000
	# 42 on I-35E	U	Dm		14,000
	# 43 on I-35E	U	Dm		8,700
	# 44 on I-35E	U	D	10,900	
	# 45 on I-35E	U	Dh		
	I-35W & I-694	U	C	20,000	
Ohio	# 5 Ohio Turnpike	R	T		
	I-280 & Summit Ave. Toledo	U (Urban complex)			
	I-280 & Manhattan Ave. Toledo	U (Urban complex)			
Rhode Is.	I-95 & I-195 Providence	U	Y	98,200	71,600
	I-95 & R. I. 146	U	Ym	87,600	21,100
Wisc.	I-94 & Wisc. 12	R	D	6,500	190

[a] Legend: D = diamond; Y = wye; C = cloverleaf; T = trumpet; m = modified; and h = half.
[b] Sum of ramp average daily traffic.

affecting snow removal and ice control at interchanges that are not covered in the attached summary report?

8. Do you have any suggested solutions or comments not discussed in the report?

Conferences

Formal two-day staff conferences were held in Washington, D.C., in April 1968, and October 1969. The participants had extensive highway maintenance experience with the problems of snow removal and ice control. In addition, conferees were well-versed in research and development techniques. With this background and experience, the first-hand reporting of the results of the winter observations and interviews with maintenance personnel provoked lively discussion and contributed greatly to the information developed in this study. The conference objectives were: (1) to identify the problems and factors influencing snow removal and ice control at interchanges; (2) to suggest solutions to the problems or improved techniques; (3) to discuss additional research that might contribute to overcoming the problems; (4) to review project progress to date; and (5) to develop project needs and plan data collection procedures for the remainder of the project.

TABLE 3

AASHO QUESTIONNAIRE SUMMARY

QUES. NO.	RESPONSE [a] YES	NO	OTHER
1	18	17	4
2	13	24	2
3	2	34	3
4	20	17	2
5	1	36	2
6	8	29	2
7	2	33	4
8	3	32	4

[a] 13 "No" states and 2 "Other" states are without major snowfall or without urban interchanges in snow belt.

In January 1970, the researchers met in Boston, Mass., with maintenance engineers and superintendents from Massachusetts, Connecticut, and Rhode Island for a special day-long conference on snow and ice control problems. Information on specific snow removal requirements and techniques in the Northeast was obtained using the interim findings of the study as a discussion guide.

CHAPTER TWO

FINDINGS—FACTORS INFLUENCING SNOW AND ICE CONTROL AT INTERCHANGES

Most highway maintenance agencies in their planning and operations do not consider or treat interchanges separately or discretely but include them in the over-all problem of snow removal and ice control on highways. Maintenance engineers recognize that interchanges create certain problems but not necessarily unique ones.

Because highway maintenance organizations and snow removal equipment are designed primarily to accommodate main-line problems, research and experimentation in organization and equipment as they affect interchanges have been given little attention as a separate problem.

Although snow removal and ice control problems on interchanges are basically similar to those on the main line there are certain differences. First, the greater the average daily traffic (ADT) on the ramps, the more attention is paid to snow removal and ice control at interchanges. In rural areas where the greatest traffic occurs on the main line, interchanges are only incidental to the snow removal plan. The bottleneck, if any, is on the highway itself and not at the interchange. A typical example is the interchange on I-94 with Wisconsin Route 12 where the main-line ADT is 6,500 vehicles and the ramp count is less than 200. Here, main-line plowing rates a high priority over ramps.

In contrast, however, where the average traffic count is high, particularly in urban areas, the interchange is likely to be a bottleneck, because many vehicles must get on or off through the interchanges; otherwise, traffic tieups occur. Consequently, in urban areas a great deal more attention is paid to the interchanges. Examples are the interchanges of the New Jersey Turnpike where the Turnpike Authority's equipment is assigned exclusively to interchanges and snow removal on the main line is contracted to private equipment fleet operators.

Secondly, interchanges vary in design and operating characteristics over an infinite range. In general, each is unique. Although interchanges can be classified into types (such as the Y and the T for three-legged interchanges, the trumpet, the diamond, and the cloverleaf for four-legged interchanges), each has to be adapted to the terrain, traffic, feeder roads, available right-of-way, design policy, and economic factors.

Because the problem of snow removal and ice control at interchanges is so interwoven with the general problem of snow removal and ice control, it has been difficult to separate them. Through interviews, observations, and staff conferences, this study has been able to identify some specific elements or factors that contribute to or accentuate snow removal and ice control problems at interchanges.

The factors are presented in two categories—(1) Physical and (2) Operational—along with the specific problems that each factor generates.

PHYSICAL FACTORS

Geometrics

The highway design engineer is usually confronted with many conflicting alternatives. Although traffic requirements, economy, and normal operating characteristics must be basic factors in establishing design criteria, snow removal and ice control problems at interchanges may warrant significant modification of design standards in some instances.

The geometrics of an interchange, including such items as type, grade, alignment, pavement width, cross section, slope, rounding, and superelevation, affect snow and ice control operations in numerous ways. The selection of the type of interchange is based on terrain, traffic, and availability of right-of-way. Each interchange may contain several types of ramps (i.e., diagonal, loop, semi or direct connection) and these may require somewhat different plowing requirements. Partial interchanges may serve traffic needs but prevent efficient routing of maintenance vehicles.

Ramp gradient can affect the plow speed, which in turn affects traffic movements, snow cast, and chemical spreading rates and patterns. Maximum ascending grades, combined with icy pavement conditions, make ramps difficult to plow, especially if stopping and starting operations are required. In urban areas where right-of-way is limited, and ramps are designed with small-radius curves, a problem may be experienced with maneuvering plows through these tight curves.

Cross sections, slopes, and shoulder roundings are of concern as they affect snow drifting. Abrupt changes in slope between shoulder and roadside may contribute to drifting when wind direction and velocity are favorable. Slopes located in positions exposed to the sun rather than in shadows promote melting and simplify maintenance.

The requirements for superelevation on ramps are dictated principally by vehicle speeds and curve radii. The AASHO *Policy on Geometric Design on Rural Highways* recommends superelevation rates, including values for areas where snow and ice is a definite consideration. Snowmelt drainage across the superelevated roadway also can present an extremely hazardous situation. Refreezing of melt from snow deposited on the high side of superelevated ramps is a costly problem where pavement superelevation is extended through the shoulders.

Structures

Adequate snow storage is important in interchange bridge design. Bridge shoulders must be wide enough to accommodate temporary snow storage. The inadvertent casting of snow from bridge decks to the traveled way below is another problem that should be considered in the design of bridge parapets and rails. The phenomenon of bridge decks becoming slippery prior to adjacent pavement is a factor that influences snow removal and ice control at interchanges where turning movements on structures are commonplace. Melt water on bridge decks (Fig. 6) may result in a hazard under freezing temperatures. The extent of this problem is the subject being studied under NCHRP Project 6-11, "Economic Evaluation of the Effects of Ice and Frost on Bridge Decks."

Appurtenances

Pavement obstructions, such as curbs, raised button delineators, rumble strips, expansion dams on structures, manhole covers, and valve boxes in the traveled way of the interchange area may interfere with efficient plowing operations. Low-lying appurtenances of this type within the pavement area are quickly covered during a snowfall. The snowplow operator must slow down when he knows he is in the vicinity of an obstruction in order to prevent damage to the appurtenance or the plow blade.

Signs, bridge railings and parapets, guardrails, light standards, delineators, right-of-way fences, and landscape plantings may obstruct the wind under certain conditions, producing eddies and causing drifting across the pavement. Also, swirling, drifting snow can obscure driver vision. When appurtenances are being located, the effects of drifting snow can be minimized by considering the direction and velocity of the prevailing wind.

Signs, curbs, and vertical delineators can be buried or covered with blown or plowed snow. Under certain weather conditions signs become obscured by blowing, sticking snow. These situations confuse the motorist, particularly one unfamiliar with the area.

Signs, parapets, light standards, guardrails, and vertical delineators located close to the edge of the pavement or shoulder interfere with efficient plow operations, particularly when wing plows are used in clean-up operations. A safety hazard is created when the plow must pull out into traffic to plow around an obstacle near or on the shoulder.

Turnarounds and Crossovers

Lack of turnarounds or crossovers may force snow and ice equipment to deadhead to the next interchange, which may sometimes be 10 to 15 miles distant, turn around, and return to plow the remaining ramps on the initial interchange. If some means of turnaround is not provided, equipment may duplicate chemical spreading or plowing coverage or may need to maneuver against traffic. This latter practice is extremely hazardous and is prohibited by operating agencies.

For complete flexibility in maintenance operations, a place for equipment to change direction must be provided

Figure 6. Melt water on bridge deck subject to refreezing.

on each leg of the interchange. Safety is a prime consideration in the location and design of crossovers. The most common location for crossover is in the median, but such use is extremely hazardous where main-line traffic is heavy, or where the median is not sufficiently wide to get the vehicle entirely off the traveled pavement. Some agencies with responsibility for maintaining heavily traveled roadways absolutely forbid median crossovers.

Some interchange ramps, particularly in urban and metropolitan areas, exit into one-way streets. When clearing these ramps, heavy snow removal equipment must traverse a number of blocks in city traffic before returning to the interchange via the closest entrance ramp. During snowstorms, when snarls are likely to occur on city streets, much-needed interchange equipment can be out of operation for an unduly long period.

Figures 7 through 10 show layouts of some of the interchanges observed in this study. They illustrate a number of points: (1) the amount of deadhead travel required of most equipment in interchanges; (2) the effect of turnarounds on deadhead travel; and (3) the detailed planning required to ensure adequate and timely coverage of all elements of the interchange with the minimum crew and equipment.

Snow Storage Areas

The most prevalent problem concerning snow storage is the lack of adequate area, particularly in urban interchanges where the right-of-way is limited. Limited storage space requires the removal of stored snow either during the storm or immediately thereafter.

Inadequate storage area on structures fosters the casting of snow over or through bridge rails onto adjacent traveled roadways or properties below. Where shoulders or sidewalks exist on structures there is usually sufficient temporary storage for each storm. When no shoulders exist it is sometimes necessary to use the outside lane for temporary storage, and suffer the consequences of closing one lane to traffic temporarily. Usually, snow is fully removed from the bridge deck once the storm is over to make room for snow from the next storm and to protect the structure from excessive damage by brine solutions and freeze-thaw cycles.

Snow storage areas create a number of related problems. High windrows of snow between the main line and ramps may block sight distances at ramp openings. Windrows oriented at right angles to prevailing winds may cause snowdrifts across the roadway.

Drains

Snow storage areas, whether they be shoulders, paved medians, islands, or gores, must have drains adequately sized and located to handle drainage not only for rainstorms but also for snowmelt. Where raised gores, for example, without drains are used for snow storage, melt water may flow across the traveled way and refreeze even though runoff from rainfall would present no problem.

Adjacent Development

Where land adjacent to interchanges is highly developed, the interchange is likely to be compact and there will be less storage area for cast, blown, or handled snow. Adjacent land development also must be considered when one is using chemicals for snow and ice control. Without proper drainage, damage to vegetation from brine runoff may be extensive.

OPERATIONAL FACTORS

Location of Maintenance Yards

Improperly located maintenance yards create problems of deadheading for reloading of chemicals and equipment refueling or repairs. Maintenance areas located near a central interchange may allow access to the highway in either direction and reduce deadhead travel of snow removal equipment. Some highway interchanges of unusual length or configuration may have additional temporary stockpiles of materials located closer to points of heavy consumption than central storage yards afford.

One problem with the location of a maintenance yard or a material storage area involves the aesthetic acceptability. Maintenance and storage yards with materials and equipment stored in the open can be a problem if the yard is located within or adjacent to an interchange area where more than one side is subject to public view and sometimes to a panoramic view from ramps and structures.

Selection of Removal Procedures

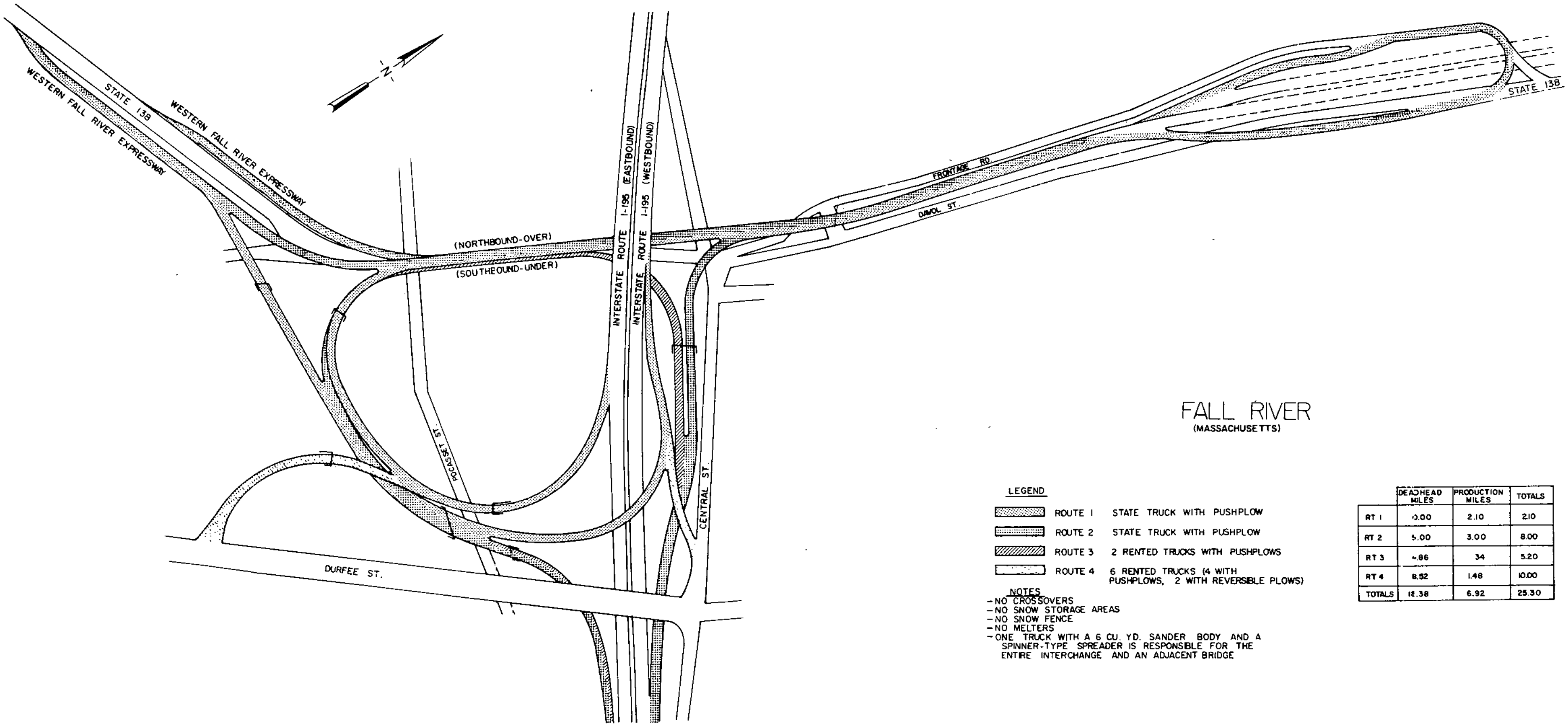
Loss of Plow Path Width on Sharp Curves

A number of individuals expressed concern over the reduction of plow path width on sharp curves, particularly those on cloverleaf ramps. A geometric analysis is summarized in Figure 11 (details are included in Appendix D) and indicates that this loss is minimal. The concern, however, does emphasize the requirement for maintaining a wide plow path on one-way curved ramps in heavily traveled urban interchanges if traffic capacity and speed are to be maintained. This requirement dictates the necessity for a double pass if only one plow is assigned to the ramp.

Windrows Across Ramp Openings

Windrows deposited by plows across ramp entrances and exits (Fig. 12) often become a hazard to vehicles turning off the main line and sometimes to vehicles entering the main line because drivers are not expecting such obstacles in their paths.

In most jurisdictions the main line is plowed by two or three plows in tandem. When all plows remain on the main line through the interchange, the windrow is deposited across the ramp. If the right plow veers off at the interchange to clear the ramp entrance, the main-line right-hand lane remains unplowed through the interchange area. In either case a dangerous situation remains until the windrow and lane are cleared.



	DEADHEAD MILES	PRODUCTION MILES	TOTALS
RT 1	0.00	2.10	2.10
RT 2	5.00	3.00	8.00
RT 3	4.86	34	5.20
RT 4	8.52	1.48	10.00
TOTALS	18.38	6.92	25.30

Figure 7. Interchange I-195 and Mass. 138, Fall River, Mass.

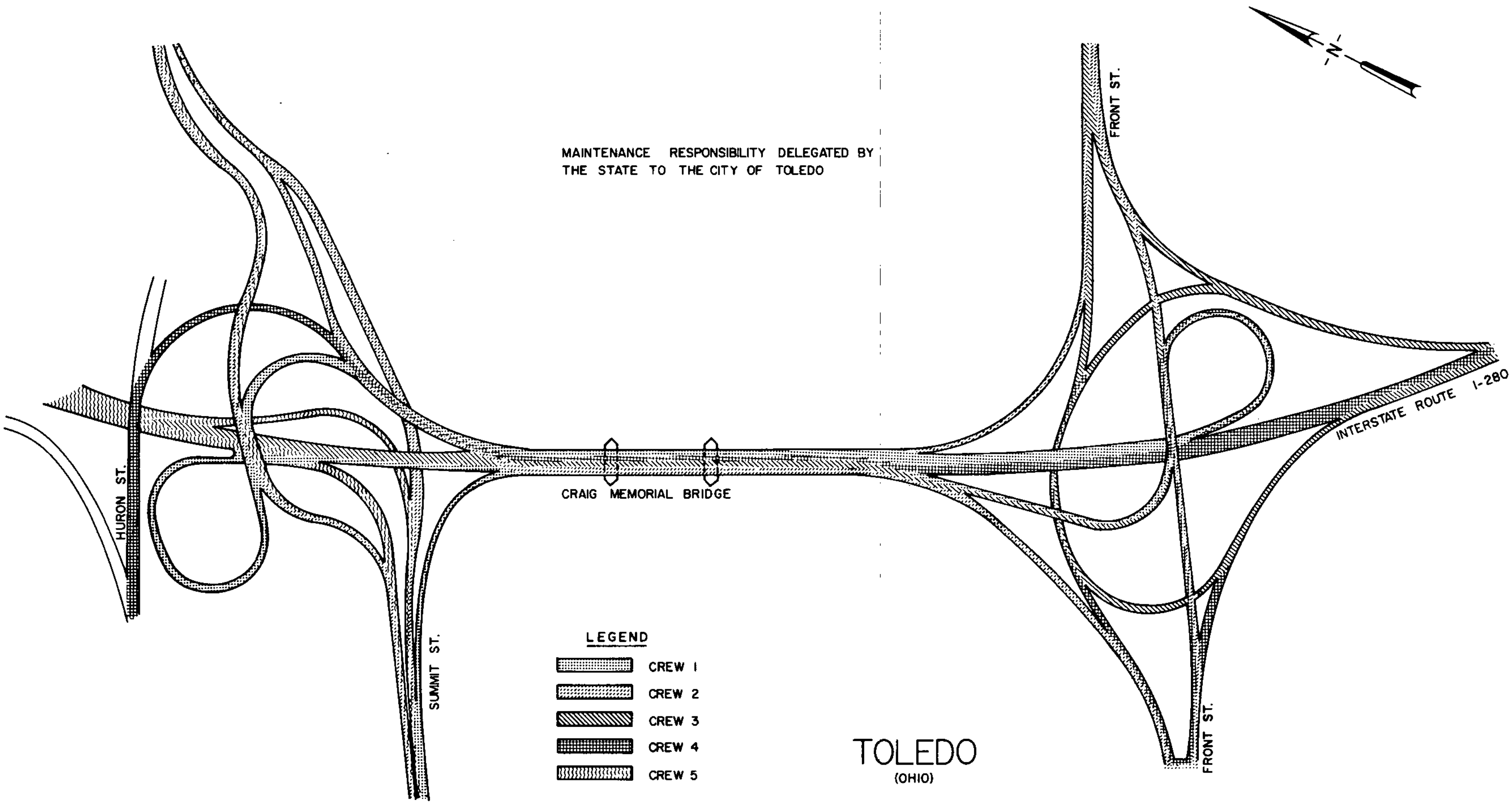


Figure 8. Interchanges on I-280, Toledo, Ohio.

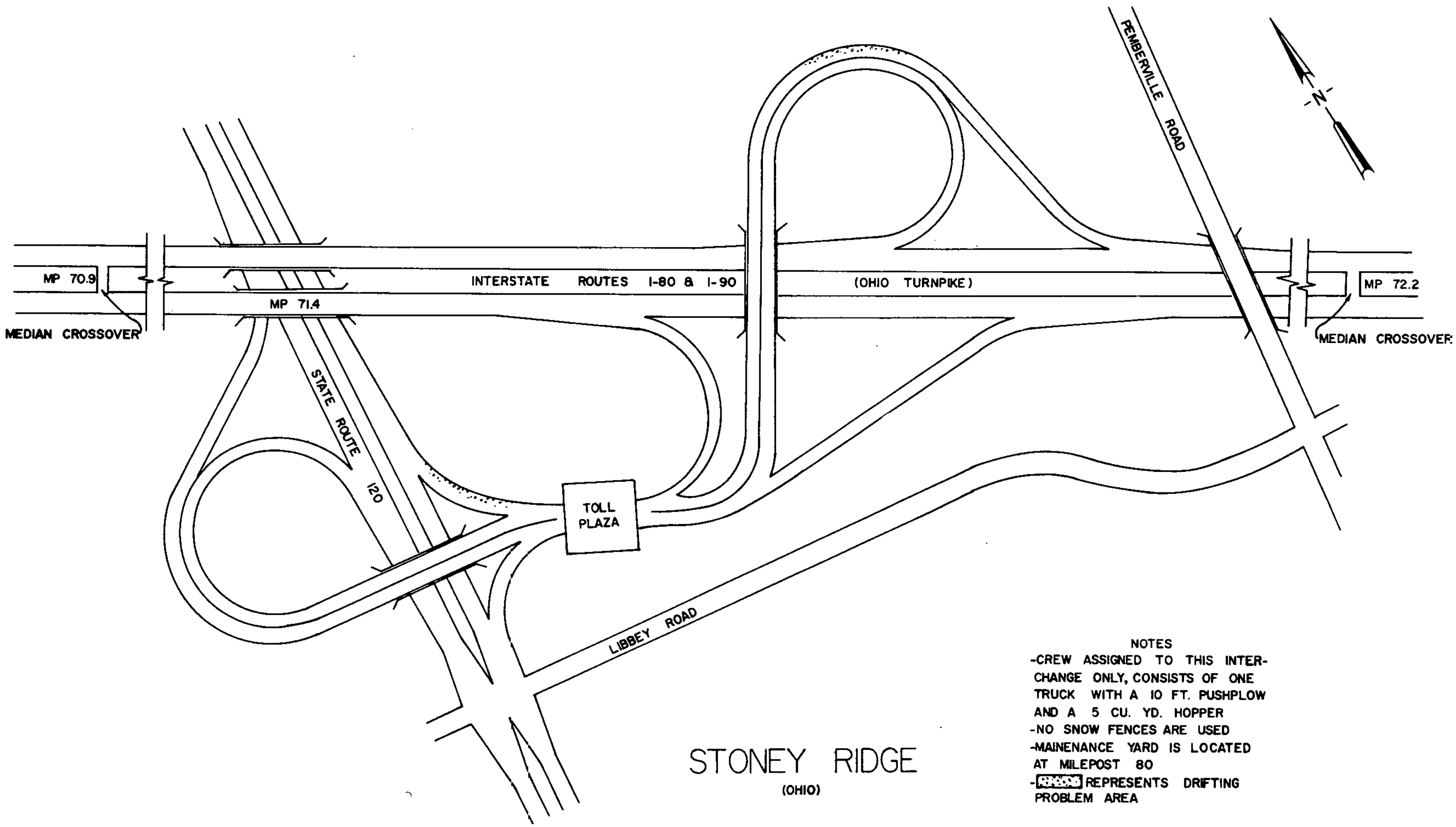


Figure 9. Interchange No. 5 on Ohio Turnpike.

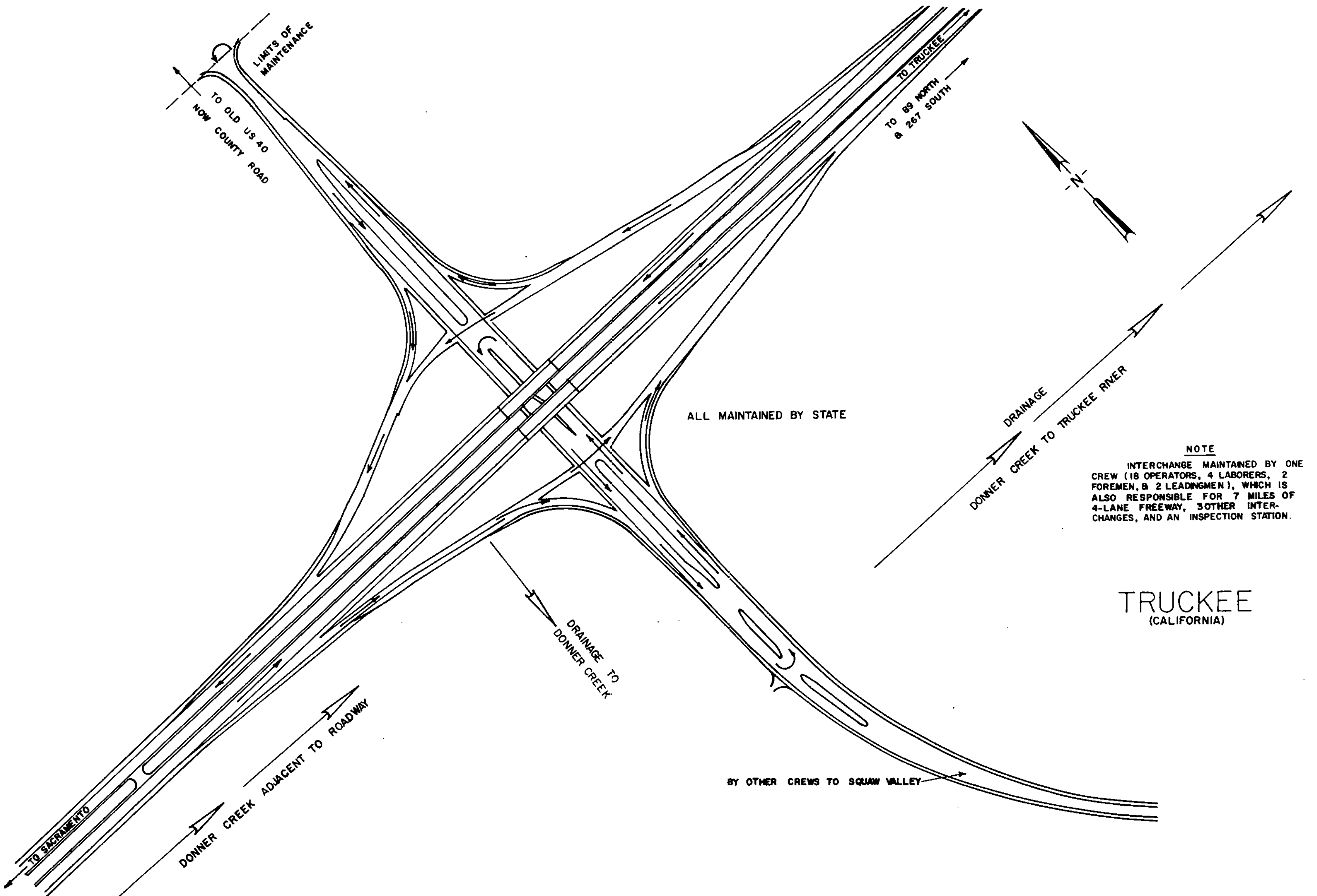


Figure 10. Interchange I-80 and Calif. 89, Truckee, Calif.

Windrows Parallel to Roadways

Windrows deposited by plows parallel to the roadway at the edge of the pavement or shoulder, under the right conditions of wind and temperature, may act as snow fences and cause drifting on the traveled way.

Windrows deposited at the tip of gores between ramps, or between ramp and main-line pavements, in heavy snowfall country can create a hazardous condition by obstructing the view of the drivers on merging ramps or entering the main line from an entrance ramp.

Plowing to High Side of Superelevated Ramps

The melt from snow plowed to the high side of superelevated ramps may flow across the traveled way, as shown in Figure 13. The melt water is subject to refreezing as the temperature drops, creating icy conditions that are hazardous for the unwary motorist. Often such conditions in interchanges require continued chemical treatment by maintenance crews long after the snowstorm has ended.

Elevation of Plow Blade

A "bare pavement" policy is generally in effect for limited-access highways. To attain this goal many agencies, even after the adoption of chemical programs, have continued to allow the plow to be carried with the plow blade flush on the pavement rather than on casters or shoes. With the tremendous increase in the use of chemicals to melt snow and prevent a bond between the snow and the pavement surface, blades directly on the pavement surface wear rapidly, requiring frequent and costly replacement.

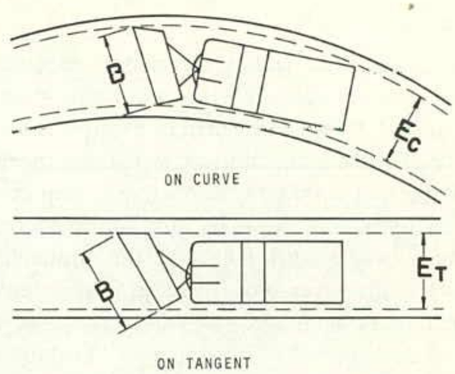
Chemical Spreading

The spreading of chemicals at interchanges is not as simple an operation as it is on the main line. Ramp grades, traffic congestion, and different radii of curvature on the ramps all affect the speed, the spreading rate, and the spreading pattern of chemical trucks. The inability to control the rate of spread from the cab as the speed of the vehicle varies on the ramps and the inability to control the direction of cast of spread materials from the cab are handicaps in ramp operations.

Storage of Materials

Chemicals, although a boon to snow removal in general, offer problems if insufficient and inadequate storage and improper materials handling equipment are provided.

Storage problems that may arise from the increased use of chemicals and that indirectly affect interchange snow removal include the potential pollution of surface and underground water supplies; vegetation damage by runoff brine from chlorides stored in the open; the caking and lumping of chemicals improperly stored both in the open and under cover; the reliance that must be placed on suppliers for the timely replenishment of chemicals when storage facilities are too small; and the costs of closed storage, either in surface bins or elevated structures.



		EFFECTIVE PLOW WIDTH	
MOLDBOARD WIDTH (B)	PLOW ANGLE	ON TANGENT (E_T)	ON 230' RADIUS CURVE (E_C)
8'	30°	6'-11"	6'-7 3/4"
9'	30°	7'- 9 1/2"	7'-5 1/2"
10'	30°	8'- 8"	8'-3 1/2"
11'	30°	9'- 6 1/4"	9'-1 1/2"
12'	30°	10'- 4 3/4"	9'-11 1/2"

Figure 11. Reduction of plow path width on short radius curves and on tangent.

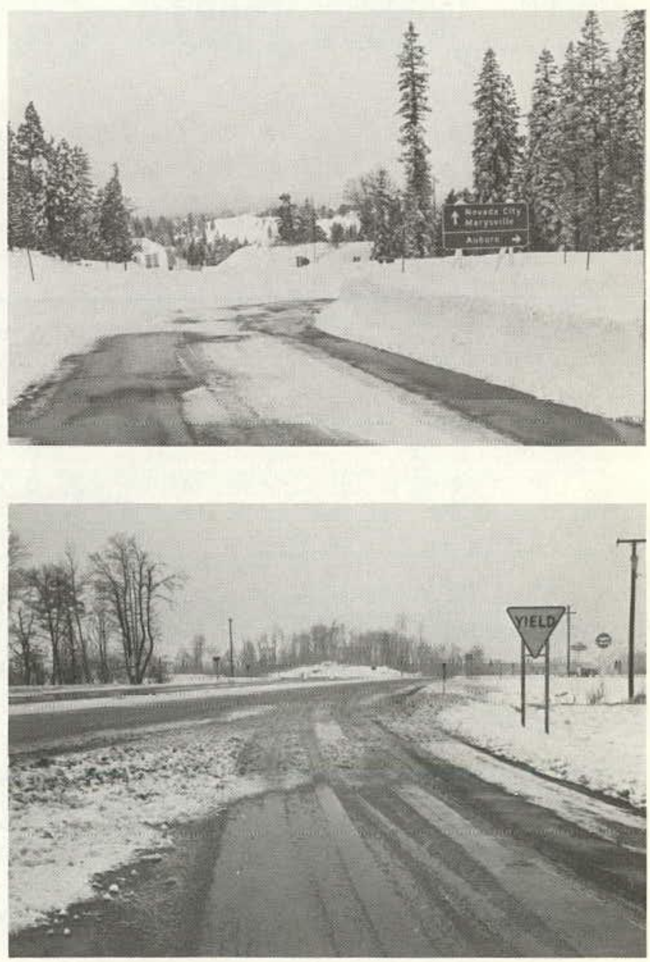


Figure 12. Windrows deposited across ramp openings.

Influence of Traffic

The amount of traffic on ramps generally determines whether maintenance engineers consider snow removal and ice control at an interchange to be a problem. The heavier the traffic the more critical is the maintenance of ramp capacities. In addition, heavy traffic diminishes the casting capability of snowplows because snowplow speed is slowed. Heavier traffic also increases the probability of stalled vehicles. To overcome these problems, coverage of the interchanges is made at greater frequency, or separate crews are assigned to interchanges. In some instances contract towing services for stalled vehicles are provided.

Creation of Jurisdictional Boundaries

Inappropriately drawn jurisdictional boundaries between maintenance organizations may cause coordination problems in snow removal activities. In certain instances when snowplows must enter other jurisdictions to turn around, they become enmeshed in traffic or are confronted with a snow removal problem before being able to return to the interchange.

The obvious solution to such problems is to delineate boundaries so that there is no question as to the responsibility for elements of the interchange and so that efficient equitable trade-offs are made where operational rather than legal boundaries can be determined.

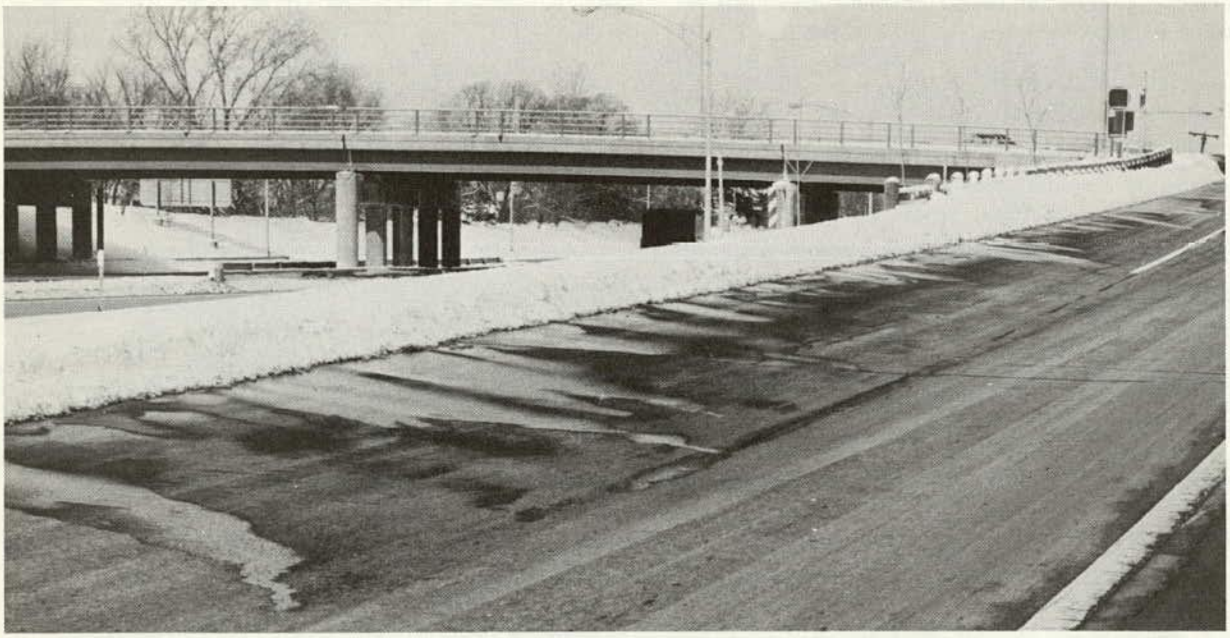


Figure 13. Melt water flowing across superelevated ramps.

CHAPTER THREE

APPLICATION OF FINDINGS—GUIDELINES FOR DESIGN OF INTERCHANGES TO ACCOMMODATE SNOW AND ICE CONTROL

Significant influence on snow and ice control operations can be exercised during the design of interchanges. Often a design decision calling for a nominal one-time expenditure may prevent a recurring maintenance expenditure over the life of the interchange, as well as provide a continuing benefit to the highway user during storm periods.

The following guidelines have been developed through this research project as an aid to the engineer responsible for planning, designing, or evaluating the design of a highway interchange for adaptability to snow removal and ice control operations.

GEOMETRICS

Certain features in the geometry of the interchange can be instrumental in controlling or reducing the effort required to plow or spread chemicals.

Although the ramp radius and design speed control its superelevation, the resulting cross section may affect the snow storage areas and snowmelt drainage pattern. In regions of heavy snow, consideration should be given to the use of large radius ramp curves to reduce the required superelevation and facilitate the operation of snow and ice control equipment on the ramps.

Bifurcations

The bifurcation, ramp separation, or exit/entrance terminal must be designed with as little obstruction to plowing as possible. Where curbs are used for the approach nose, to improve delineation and visibility, they may be damaged by snowplows or present a hazard to plowing operations. Alternative solutions to the use of curbs should be considered to provide an approach end treatment without obstruction to plowing, consistent with safety requirements. Rumble strips frequently employed as a warning to vehicle operators also may be a problem in snow-plowing operations.

Drainage in the exit or entrance terminal area must be carefully examined to identify conditions where cross pavement drainage of snowmelt could be eliminated by slope changes or the addition of drains. Ramps should enter or exit the main line on a tangent to allow water to drain away from the main line.

Current design practice calls for flat horizontal curvature for entrance or exit ramps, usually 1°. Snow storage area may be enlarged by increasing this takeoff curvature to 1° 30′, for example. Figure 14 shows the relative increase obtainable.

Parallel Ramps

Of immediate concern when one is planning parallel or contiguous ramps is the problem of snow storage and snowmelt. Adequate, depressed locations adjacent to the ramps can provide readily available storage of plowed snow. Whether the ramps are superelevated in equal or opposite directions, their design should be such that plowed snow does not form windrows between the ramps that could result in sheet flow of water or drifting across the pavements. Especially hazardous is the situation of parallel ramps superelevated in the same direction with continuous pavement between and separated only by a median guardrail. In snow areas, such a design should be avoided in preference to one containing pavement separation and/or curb and gutter drainage.

Alignment and Grade

Combinations of vertical alignment, horizontal curvature, superelevation, and grade must be examined carefully to ensure a minimum of problems. In areas subject to snow and ice, ramp gradients should not exceed 5 percent, according to AASHO design policy, in order that plowing equipment and vehicles will not encounter difficulty negotiating the ramp. A minimum grade of 1 percent is desired for drainage.

The main line and ramps should have southern exposure to the sun, if possible, to speed snowmelt. Cuts may be flattened or the alignment may be designed to provide the exposure, if this is feasible and economical.

In open, level terrain, the wind may be effective in clearing the highway of snow if the grade line is raised

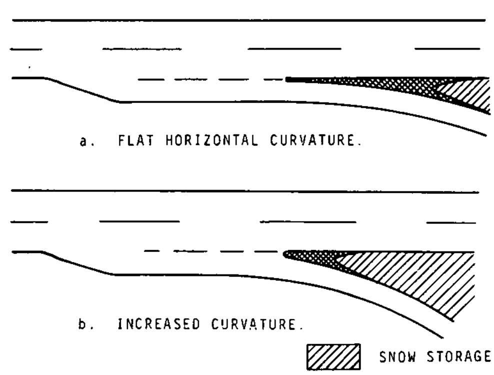


Figure 14. Snow storage area versus degree of curvature of ramp.

above the adjacent ground level. Several north-central states subject to blizzards elevate highway grade lines 3 to 5 ft above the normal accumulated snow surface so that wind will blow the highway surface free. At interchanges, however, consideration should be given to assuring that the rise in main-line grade will not cause drifting on the ramps.

Superelevation

In areas where snow and icing conditions prevail, maximum superelevation rates for ramps of 0.06 to 0.08 ft per foot are generally recommended (AASHO). Normal non-snow and -ice conditions may allow rates up to 0.12. A minimum rate of 0.02 for all conditions is required to effect drainage.

Superelevation rate is also controlled by several factors other than the amount of snow and icing; for example: (1) terrain condition, (2) rural/urban environment, and (3) frequency of slow-moving traffic. In urban areas with high traffic volumes, turning or crossing movements, signals, and slower operating speeds it has been common practice to establish low maximum rates of superelevation. In some cases it is difficult to slope pavements for drainage without negative superelevation for some turning movements.

To retain a smooth cross section and prevent drifting, superelevated ramp slopes on the high side should be designed so that the transition angle does not exceed approximately 14°. For example, if the superelevation rate is 0.06 ft per foot, or 3½°, and the high side is to windward, the side slope should be flattened to approximately 5½ on 1, or 10½°, for a total transition angle of 14°.

Typical Sections

When one is designing cross sections of main line or interchange ramps, numerous variables affecting snow and ice control must be considered. Drifting, snow storage, and drainage are a few of the problems that proper roadway cross sections can help to solve. More can be accomplished toward improved winter maintenance operations by proper cross-section design than by any other single design factor, especially in areas of heavy snowfall.

Shoulders

The design criteria of a number of agencies provide for reverse shoulder slopes on the high side of superelevated ramps, especially when the operator must plow to the high side and when the shoulders must be used for snow storage. This will provide for drainage of the snowmelt away from the ramp pavement and prevent cross drainage and refreezing of water on the traveled way. Accident records for those agencies interviewed indicate that reverse slopes are not a safety hazard when vehicles are traveling at design speeds.

Cross-slope breaks may be hazardous to traffic. Algebraic differences in the pavement and shoulder slope of 0.06 or greater are undesirable. The pavement slope may be carried into the shoulder approximately 2 ft where it changes to a negative 2 percent. A compromise sometimes used on superelevated sections is a continuously rounded shoulder cross section. This allows some surface runoff across the pavement but eliminates a severe slope change. "Cleanup" operations required after a snowstorm must be anticipated by eliminating obstructions in the shoulder area that would restrict the use of snow blowers or front-end loaders. In addition, the shoulder must be designed with sufficient load-carrying capacity to accommodate the fairly slow-moving, heavy vehicles that may be required.

Cut Sections

In the northern states, snow and ice on the roadway are a probable cause of vehicles going out of control. After an in-depth analysis of out-of-control vehicle accidents, New York State now requires 30 ft of 6 on 1 slope from the edge of the pavement. The findings revealed that a high percentage (80 percent) of recovery of control could occur within the 30-ft width.

Highways passing through deep cuts present problems of lack of snow storage area, drifting, shadows, and reduced melting from the sun. To provide adequate snow storage, decrease drifting, and allow out-of-control vehicles area for recovery, the preferred cut slopes would be 6.5 on 1 downward for 30 ft beyond the pavement edge, 4 on 1 beyond the guardrail to a 4-ft ditch, then upward at 3 on 1 slope, with a 50-ft rounding at the top of the bank. Example cross sections of superelevated ramps are shown in Figure 15. Such flat slopes may not be economical, especially in urban areas, except for very shallow cuts.

The literature on the subject of drifting suggests design considerations to overcome the drifting problem. These were corroborated by observation and interviews throughout the course of the project.

For the pavement and shoulders to remain free of snowdrifts the horizontal distance from the shoulder edge to the top of the cut must be at least 6.5 times the depth of cut. Cuts deeper than 25 ft are less vulnerable to drifting than are shallower cuts because there is more room on the side slopes to hold the snow. Deep cuts should have wide ditches for snow plowed from the roadway. Where prevailing winds are fairly constant, the extra ditch width should be placed on the upwind side of the road. If skillfully handled during construction, borrow obtained from widened cuts may be used to raise embankments and flatten fill slopes.

Fill Sections

Pavement fill sections about 4 ft high in flat country usually blow clear. For fills above 4 ft, 6.5 on 1 slopes for 30 ft beyond pavement edges are preferred to prevent or reduce snow drifting and, if possible, a 4 on 1 slope is preferred for the next 24 ft, with rounding at each transition. All slope transitions in cut and fill sections should be rounded to obtain a "streamlined" cross section. The economic feasibility of providing the recommended slopes is determined for several examples in Appendix G.

Medians

Wide, depressed medians are desired, and are often necessary in urban areas, especially for snow storage. The

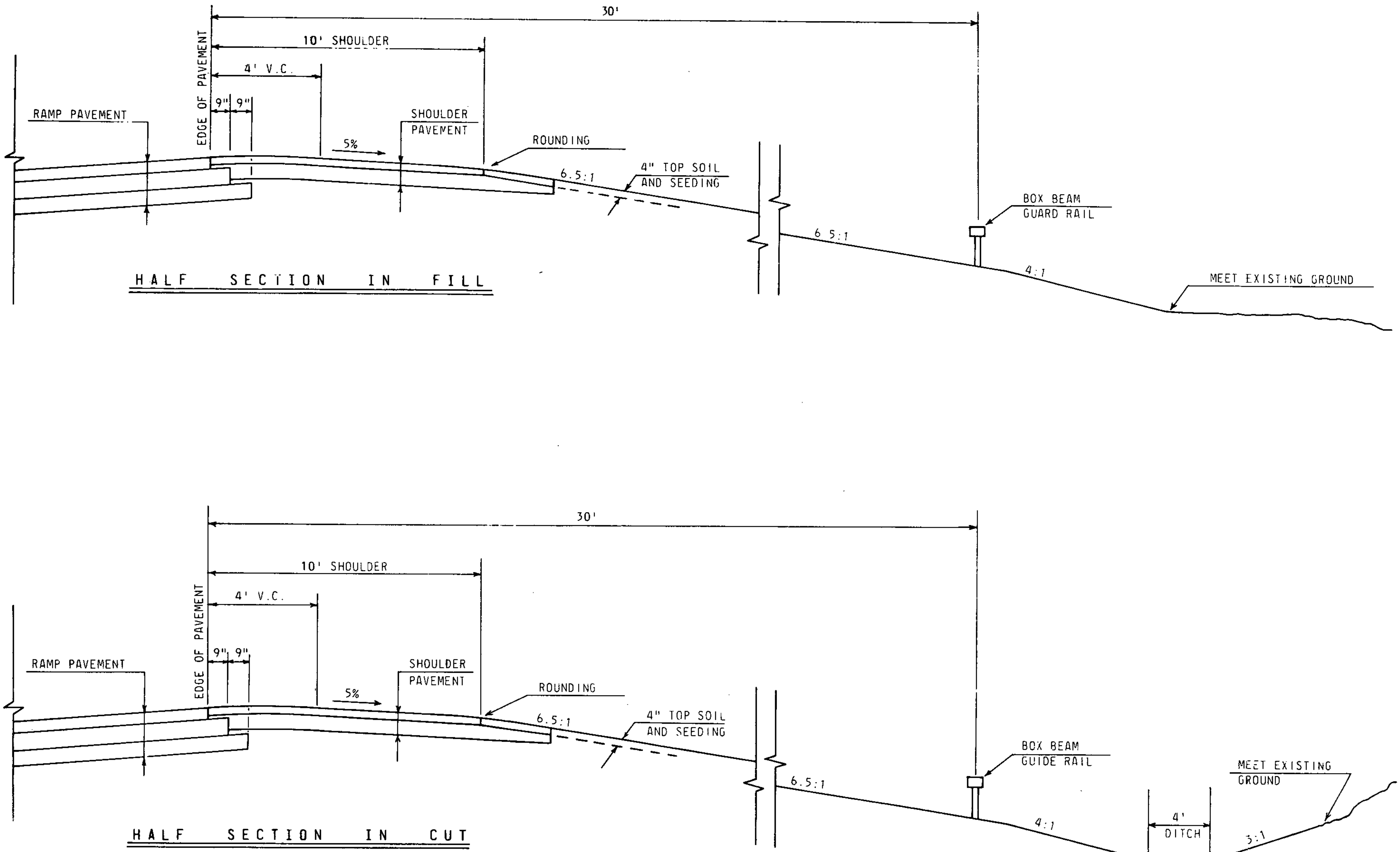


Figure 15. Typical sections incorporating desirable snow and ice control features.

provision of sufficient, well-drained snow storage areas to accommodate normal accumulation so that no snow need be hauled either within or from the interchange would simplify the snow removal problem. This is a challenge to the design engineer, particularly in urban areas where land is at a premium and tight interchanges are necessary.

To eliminate surface runoff across the pavement, the median should be depressed, with either inlets or drain lines to catch and transport drainage. In some mountainous areas with heavy snowfall, 180-ft-wide medians are used to provide for snow cast and storage.

STRUCTURES

Bridge decks present the problems encountered on roadway pavements as well as additional problems. Drainage, snow storage, and drifting may be difficult to control because of the unique geometric configuration. Icing also can be a significant problem and must be considered when weepholes or spouts might discharge water over a traveled way.

When one is laying out an interchange where cost is not appreciably affected by the choice of which road goes over the other, AASHO suggests that the road having the greater volume of traffic be designed to go over the other because of the possibility of drifting snow on the lower road. The bridge going over will generally be less subject to drifting, depending on wind velocity and direction. However, melting will occur sooner on the upper roadway, but with the added complication that the temperature of the upper roadway will drop faster than that of the lower pavement, which may cause icing. Portions of the lower road will be in shade and also subject to icing.

Bridge parapets, guardrails, and light standards may act as snow fences to reduce wind velocity and cause snow drifting. On bridges over roadways, parapets and curbs should be designed to prevent plowed snow from being cast onto underlying roadways.

Bridges with open guardrail or parapet designs should be considered over rivers in order to facilitate snow casting and to eliminate windrows on the deck. Guardrails of low-profile aerodynamic design that present limited obstruction should be used where practical.

Bridge deck widths should be designed with snow storage requirements considered. The 1968 AASHO *Highway Design and Operational Practices Related to Highway Safety* requires full shoulders on the entire length of bridges 250 ft or less in length. This will help accommodate plowed snow and reduce the amount cast over the railing to the underlying roadway. On bridges over rivers or open lands, open grate shoulder sections may be appropriate to reduce windrows and cross-pavement drainage of stored snow.

APPURTENANCES AND VEGETATION

Among the items included under appurtenances are curbs, guardrails, light standards, signs, delineators, buttons, and right-of-way fences. These items may be barriers or obstacles to plowing, may cause drifting on the pavement, or may cause damage to the plow blade or vice versa.

Curbs, Guardrails, and Signs

Curbs are undesirable and should be used only when absolutely required for drainage, visibility, or safety. Median and shoulder curbs present a hazard to plowing; they are inconspicuous after a light snow, and after a heavy snow they make plowing more difficult. Conventional plow blades may damage both asphalt and concrete curbs. Pavement edge delineators and center-line buttons also create obstructions to plowing, and alternative methods of delineation are needed.

Guardrails, light standards, signs, and right-of-way fences act to reduce wind velocity and cause snow deposits and drifting. Guardrail and right-of-way fence may be modified to a more streamlined, low-profile design. Use of flatter side slopes that will allow guardrails to be located further from the pavement edge (or eliminate the requirement altogether) and keep snowdrifts off the traveled roadway should be considered.

Landscaping

Properly located shrubs or trees can help to control snow drifting on a new or existing interchange. The use of plant materials where practical can be a long-term replacement for costly erecting and taking down of snow fences.

Trees or shrubs may be used to outline ramp approach noses and other geometric features or obstructions (curbs, for example) that would be obscured by normal snows. The color contrast between the snow and evergreens may help to guide drivers through the interchange. Trees or shrubs should not be of a type that would cause vehicle damage on impact, nor should they be located so as to obscure signs or reduce sight distance.

Vegetation with dense foliage should not be located to cast shadows on the pavement that would reduce melting or cause freezing of melt water. Plantings should be far enough away from the pavement edge not to restrict snow cast, create windrows, or present a safety hazard.

The effect that snow removal chemicals have on roadside trees and shrubs must be considered during interchange landscape design. Melt water with high concentrations of sodium chloride or calcium chloride may severely damage or kill vegetation. Provision for drainage of the melt water away from the plants is the best solution to this problem. In addition, shrub or tree varieties that are brine-resistant should be selected. (See *NCHRP Report 91*, 1970.)

CROSSOVERS

An economic warrant exists for constructing crossovers where the cost of equipment deadheading over the life of the interchange is greater than the cost of providing a crossover. Overriding safety considerations may exist, however, that preempt economic warrants and eliminate crossover consideration except where grade separation is possible.

The New Jersey Turnpike Authority, taking advantage of existing crossroad underpasses, has built small, inconspicuous ramps leading down off the main-line pavement to narrow maintenance roadways parallel to the public crossroad (Fig. 16). This permits maintenance equipment to pass under the main line. Fences are erected through the underpass adjacent to the bridge abutment between the maintenance roadway and the crossroad to prevent unauthorized access of crossroad traffic to the Turnpike.

On that portion of the New Jersey Turnpike that is being widened by the construction of generally parallel new roadways, both private underpass and overpass structures for equipment turnarounds are included as part of the construction package.

The Connecticut State Highway Department on the Connecticut Turnpike has constructed special ramps to local road overpasses for maintenance purposes to create a partial interchange between main interchanges and reduce plow and other maintenance vehicle deadhead time. Because Connecticut uses the barrier toll collection system, these local interchanges are also available to Turnpike patrons as well as to the state highway maintenance equipment.

Several solutions to the crossover problem are shown in Figure 17. The economics of providing crossovers versus the benefits to be derived in maintenance operations is explained and examples are provided in Appendix F.

DRAINAGE

Drainage across ramp pavements, whether from superelevated shoulders, gore areas, or narrow medians, can present a serious safety hazard to traffic during periods of below-freezing temperatures.

Drains should be designed and located so that no obstruction to plowing is created. When located in the traveled way, the drain should be flush with the pavement so that the plow blade will ride over it and clean frozen snow, ice, or debris from the grate. Also, curb drains positioned flush with the curb face will be cleaned by the plows, whereas recessed or indented drains may require special hand cleaning after plowing. In the design of the grate, consideration should be given to the need for elevating the grate to pavement grade after future resurfacing operations.

When the gore is used for snow storage, the snow melt may refreeze and cause ice formation in the drainage path. The main-line and ramp grades may cause the gore area to drain toward the point or nose, then over the pavement. If the gore cannot be reverse-graded to drain away from the pavements, an inlet and drain pipe should be considered for this area.

When one is determining pipe sizes for highway drainage, consideration should be given to maintaining flow during periods of snow, ice, and freezing weather. When the pipe is open at the lower end there is a flow of cold air down the pipe that may freeze some of the melt water in the pipe, gradually building up an ice deposit. For this reason, a larger pipe may be warranted so that the capacity of the pipe may outlast the cold wave. In many cases, a smaller inlet and pipe can be used if the pipe discharges into a closed drainage system below the frost line.

The critical drainage factor for snow storage areas may be the water equivalent of accumulated snowfall. If heavy snow accumulates as a result of frequent storms, repeated plowing, and prolonged below-freezing temperatures, a warm period may produce fast melt and high runoff.

Classic drainage design practice, however, has been based on rainfall runoff. In small areas such as gores and raised medians the rainfall runoff is usually of such small consequence that it is permitted to flow across the pavement. Awareness, after the fact, that these areas are prime snow storage locations and that snowmelt runoff is critical because it is subject to refreezing has led to installation of drains and catch basins.

When one is designing or specifying pipe sizes, the critical design factor should be based on water from snowmelt, or rainfall, or a combination of both. There is a snow condition where the snowmelt may become critical. This occurs when 6 to 12 in., for example, of high-density snow on the ground and a heavy rainstorm during a January or early spring thaw combine to exceed the "rainfall only" design capacity factor. However, data developed in Appendix H show that snowmelt alone, under normal conditions, will not exceed rainfall runoff and thus will not be the critical design factor from a capacity viewpoint. The

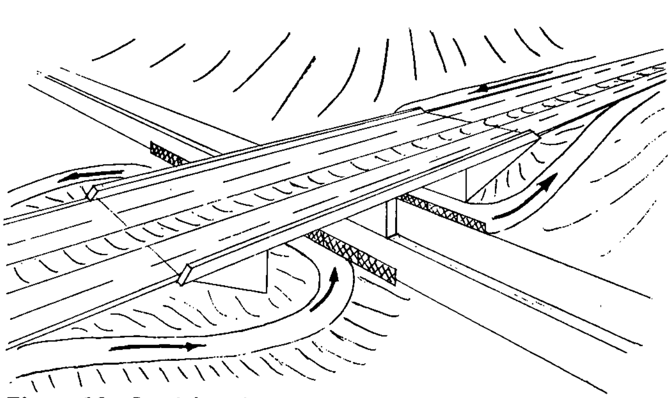


Figure 16. Special maintenance ramps on New Jersey Turnpike using existing underpass.

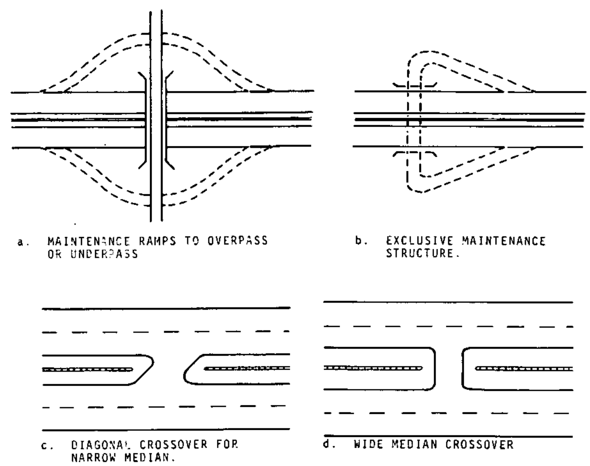


Figure 17. Special ramps and crossovers serving maintenance vehicles.

interception of surface water from snowmelt may dictate the need for drainage, however, where capacity requirements would not.

EQUIPMENT AND MATERIAL STORAGE

Proper consideration of the entire program of snow removal and ice control at interchanges during the design phase will assist the removal effort through reduced maintenance expenditure and increased user and crew safety and operational efficiency. The location of maintenance yards and auxiliary equipment and materials storage areas should be considered as a part of this design effort. In some instances, maintenance facilities and yards may be included within the interchange itself. Of primary concern, however, will be the traffic patterns and conflicts that may be generated by the presence of the maintenance yard. Aesthetic considerations also may override convenience when one is locating yards.

NON-CHEMICAL MELTING DEVICES

A number of agencies are experimenting with or testing thermal methods of melting snow in critical areas. The Indiana Toll Road Commission installed pavement heating devices in toll plazas. Embedded heating pipes in ramps were used on the John F. Fitzgerald Expressway in Boston. Toronto, Canada, and the New Jersey State Highway Department have tested embedded electric heating cables in pavements.

The U.S. Army Cold Regions Research and Engineering Laboratory is studying methods for applying electromagnetic energy to break the ice-pavement bond, and also for applying electric currents to a thin conductive asphalt overlay.

The high cost of installation, operation, and maintenance generally precludes the use of non-chemical methods of snow removal. Only where cheap electric power, hot liquids, or steam are available may this approach to snow removal prove economically feasible. None of the non-chemical techniques has yet been perfected.

CHAPTER FOUR

APPLICATION OF FINDINGS—OPERATIONAL PLANS FOR INTERCHANGE SNOW AND ICE CONTROL

There are several significant elements that a maintenance engineer should consider in developing operational plans for snow removal and ice control at interchanges. These elements and proposed analytical procedures are outlined in this chapter.

As a basis for planning, details of the physical layout and geometry of the interchange are needed. The information should include: (1) type of interchange (i.e., directional, non-directional, trumpet, Y, T, diamond, or cloverleaf); (2) lane-miles for each ramp; (3) location and type of turnarounds; (4) distance to turnaround or next interchange; (5) ramp geometrics, such as curve radii and cross section; (6) location of drainage facilities and snow storage areas; and (7) types of feeder roads and streets.

To determine the expected magnitude of the snow and ice control problem, information on the environment, weather, and traffic is needed. Information on snowfall intensity, accumulation, water equivalent, and wind in the vicinity of the interchange should be known.

Average daily traffic for the main line and interchange ramps, hourly variations in the traffic, and vehicle classifications are additional, significant variables that must be determined prior to interchange snow removal planning.

ORGANIZATION AND TRAINING

Snow removal is in the nature of an emergency operation; therefore, its efficiency is strongly affected by organization and training factors. The two problems most frequently encountered are determining the most efficient mix of men and equipment for snow removal operations and the development of adequate training programs for snow removal crews.

Some of the specific organization and training elements that affect the efficiency of snow removal in interchanges include: the preassignment of specific areas of responsibility for each individual; the training and familiarity of equipment operators and foremen with their equipment and their assignments; the provision of adequate radio communications for all elements of snow removal organization; the prearrangement for supplemental assistance for major storms that tax the capability of the section foreman, crew, and equipment; and the scheduling of a staff and crew rotation system for storms of long duration. Most organizations provide periodic training programs to develop individual operator skills, crew coordination and cooperation, and assignment responsibilities.

Just as the organization, training, and degree of experience of the crew affect snow removal so do the operational plans. Most organizations plan snow removal and ice control procedures in minute detail from weather reporting, alerting, and assignment of crews and equipment, to final cleanup. Private weather services are frequently used for forecasting storms. Because many storms begin early in the evening or early in the morning rather than during a normal workday, plans for calling out off-duty crew members are important and detailed. Plans usually permit from 1 to 2 hr to get complete crews on the highway after the alert is given. In most plans crew members are assigned to specific units of equipment and specific sections of interchanges and/or main line.

Some organizations provide separate crews for each interchange. Others incorporate interchanges in the workload of the main-line crews. The number, size, and type of plows, the employment of blowers or rotaries, the number of chemical spreading units, and the operators assigned are determined in advance. Routes to be traveled in covering assignments and in returning to material yards for refilling or refueling are all detailed before the snow season. Application rates for chemicals are spelled out in detail and usually are based on the type of storm and the direction of temperature change. Training in equipment operation and practice runs over assigned zones are conducted in the fall by many snow and ice control agencies.

One organizational technique used to overcome snow removal problems at interchanges is that employed by the New Jersey Turnpike Authority. On the Turnpike, a heavily traveled urban thoroughfare, snow removal on interchanges is considered a more critical problem than on the main line. Therefore, the less complex plowing and spreading operation on the main line is performed by contractors, whereas the responsibility for snow and ice removal at interchanges is assigned to in-house personnel who are more familiar with the area, who are better indoctrinated and trained, and from whom a more reliable performance can be expected.

One agency has adopted what it has termed the team concept during snow removal operations. It emphasizes the clear-cut, separate but cooperative responsibility of three elements: the police, who have the responsibility to direct and control traffic; maintenance personnel, who are primarily responsible for removing snow and ice; and service contract personnel, who provide towing, repair, and other services to stalled motorists. Each element is aware of the other's tasks. Adequate communications between elements are available and are considered most important.

The George Washington Bridge section of the Port of New York Authority retains one team in reserve for rescue purposes. Should one of the crews become stalled in traffic or snow, the reserve team is dispatched to clear the trouble and free the original team.

OPERATING PROCEDURES IN INTERCHANGES

Currently, the most prevalent method of snow removal in urban interchanges is to employ chemicals in dry or liquid form at the outset of a storm to prevent adhesion of snow and ice to pavements and then to employ plows to remove the added snow accumulation and slush caused by the chemicals.

Some jurisdictions plow and spread chemicals simultaneously. Some organizations ride the plow on the pavement and others raise the plow blade from ¼ in. to 1 in., riding it on shoes or casters. Raising the blade slightly greatly reduces blade wear and permits a thin film of brine, which will melt additional snowfall, to remain on the pavement.

Plowing

A plowing technique frequently employed in mountainous areas, and in particular the California Sierras, includes the use of "chain patrols." Because of the intensity and depth of snowfall occurring at higher elevations, during major storms no attempt is made to provide bare pavements. Instead, snowplows (usually rotaries and blowers) are used to keep the roadway and ramps open but not to remove the 2- to 3-in. snowpack on the surface. During such periods, traffic is intercepted by "chain patrol" crew members at predetermined points in lower elevation sections of approach routes where vehicles are not permitted to proceed without tire chains mounted on drive wheels. At the conclusion of the storm, chemicals and blade plows or motor graders are used to remove the snowpack, after which tire chain requirements are lifted. Essentially, the same basic snow removal program, without the mandatory use of the chains by highway users, is employed by many agencies throughout the snow belt for rural and low-traffic interchanges.

Maintaining adequate plow speeds is an operational necessity. There must be sufficient speed to cast the snow clear of the pavement and shoulders. Also, the plow must maintain the same speed as traffic to prevent slowdown and snarls. The latter is obviously much more important in metropolitan than in rural areas, particularly during rush-hour traffic. On some interchanges with long, steep ramps, plows may be slowed by heavy trucks or traffic congestion.

Parked or stalled vehicles interrupt plowing continuity by forcing the plows to deviate from the normal pattern or may halt the plow completely until the stalled vehicle is moved. The latter is a particular hazard on steep interchange ramps.

On one heavily traveled highway, parking areas near interchanges, to which stalled and abandoned vehicles may be hauled by service trucks, have high priority for early clearing. With these parking areas available there is no problem of prolonged blocking of the traveled way by abandoned vehicles.

When the same snow removal equipment is used on the main line and the interchange, the general practice is to have the plows proceed down the main line in echelon. On approaching the interchange the right plow veers away and cleans the right ramp or ramps and rejoins the team. This plow may require a crossover on the connecting roadway to accomplish this maneuver. If the interchange is of cloverleaf design another plow in the echelon formation may plow the four-loop ramps and rejoin the team.

So that snow storage will be provided for the next storm, storage areas adjacent to the pavement should be considered temporary and the snow further removed once a storm is over and men and equipment are available. One removal method is to load and haul the snow to a dumping area. Another is to cast the snow further back using rotaries or snow blowers. Both operations are shown in Figure 18. The latter finds application in rural areas and particularly in terrain where there are disposal areas away from the right-of-way. Regardless of the method used, the double handling of snow is time-consuming and costly.

An economic analysis can be made for each problem area to determine which technique for snow disposal is the most efficient for the interchange under study.

Special delineators may be located along the traveled way to indicate to the plow operator where snow cast should be reduced or controlled. On structures, temporary baffles are sometimes installed along bridge rails to prevent windrowed snow from being cast onto the roadway below. These baffles should be used cautiously or they may cause a snow drifting problem.

To warn plow operators of obstructions, special marking devices may be used, such as colored delineators or identifying panels on the sides of the roadway. Different codes may be used to indicate to the operator to change speed, raise or lower the plow blade, or to perform some other maneuver. Flexible plow blades and trip release mechanisms are being used that yield to obstructions without damage to the appurtenance or to the equipment.

Operational techniques for alleviating wind obstructions and drifting are the prompt removal of snow windrows adjacent to the pavement; the strategic placement of snow fence or landscape plantings to control drifting; and the careful maintenance of roadside vegetation, particularly location of plants and height of cuts.

When storage room is available, windrows or snowdrifts are bladed down side slopes usually with wing plows, as shown in Figure 19. Where adequate storage areas exist within the interchange but where plows may be prevented from pushing the snow, blowers may be used to cast windrowed snow into a storage area.

There is apparently no best method for removing the windrow across the entrance and exits to ramps. Current alternatives are: (1) to leave the cleanup for succeeding rounds of the plows, which allows the hazard to remain for an extended period; (2) to route one of the main-line plows through the interchange for cleanup—an efficient practice in most instances; or (3) to assign a separate piece of equipment to the interchange, which is economical only at busy major interchanges and where equipment turnarounds are available.

Techniques for reducing the windrow across ramp openings include use of operator-controlled end gates on the plows and rotation of the plow blade to a doze position while passing the ramp opening.

To ensure that all elements of the interchange are covered, a detailed analysis must be made to determine the most economic routing. A common practice is to assign ramps to special interchange crews, while the through lanes are the responsibility of a main-line crew. It may be necessary to provide a crossover on each leg of the interchange if deadheading is to be kept to a minimum. Figure 20 shows the use of these techniques on cloverleaf interchanges in Illinois.

Where interchanges are closely spaced, particularly in urban areas, it is a general practice to assign more than one interchange to a crew. One organization attempts to average the ramp mileage assignments at about five miles for each equipment unit.

In those locations where maintenance yards are situated away from the interchange, current techniques for reducing deadheading include the use of special "traveling" mechanics and repair trucks for field servicing of equipment, and the use of straight chemical snow-melting materials to extend the coverage capacity per truckload.

Most jurisdictions that permit median crossings require elaborate precautions of their equipment operators who use them. A typical procedure is that of the New York State Thruway which requires that a vehicle using a crossover pull off the highway on the right shoulder, stop, and wait until traffic is clear before proceeding to the median, where it must stop before making a left turn onto the other directional roadway.

Chemical Spreading

The spreading rate of chemicals and abrasives varies by jurisdiction and within jurisdiction by climate and local experience. The mixtures of various chemicals and abrasives also vary considerably from organization to organization.

One agency whose jurisdiction includes a complicated urban interchange ramp system provides that in snowstorms crews dump salt in heavy layers across ramp entrances rather than travel down the ramp with normal spreading equipment. The vehicle tires of the heavy traffic then track and distribute the salt over the length of the ramp pavement. Distribution is aided by gravity and brine flow on down-ramps. Salting crews are released to other problems and are not so likely to become tied up in busy urban streets at the end of the ramps.

Chemicals should be spread on the high side of superelevated ramps so that the brine will flow down and across the pavement.

CRITICAL INTERCHANGE IDENTIFICATION

Three major variables must be quantified in order to conduct a meaningful economic evaluation of snow removal operations in interchanges; i.e., (1) daily vehicle-miles of service rendered; (2) vehicle delay; and (3) maintenance operations cost.

Vehicle-Miles of Service

When one is developing snow removal operational plans, consideration must be given to the amount of traffic served. Major arteries, Interstate routes, and other highways with a high number of vehicle-miles of travel will generally be of top plowing priority. Interchange ramps with high traffic volumes that serve these major routes will also have high priority. Thus, the need to plow is based on traffic demand, and the maximum benefits of snow removal operations will be enjoyed by the highway user. Road-user cost alone will permit a reasonable basis for evaluating the benefits of snow and ice control programs.

BLOWER LOADING SNOW FOR REMOVAL FROM TEMPORARY STORAGE

BLOWER CASTING SNOW FURTHER BACK.

Figure 18. Snow blower operations.

Emergency and Service Vehicles

The importance of the operation of such vehicles as ambulances, fire-fighting equipment, and school buses could in some instances be the primary basis for determining the criticality of snow and ice control operations at an interchange. The location of a hospital near an interchange is an example of this type of consideration. Costs or losses incurred as the result of delays in the operation of vehicles of this type are difficult to determine and, except for special instances, are not likely to be a major economic consideration.

Daily vehicle-miles of service is the product of ADT times ramp mileage. No distinction is made between trip types, trip mileage, etc., because the needed data are the over-all number of vehicles operating in the ramp area that will be delayed by adverse conditions of snow and ice.

Vehicle Delay

To compare the economics of alternative plans during snow and ice conditions, data must include the total delay encountered by each vehicle during the trip through the interchange. The cost of such delay will be a function of vehicle-user cost which, in turn, consists of vehicle operating costs, time costs, and comfort and convenience costs.

Vehicle operating costs decrease with running speed (assuming vehicles slow down only without complete stops). Time costs increase with running speed. The cost of comfort and convenience is constant for given "levels of operation" as defined by AASHO. When operating costs are assumed constant, any figure for the difference in user costs as a result of reduced operating speed will be exaggerated. For the purpose of demonstration, therefore, vehicle operating costs are neglected in the analysis.

Figure 19. Wing plow clearing snowdrifts from shoulder.

Comfort and convenience may also be neglected because all operations will be assumed to be under snow and ice conditions (i.e., a "restricted operation" level).

Vehicle-user costs in the ramp area then become a function of time only, and time on the ramp is directly related to vehicle speed and ramp length.

In this project, data on the amount of delay time experienced by the motorist under snow and ice conditions were developed (Appendix E). General relationships presented in the 1965 American Public Works Association (APWA) report, *Snow Removal and Ice Control in Urban Areas,* were used to develop curves indicating the percentage of vehicle average over-all speed likely to be maintained on the interchange ramp under various snowstorm conditions. This speed is termed the snowstorm speed factor. As Figure 21 shows, the longer the storm duration and the more intense the storm, the slower will be the average vehicle speed.

Plowing, which occurs at various intervals throughout the storm, will help to restore vehicle speeds. If the storm continues, however, vehicle speeds will be restored to only 80 percent (snowstorm speed factor of 0.8) of normal because of reduced sight distance, slippery conditions, etc.

If a storm of 2 in. per hour were encountered with a plowing frequency or maintenance cycle of 2 hr, the snowstorm speed factor curve would appear as shown in Figure 22.

Knowing the vehicle speeds under various environmental and operational conditions allows determination of the capacity of a ramp to handle traffic under snow conditions. This traffic capacity may be compared with the ramp design capacity to establish whether a problem will occur (i.e., whether a "critical" interchange exists in terms of snow removal). Conversely, the analysis may be used to determine the frequency of plowing necessary to avoid a problem.

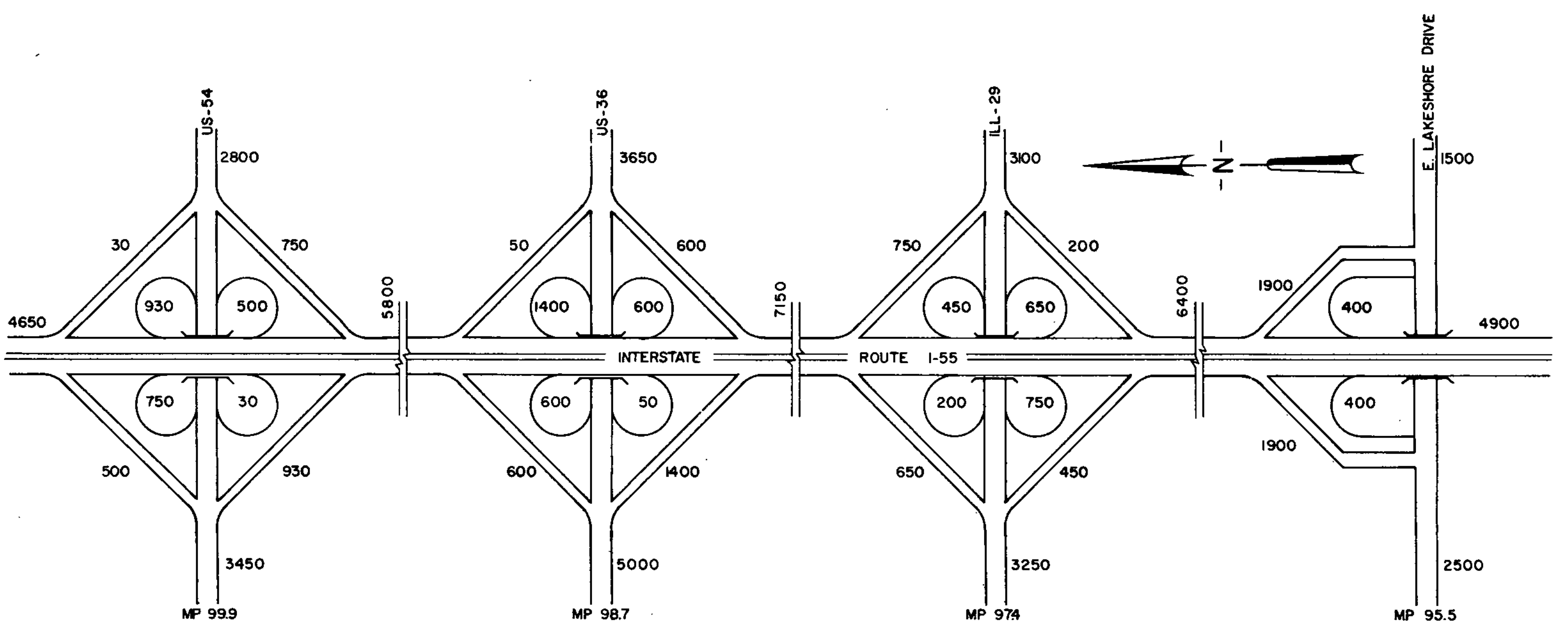
For example, if the normal ramp operating speed is 50 mph and a snowstorm speed factor of 0.60 or 60 percent of the normal operating speed is indicated, the snowstorm operating speed will be 30 mph. This is equivalent to a delay per vehicle per mile of ramp of 0.80 min.

Stanford Research Institute data indicate that cost of time is a function of family income and amount of time saved, or, conversely, the delay time. To generate the total delay cost per vehicle per mile at ramps it is necessary to multiply the delay time by the cost of time. Multiplying again by the vehicle mile total gives the total daily cost of delay for a given ramp.

For example, if the delay time is 0.80 min per vehicle per mile and time cost is $2.56 per vehicle per hour, the delay cost is approximately $0.035 per vehicle per mile. For a one-mile ramp and an ADT of 6,000 (i.e., 6,000 vehicle-miles) the total cost of delay is 6,000 × $0.035, or $210 per day.

Maintenance Cost

The third variable contained in an economic analysis is the maintenance operations cost. This cost must include all maintenance funds expended for snow and ice control activities for the time period in question, including wages,



NOTES
- TRUCK ONE IS RESPONSIBLE FOR THE TWO NORTHERN INTERCHANGES, TO INCLUDE TWO REST AREAS - 3.8 & 2.2 MILES NORTH OF US-54, I-55 CLOVERLEAF -
- TRUCK TWO PLOWS THE TWO SOUTHERN INTERCHANGES PLUS THE CLOVERLEAF PORTION OF THE US-36, I-55 INTERCHANGE
- MAINLINE CLEARING IS HANDLED BY OTHER UNITS
- MAINTENANCE YARD IS LOCATED 1.1 MILES SOUTHWEST OF THE US-36, I-55 INTERCHANGE
- NUMBERS SHOWN REPRESENT AVERAGE DAILY TRAFFIC
- CROSSOVERS EXIST HALFWAY BETWEEN INTERCHANGES

	DEADHEAD MILES	PRODUCTION MILES	TOTAL
TRUCK 1	13.4	11.9	25.3
TRUCK 2	10.3	5.0	15.3
TOTAL	23.7	16.9	40.6

SPRINGFIELD
(ILLINOIS)

Figure 20. Interchange on I-55, Springfield, Ill.

salaries, equipment, and materials. These costs are generally available on an annual and monthly basis.

When one is evaluating snow removal operations, it is necessary to define the objectives or order of priorities that are to be accomplished. The overriding objective is to clear the snow from the pavement as quickly as possible. There are, however, several restraints that guide and limit the operations. These are: (1) user safety; (2) crew safety; and (3) protection of structural integrity.

Each of these may be thought of as secondary objectives during snow removal. Each may not be maximized, however, and an order of priority must be established. For example, the use of chemicals to intensify snow melting on bridge decks increases user and crew safety. The resulting brine, however, has a deteriorating effect on the concrete deck and other structural components.

Meaningful economic data may be difficult to obtain. For example, it would be difficult to isolate the cost of bridge deck deterioration caused by chemical solutions from the total cost of deterioration by all causes.

When operational alternatives are evaluated, the relative total benefit from each must be considered.

Several areas in which benefits may be realized include:

1. Increased safety and convenience for drivers and maintenance personnel.
2. Reduced driver delay time.
3. Reduced expenditures for maintenance activities.

User-Crew Safety

Although it may be feasible to apply costs to highway accidents and fatalities, the safety and economic benefits from a particular change in the operational plan may be increased by providing bare pavement as soon as practical, by eliminating cross-pavement drainage, by clearing signs and delineators of snow, or by a number of other similar procedures.

Many of the safety benefits to be derived by the highway users may also be enjoyed by the maintenance crews when they are performing their operations. However, many operations are performed at some risk. For example, the use of median crossovers by crews is especially dangerous and should be restricted to low-volume highways. De-

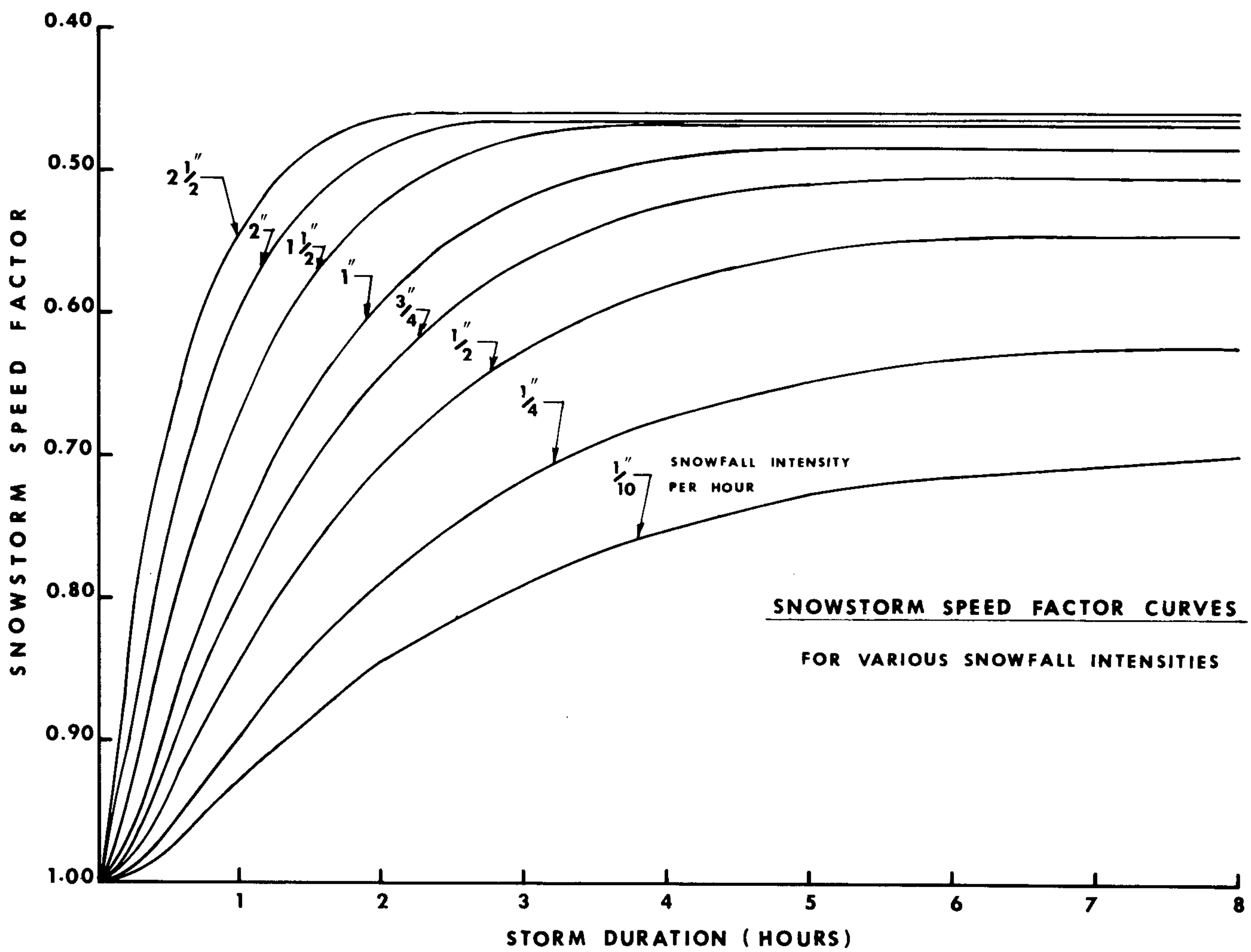


Figure 21. Snowstorm speed factor curves.

lineators, curbs, bridge parapets, and other physical features that tend to become obscured under snow cover are a hazard to plow operators. Accidents have occurred in which a driver has been thrown into the vehicle windshield when the plow blade struck a snow-covered obstacle.

Protection of Structural Integrity

Consideration must be given to protecting the investment that has been made in the highway facility. The structural integrity of the pavement or structure should be preserved to whatever degree is economically justified. Therefore, when one is evaluating operational alternatives, the degree to which the operations will affect the structural integrity must be analyzed. The previously cited example of the effect of chemical solutions on concrete deterioration is a case in point. In addition, plow blades are known to cause wear on pavement striping, and damage to curbs, delineators, and other appurtenances.

EQUIPMENT

In those highway maintenance organizations that do not maintain separate crews for snow and ice control at interchanges, equipment used must be the same as is used on the main line. However, where separate crews serve the interchange, there may be a warrant for providing special equipment to meet the peculiar needs of the interchange.

Special interchange equipment should have the following characteristics:

1. It should be compact and maneuverable to meet the demands of the interchange geometry and traffic.
2. It should be sufficient in number and material capacity to fully treat the ramps within the interchange one time without reloading.
3. Plows should be capable of clearing a 9-ft-wide swath in a single pass.
4. Plow blades should be reversible from the cab in order to plow snow to the low side of superelevated ramps and to the most suitable snow storage areas.

Many interchanges require the loading and hauling of snow from structures and, to a lesser extent, from limited-capacity snow storage areas such as gores and medians. A versatile and maneuverable piece of equipment to load snow into trucks is the rubber-wheeled, articulated front-

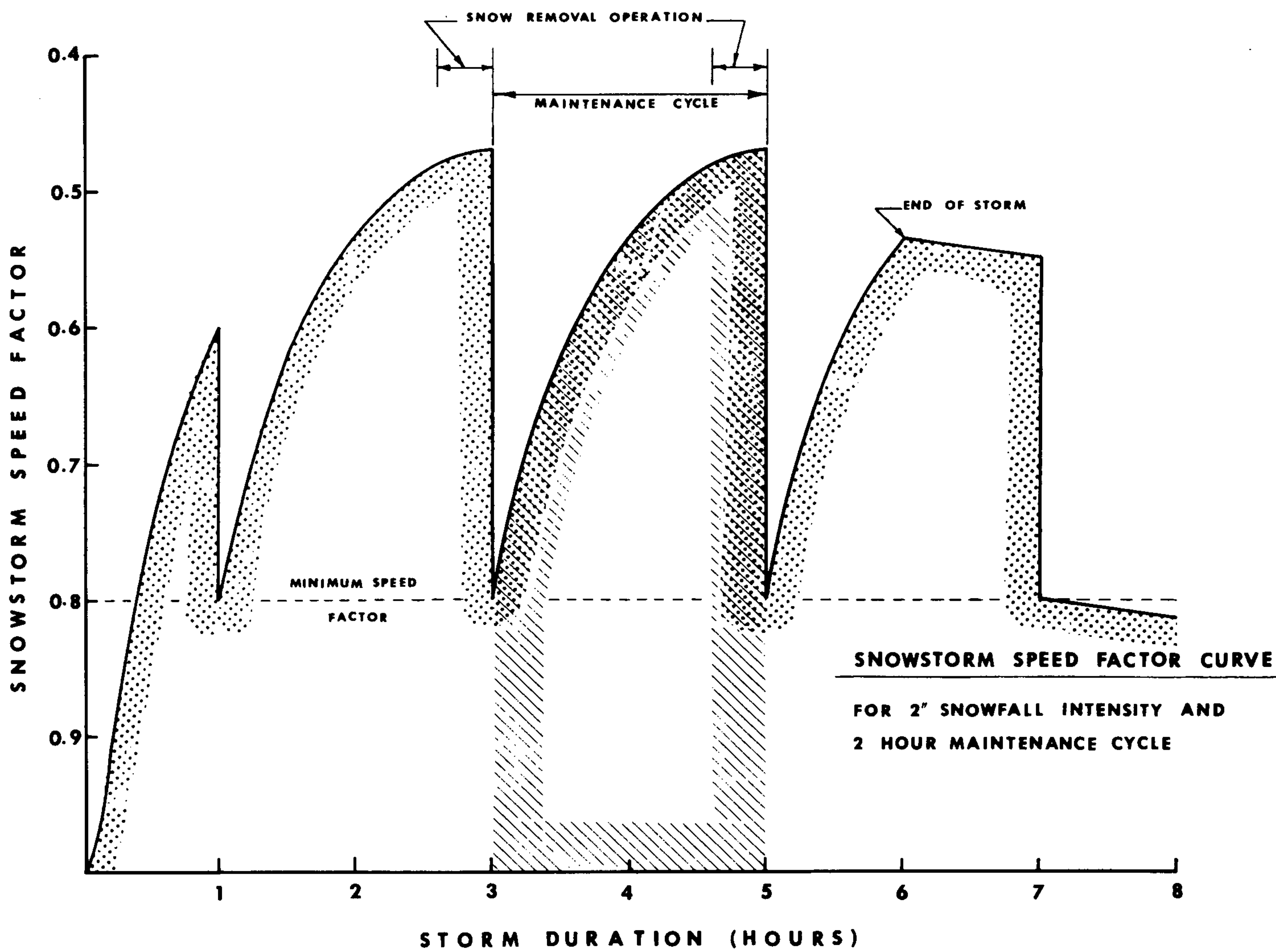


Figure 22. Snowstorm speed factor curve.

end loader. A high-capacity basket-type bucket is being marketed for snow loading.

Current and proposed changes and modifications to equipment and materials that may improve snow and ice control at interchanges are outlined in the following.

Wearing Edges and Blades for Snowplows

During the last few years, in addition to the normal mild carbon steel blades, tungsten carbide blades, carbide inserts, rubber blades, and plastic blades have found their way into the market. A number of agencies have tried and tested these blades and formed conclusions on their worth. However, no nationally recognized testing and evaluation program has been reported to give authoritative guidance in the evaluation and selection of the various types of blades.

In general, it appears that where bare pavement policy is in effect and when it is policy to ride the plow blade on the surface, carbide blades are more economical than mild carbon steel blades. Although the initial cost is higher, some agencies have reported that tungsten carbide blades have outperformed and outlasted the mild steel blades in a greater ratio than initial costs. In addition, downtime for changing blades is, of course, reduced considerably.

Reaction to rubber and plastic blades has varied a great deal. Where such blades are used properly and mounted at the proper angle, some maintenance engineers believe that they serve a purpose when snow is wet and slushy. The squeegee action may push the slush to the side more readily than a steel blade, and a cleaner pavement results. Airport maintenance engineers particularly seem to like the rubber blade. Generally, it has been reported that rubber blades wear well, probably better than mild carbon steel; however, they are reported to have little effect on compacted or hardened snow or ice.

Apparently there is mixed feeling about carbide tip inserts for blades. Some engineers have received good service from them, whereas others believe that they fracture too readily.

There has been some experimentation with serrated edges and tined edges on blades but no formal reports have been published on their performance.

Moldboard Coatings

Many foremen and equipment superintendents have used various types of waxes on the blades to prevent wet snow from sticking to snowplow moldboards. Other coatings, such as silicones and teflon, also have been used. However, so far as is known, none has been scientifically evaluated to determine which is best, and which technique is the best for applying these substances. Some equipment superintendents feel that a plain burnished moldboard is as efficient as those that are coated.

Plow Operating Features

It was the consensus of the maintenance engineers interviewed that the best type of plow for interchanges is one that is power-reversible from the cab and of sufficient size to cover one traffic lane. Such plows, of course, already exist on the market.

Some developmental work has been accomplished by a number of manufacturers in designing and fabricating an hydraulically actuated end gate for plows. When a ramp opening is reached the end gate can be dropped by cab controls to retain the snow on the blade until the ramp opening is passed. To date, the testing and evaluation of this device have been inconclusive because of mechanical difficulties and because the tested units had insufficient capacity when plowing wide exits and entrances.

Some maintenance engineers, particularly those that have interchanges with high ADT's under their jurisdiction, believe that there is a warrant for a special piece of snow removal equipment designed just for interchanges. They suggest that it should be highly maneuverable, probably with articulated steering, of sufficient weight to maintain the necessary traction, capable of spreading chemicals, plowing, and loading snow.

The Port of New York Authority in its shops has developed a self-engaging plow hitch that requires an individual outside the cab only to guide the plow truck operator to the correct position and alignment with the detached plow.

Spreader Features

An item that maintenance engineers believe applicable to interchange as well as main-line chemical treatment is a mechanical or electronic interlock between vehicle wheels or drive shaft and the chemical feeder control so that an even rate of spread of chemicals may be obtained in spite of varying vehicle speeds. Such devices are already on the market at a price. This study did not weigh the relative merits of this particular control device.

The Ohio Turnpike has developed a simple control device to be attached to spinner-type spreaders. A three-position lever directs the flow of chemicals onto the spinner so that the spread pattern may be centered to the right or left of the vehicle, or directly behind the vehicle.

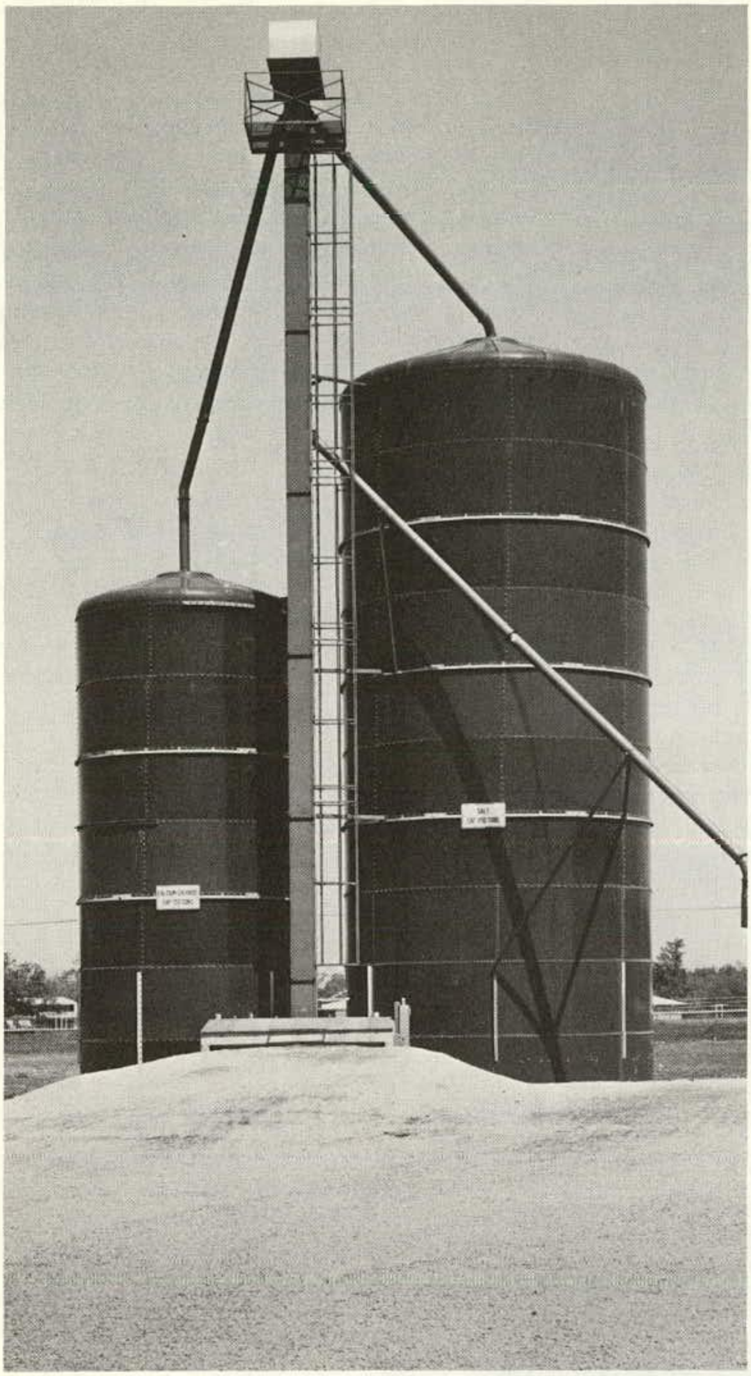
Michigan and other states have used a chute for discharging chemicals down a center-line windrow on highways with a crown of at least ½ in. per foot. Such distribution permits traffic to further spread the chemicals across both lanes, and as brine develops it flows across the pavement.

Windshield Wipers

Several problems exist with clearing snow from the plow vehicle windshield. Snow tends to freeze on the windshield glass and, in some cases, too much snow accumulates for the wiper to handle.

There are two items on the market that assist in overcoming this significant problem. One is a flexible rubber sleeve that fits over the normal windshield-wiper arms and prevents snow and ice from sticking to the arm by its flexing action.

A second device, developed in Europe and available in the U.S., consists of a rotating windshield section to clear snow by centrifugal force in lieu of the oscillating blade normally used.



CHEMICAL STORAGE SILOS FOR PROVIDING VARIABLE MIXES.

TANKER AND ELEVATED SALT HOPPER.

Figure 23. Material storage.

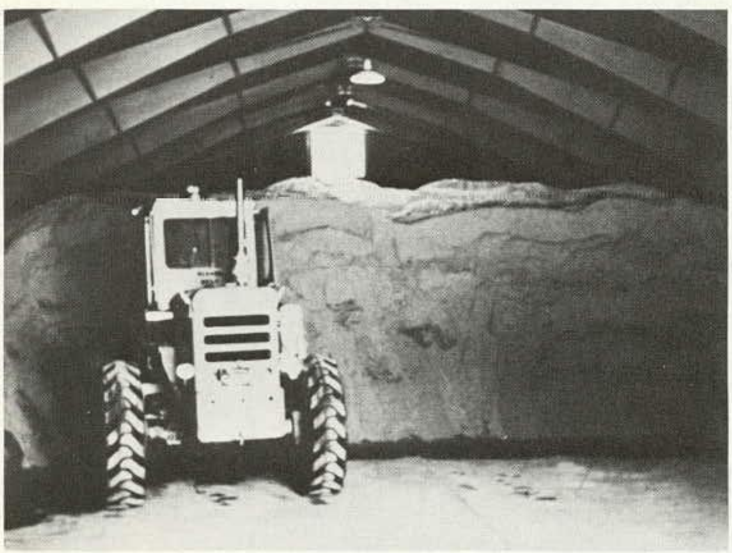
MATERIAL STORAGE

Storage and handling of the materials vary from the simplest stockpiles on bituminous pads to overhead silos with sophisticated mixing and blending chutes. Areas within interchanges may lend themselves to stockpile sites—for example, areas under large bridge structures that can be used for temporary storage of chemicals and abrasives during the snow season.

The industry is using a variety of storage devices for chemicals. They range from open storage with an assortment of plastic and tarpaulin covers through different types of ground bins to various types of elevated silos, some of which may be glass-lined. Figures 23 and 24 show several storage procedures and facilities.

Currently some agencies are erecting storage hoppers and silos. Some of the advantages are: protection of the chemicals from the weather; ease of filling by vacuum pumping from tank trucks; simplicity of loading the spreader trucks by gravity; the ease of mixing varying percentages of sodium chloride and calcium chloride; and the elimination of water supply pollution from stored materials. The principal disadvantage is the higher capital

MATERIAL STORAGE UNDER STRUCTURE



FRONT-END LOADER OPERATING IN GROUND LEVEL MATERIAL STORAGE BUILDING.

Figure 24. Material storage.

outlay. Consequently, a cost-benefit study is needed whenever hoppers or silos are considered.

A prefabricated, double-silo elevated storage unit with a mixing chute is currently available on the market. The percentage of salt to calcium chloride can be varied continuously from zero to 100 percent when loading chemicals on trucks.

Various material handling equipment is used such as front-end loaders, chain-bucket loaders, endless belts, and vacuum loaders and blowers.

CHAPTER FIVE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Numerous factors affect the efficiency of snow removal and ice control at highway interchanges. Many of these factors are inherent in the nature of interchanges, because such facilities normally include overpasses, bifurcations, curves, grades, embankments, and major signing, all within relatively limited land areas.

This study has clearly indicated, however, that few if any factors are unique to interchanges alone. Instead, snow and ice control problems in interchanges, although common to the over-all highway system, are concentrated and accentuated in the interchange area. The research also has shown that few agencies treat interchanges as distinct and separate facilities during snowstorms. Generally, they are incorporated in a system-wide plan so that equipment and crews are common to main-line and interchange ramps as the coverage of the system requires.

Thus, the solving of snow and ice control problems inherent in interchanges is best accomplished by careful development of design decisions and operational plans to reduce or eliminate the problems. Application of guidelines can be made by design engineers to evaluate the significance of interchange features in snow and ice control. Consideration then can be given to design factors such as appurtenances and slopes that reduce drifting, snowmelt drainage facilities, snow storage areas on structures and bifurcations, and other structural and geometric alternatives that accommodate efficient snow and ice control operations.

The practical economics of snow and ice control on a highway system usually preclude consideration of special and unique types of equipment, materials, or crews assigned exclusively and continuously to snow and ice control in interchange areas.

Maximum use can be made of those techniques that have produced the most efficient and successful over-all snow and ice removal program. Operations plans must give consideration to plowing and spreading procedures that will reduce or eliminate the formation of windrows across ramp openings, the minimizing of snowdrift formations, the elimination of snow melt flowing across pavements, and the prevention of other operational difficulties or failures.

A combined effort by design and maintenance disciplines can result in significant increases in efficiency, safety, and economy in the highway interchange winter maintenance program.

SUGGESTED RESEARCH

There are a number of potential improvements for snow removal and ice control beyond the scope of this study. In these areas, further basic knowledge still is needed.

Snow-Melting Materials

An abundance of information on the employment of chemicals for melting snow is available. The advantages and disadvantages, the qualities, and the characteristics of sodium chloride and calcium chloride are well documented. The techniques of applying these chemicals and abrasives are also available to maintenance engineers. In addition, most maintenance agencies have written standard operating procedures on chemical application. These procedures take into account such variables as application rates, speed, spread patterns, temperature, and types of precipitation.

Not so well known are the characteristics of chemicals such as urea, calcium formate, formamide, glycol, and alcohol which are used primarily on airfields where noncorrosive chemicals are required because of the damaging effect on engines and airframes. These costly chemicals have not found widespread use in the highway field. Additional research would appear to be warranted to develop improved production processes and reduced costs for these materials, or to produce completely new snow-melting chemicals. Such research, however, lies largely within the province of private industry.

Some research work already has been done to determine the nature of the deleterious effects of brines on concrete and vegetation. Three NCHRP reports (*NCHRP Report 1*, "Evaluation of Methods of Replacement of Deteriorated

Concrete in Structures"; *NCHRP Report 19*, "Economical and Effective Deicing Agents for Use on Highway Structures"; and *NCHRP Report 27*, "Physical Factors Influencing Resistance of Concrete to Deicing Agents") have been issued in this field. The American Public Works Association is sponsoring a study on the corrosive effects of salts on vehicles. Work continues to determine the processes that cause deterioration so that protective steps might be taken to overcome the causes of damage. Additional research is needed in developing protective systems or resistant types of highway vehicles, structures, and vegetation.

Non-Chemical Melting Devices

NCHRP Report 4, "Non-Chemical Methods of Snow and Ice Control on Highway Structures," discusses non-chemical methods of snow and ice control such as embedded pipes and electrical cable and infrared heat. The principal drawbacks of these methods are high installation, maintenance, and operating costs. Additional effort is required and should be devoted to developing materials and techniques to improve performance and lower costs so that it will be feasible to employ such methods where the conditions warrant.

Equipment

During the course of this study some of the most fruitful observations and suggestions occurred in the equipment field. Most are applicable to snow removal and ice control in general rather than to interchanges in particular.

Highway agencies that support research and development have confined their efforts primarily to administrative, design, material, and operational problems. A review of the literature indicates that little support has been given by public agencies to research and development or standardization in the equipment field.

Interviews indicated that equipment development, including standardization, would be a fertile area for the expenditure of research and development funds with a potential savings of millions of dollars.

Over the years it has become customary to rely on the equipment supplier and manufacturer and, to a limited extent, in-house personnel for advances and innovations in snow removal equipment. The same statement is true of highway construction and maintenance equipment. However, in the latter case, equipment manufacturers have been of such size that they have been able to afford substantial research and development programs to improve their product. Such is generally not the case among the manufacturers of snowplows and chemical distribution equipment for snow removal. In this field there are many small manufacturers whose products are fiercely competitive yet who can ill afford money to research and develop new equipment. Innovations have been slow and mostly of the backyard, blacksmith type. Maintenance shops of highway departments have also contributed ideas and suggestions.

The problems of equipment supply are made more acute by the fact that the responsibility for highway maintenance, including snow removal, rests at many levels of jurisdiction: state, district, county, township, municipality, and village, to name a few. Thus, there is no central spokesman for this group and no coordination or consensus on equipment specifications and operating requirements. For these reasons the development of improved snow removal equipment has been slow and sporadic.

Nor have there been many attempts at standardization where standardization is desirable. One exception is the AASHO-sponsored standard bolt-hole spacing on plow blades.

In the equipment development field it appears that additional effort could profitably be devoted to snowplow performance in the following areas: simple and more responsive cab-located controls; greater maneuverability; increased snow cast; reduced overblow at the top of plow moldboards; and blades with more durable and effective wearing edges.

It has also been suggested that a coordinated family of sizes of plowing and spreading equipment be developed so that there will be a suitable equipment selection for each application, such as main-line service, interchange operations, local roads, and city streets.

The advantages of standardization are obvious. Within appropriate sizes, standardization could permit any make and model of plow to be used with any make and model of prime mover. Competition would still be maintained among the plow and prime mover manufacturers. Mechanical maintenance and repair would be simplified and spare parts inventories would be reduced.

Particular candidates for standardization include plow hitches and hydraulic components. Discrete sizes might be established for plow hitches after which the controlling elements such as the location and dimensions of connecting pins could be standardized.

Discrete pressures and volumes might be established for hydraulic systems after which hoses, fittings, rams, and the housing dimensions of pumps and motors could be standardized. It was also suggested that the location of hydraulic controls within the control box and the location of the control box within the cab be standardized. Such standardization would enable an operator to switch from vehicle to vehicle without having to relearn control locations.

A questionnaire was sent to 33 manufacturers of snow removal equipment to obtain their reaction to this proposed standardization (Appendix C). Of the 20 responding only 16 remain in the snow removal equipment field. Although there were many reservations among the responses, the manufacturers were about equally divided for and against standardization. The principal reason cited by those in opposition was that innovation would be stifled. This is considered a normal defensive reaction. A viable standardization program is always subject to revision and updating as innovative developments warrant.

Similar questions were asked of responsible highway administrators during field interviews. They generally favored standardization, although most recognized the difficulties in agreeing on and implementing meaningful equipment standards.

In this regard it should be noted that the Department of Defense has already adopted some 23 military standards and military specifications in the field of hydraulics and hydraulic equipment. In the Department of Defense, the hydraulic fittings covered by these standards and specifications are used primarily on construction equipment, so there is an opportunity for the highway industry to consider the same standards with which the construction equipment industry is already familiar.

An additional problem would be the granting of patent rights, although this could be solved as it has been in other areas of manufacturing standardized components.

Recommended Research Projects

Several specific areas are of immediate concern and warrant research effort that can offer hope of meaningful findings and potential economic return. The first is a study on the effect of traffic, solar radiation, etc., on chemical use and application rates through the construction and operation of a test truck.

Another study could explore the use of chemical reservoirs programmed and designed for the timely release of deicing materials. An example is the mechanical salt spreader used to deice bridges in North Dakota. Further study is needed also to combine existing knowledge of pavement temperature prediction with the timely use of chemicals to break the snow-ice bond.

A study on prevention of windrows of plowed snow in interchange ramp openings is also recommended. In plowing main-line pavements, conventional snowplows cast snow right or left into windrows that may be a foot or more in height. When such windrows are created across ramp openings in interchanges as a result of plowing adjacent lanes, they represent a considerable hazard, if not a barrier, for traffic movements between the plowed lane and the ramp. The resultant slowing of main-line traffic at ramp entrances also represents an inconvenience and a potentially serious hazard to through traffic on the main-line roadways. Current methods of windrow removal such as the employment of plows with end gates and the concurrent plowing of ramp openings should be evaluated. New operational techniques for windrow prevention or removal should be developed. Geometric and other design considerations that may be of benefit in windrow prevention should also be further analyzed.

Through this more detailed attack on specific problems, potential benefits can be sought for all agencies faced with the complex yet critical need to keep highway interchanges safe and fully operational throughout the year.

APPENDIX A

BIBLIOGRAPHY

"Bare-Pavement Maintenance on the Indiana Toll Road." Reprinted from *Better Roads* for The Salt Institute, Alexandria, Va. (Nov. 1964).

BARTLETT, ROBERT G., "Controlling Winter Wonderland." *The APWA Reporter*, Vol. 36, No. 5, p. 7 (May 1969).

"Better Roads Forum." *Better Roads*, Vol. 38, No. 3, pp. 30-35 (Mar. 1968).

"Better Roads Forum." *Better Roads*, Vol. 39, No. 3 (Mar. 1969).

BOIES, D. B., and BORTZ, S., "Economical and Effective Deicing Agents for Use on Highway Structures." *NCHRP Report 19* (1965) 28 pp.

BONNER, C. M., "Keeping Ice Off Runways." *Civil Eng.*, pp. 73-74 (Jan. 1968).

BROHM, D. R., and EDWARDS, H. M., "Use of Chemicals and Abrasives in Snow and Ice Removal from Highways." *HRB Bull. No. 252* (Jan. 1960) pp. 9-30.

BUTLER, BERTELL C., "The Economics of Ice and Snow Removal in Urban Areas." *Report No. 224-1*, Ohio State Univ. (June 1964) 149 pp.

"Bury Off-Peak KWH Now, Heat Later with Stored BTUs." *Electrical Construction Design*, Eng. Dept., Smith-Gates Corp., Farmington, Conn., pp. 26-31 (Winter 1968).

"California Keys Equipment to Snow Jobs." *Rural and Urban Roads*, Vol. 7, pp. 42-43 (July 1969).

CARAZZA, JOSEPH F., "Snow Center Operates in Emergencies." *Rural and Urban Roads*, Vol. 7, No. 7, pp. 54-57 (July 1969).

CARLSON, JOHN G., "Snow Melter Saves Money for Nation's Largest Town." *Public Works*, Vol. 98, No. 8, pp. 96-98 (Aug. 1967).

CARR, FRANCIS H., JR., "Massachusetts and Industrial Pre-Mixture of Sodium and Calcium Chloride for Snow and Ice Control." Presented at HRB Committee on Snow and Ice Control, 49th Ann. Meeting, Washington, D.C. (Jan. 15, 1970).

CHIERUZZI, ROBERT, "Field Evaluations of Calcium Chloride-Sodium Chloride Mixtures." Ohio State Univ., 9 pp.

CLARY, ADRIAN, "Problem Areas in Winter Maintenance." Presented at the Fall Conf., Maintenance Committee, Internat. Bridge, Tunnel and Turnpike Assn., Albany, N.Y. (Oct. 9, 1967) 15 pp.

CRON, FREDERICK W., "Snowdrift Control Through Highway Design." *Public Roads,* Vol. 34, No. 11, pp. 227-50 (Dec. 1967).

DICKINSON, W. E., "Snow and Ice Control—A Critical Look at its Critics." *Hwy. Res. Record No. 227* (1968) pp. 48-49.

DICKINSON, W. E., "New Salt Blend Has Good Abrasive Action." *Better Roads,* Vol. 39, No. 3 (Mar. 1969).

DUZS, LOUIS, "Fleet Safety Requires Trained, Alert Operators." *Public Works,* Vol. 98, No. 12, pp. 98-100 (Dec. 1967).

EBERHART, JAMES, "An Evaluation of the Relative Merits of Sodium Chloride and Calcium Chloride for Highway Ice Treatment." Ohio State Univ., pp. 1-24 (July 19, 1958).

FAIRLIE, DONALD M., "Northeast Conference on Urban Snow Removal." *Proc. American Public Works Assn., Special Report 25* (1962) 55 pp.

FINNEY, E. A., "Snow Drift Control by Highway Design." *Bull. No. 86,* Vol. 15, No. 2, Mich. State College, Eng. Experiment Station, pp. 39-42 (Sept. 1939).

GARNER, G. R., "Accidents at Median Crossovers." *Hwy. Res. Record No. 312* (1970) pp. 55-63.

GOLD, L. W., and WILLIAMS, G. P., "Snow Removal and Ice Control." *Tech. Memo. No. 83,* proceedings of a conference of the National Research Council of Canada held in Ottawa (Feb. 17-18, 1964).

"Guidelines for the Storage of Deicing Chemicals." *Public Works,* Vol. 97, No. 8, pp. 82-84 (Aug. 1966).

HANES, R. E., ZELAZNY, L. W., and BLASER, R. E., "Effects of Deicing Salts on Water Quality and Biota." *NCHRP Report 91* (1970) 70 pp.

HAMMOND, GEORGE A., "Planning Snow Removal at Urban Interchange Sections." *Proc.,* Fall Conf. on Eng. Maintenance of Internat. Bridge, Tunnel and Turnpike Assn., pp. 47-56 (Oct. 17-19, 1965).

HEGMAN, R. R., and MEYER, W. E., "The Effectiveness of Antiskid Materials." *Hwy. Res. Record No. 227* (1968) pp. 50-56.

HICKS, JAMES R., "Snowdrift and Control." U.S. Army Cold Regions Research and Eng. Lab., pp. 1-7 (Mar. 1964) (mimeograph).

HIMMELMAN, BLAINE F., "Ice Removal on Highways and Outdoor Storage of Chloride Salts." *Hwy. Res. Record No. 11* (1963) pp. 1-22.

"Hitches, Snow Plows, Front-of-Vehicle Mounting." *Military Specs. Mil-H-14435A* (Nov. 19, 1964).

HUTCHINSON, F. E., and OLSON, B. E., "The Relationship of Road Salt Applications to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways." *Hwy. Res. Record No. 193* (1967) pp. 1-7.

"Instructions for Making and Recording Snow Observations." *Instruction Manual 1,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army (May 1954) 7 pp.

ISHIDA, TAMOTSU, and SHIMIZU, HIROMIR, "Resistance to Air Flow Through Snow Layers." Part 1, *Translation 60,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill., pp. 1-8 (Oct. 1958).

JELLINEK, H. H. G., "Bonding of Flat Ice Surfaces." *Research Report 61,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill. (July 1960) 6 pp.

JELLINEK, H. H. G., "Adhesive Properties of Ice." *Research Report 62,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill. (July 1960) 10 pp.

JORGENSEN, ROY, AND ASSOCIATES, "Non-Chemical Methods of Snow and Ice Control on Highway Structures." *NCHRP Report 4* (1964) 73 pp.

JORGENSEN, ROY, AND ASSOCIATES, "Virginia Maintenance Study." Vol. 1 (Dec. 15, 1964) 112 pp.; Vol. 2 (Jan. 15, 1966) 300 pp., Virginia Dept. of Highways.

KALLAS, B. F., "Performance of Asphalt Pavements Subjected to De-Icing Salts." *Hwy. Res. Record No. 24* (1963) pp. 49-61.

KOBEKO, P. P., and MAREI, F. I., "Wetting and Strength of Adhesion." *Translation 59,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill. (July 1958) 6 pp.

KRICK, L. H., "Sealing Concrete Surfaces Against Bad Effects of Winter De-Icers." Presented to the Assn. of Highway Officials, North Atlantic States (Mar. 25, 1965) 9 pp.

KRICK, L. H., "Staffing Standards for Snow and Ice Control Equipment for New York Department of Public Works." (Feb. 2, 1967) 17 pp. (mimeograph).

LANDAUER, J. K., and ROYSE, F., "Energy of Snow Compaction and Its Relation to Trafficability." *Research Paper 14,* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill. (Oct. 1956) 11 pp.

LANDERS, F. W., "Snow Removal Under Emergency Conditions." *Rural and Urban Roads,* Vol. 7, No. 7, pp. 52-53 (July 1969).

LANG, C. H., and DICKINSON, W. E., "Chemical Mixture Test Program in Snow and Ice Control." *HRB Bull. 252* (1960) pp. 1-8.

LEE, R. E., "Importance of Communications in Highway Maintenance and Operations." Paper by Div. Operations Engineer, Ohio Dept. of Highways, 5 pp.

LIEBMAN, HENRY, "Turn on the Heat Lamps—It's Snowing." Reprint from *Public Works* (Aug. 1965) 4 pp.

MALISCH, W. R., RAECKE, D. A., FISCHER, D. M., LOTT, J. L., KENNEDY, T. W., and KESLER, C. E., "Physical Factors Influencing Resistance of Concrete to Deicing Agents." *NCHRP Report 27* (1966) 41 pp.

MALOTT, H. R., "Buy Salt Early—Be Prepared to Store It." *Rural and Urban Roads,* Vol. 7, No. 7, pp. 37-40 (July 1969).

"Manual on Snow Removal and Ice Control in Urban Areas." *Tech. Memo. No. 95,* National Research Council of Canada (Nov. 1967) 135 pp.

MEDAL, G. L., "Snow and Ice Control." State of Illinois, Div. of Highways, District 10 Maintenance (Nov. 1967).

MEEKER, E. W., and WARNES, C. E., JR., "Thin Bonded Concrete Repairs on the Ohio Turnpike. *Hwy. Res. Record No. 61* (1964) pp. 43-47.

MILLER, LAWRENCE, "Calcium Chloride—Salt, Snow and Ice Control." *Research Report 2—Winter 1961-1962,* Conn. State Highway Dept. (Oct. 9, 1962) 10 pp.

MINSK, L. D., "Electrically Conductive Asphalt for Control of Snow and Ice Accumulation." *Hwy. Res. Record No. 227* (1968) pp. 57-63.

NEUZIL, D., and PEET, J. S., "Flat Embankment Slope versus Guardrail: Comparative Economy and Safety." *Hwy. Res. Record No. 306* (1970) pp. 10-24.

PENTECOST, J. L., ET AL., "Development of a Pavement Heating System to Remove Snow from Airport Runway Inset Lights." *SRDS Report RD-65-109,* prepared for FAA (Dec. 1965).

PITTMAN, J. M., "Experience with Electrically Heated Pavement." *Public Works,* Vol. 100, No. 9, pp. 97-100 (Aug. 1969).

PRIOR, G. A., and BERTHOUEX, P. M., "A Study of Salt Pollution of Soil by Highway Salting." *Hwy. Res. Record No. 193* (1967) pp. 8-21.

PUGH, H. L. D., and PRICE, W. I. J., "Snow Drifting and the Use of Snow Fences." *Radar Record,* Vol. 7, No. 47, pp. 4-23 (Jan. 1954).

RHODY, F. J., "Heat Pump Installation at Atlantic City." Presented to Maintenance Committee No. 5 of the Highway Research Board, 4 pp.

ROBERTS, E. C., and ZYBURA, E. L., "Effect of Sodium Chloride on Grasses for Roadside Use." *Hwy. Res. Record No. 193* (1967) pp. 35-42.

ROGUS, C. A., "Rock Salt for Snow and Ice Removal." Reprint from *Public Works* (Nov. 1957) 4 pp.

"Rubber Snowplow Blades and Lightweight Snowplows Used for the Protection of Raised Traffic Markers." *HRB Abstracts,* Vol. 40, p. 2 (Jan. 1970).

"Rubber Snowplow Blades Earn Endorsements." *Public Works,* Vol. 98, No. 8, pp. 98-99 (Aug. 1967).

SAUNDERS, A. H., "Snow Control at Washington, D.C. Airports." *The APWA Reporter,* Vol. 36, No. 5, pp. 7-9 (May 1969).

SCHNEIDER, T. R., "Snowdrifts and Winter Ice on Roads." *Tech. Translation 1038,* National Research Council of Canada, Ottawa (1962).

SCHRAUFNAGEL, F. H., "Pollution Aspects Associated with Chemical Deicing." *Hwy. Res. Record No. 193* (1967) pp. 22-33.

SHARP, D. J., "New Concepts and Equipment in Snow and Ice Control." *Rural and Urban Roads,* pp. 46-47 (Oct. 1967).

SISLER, SAMUEL, "Test on Corrosion Inhibitors in Snow and Ice Control." Report from BANOX Div., Calgon, Inc., 323 Fourth Ave., Pittsburgh, Pa., 2 pp.

"Snow and Ice Control in Urban Areas." Municipal Roads and Streets Committee, Canadian Good Roads Assn. (Sept. 1966).

"Snow and Ice Control Issue." *Rural and Urban Roads,* Vol. 6, No. 7 (July 1968).

"Snow Plow, Truck Mounting; Straight Blade, Reversible." *Military Specs. Mil-S-52466(MO)* (Sept. 27, 1965).

"Snow Plow, Vehicle Mounting; Straight Blade, Reversible; V-Blade; and Rollover Blade." *Military Specs. Mil-S-52520* (June 15, 1965).

"Snow Removal & Ice Control in Urban Areas." American Public Works Assn., Research Foundation, Project No. 114, *Progress Report No. 1,* 45 pp. (Apr. 17, 1963); *No. 2,* 49 pp. (July 1963); *No. 5,* 148 pp. (May 1964); *No. 6,* 22 pp. (Jan. 1965).

STAIB, F. C., "Economic and Practical Evaluation of Chemical Mixtures for Snow and Ice Control." Paper by Maintenance Superintendent of the Ohio Turnpike Comm., Berea, Ohio (Nov. 8, 1965) 9 pp.

"Use of Salt for De-Icing Streets." Reprinted from *The Foundation,* Civic Affairs Committee of The Engineering Society of Detroit (Mar.-Apr. 1956) 8 pp.

"User Report on Rubber Plow Blade Performance." *Rural and Urban Roads,* pp. 44-45 (Oct. 1967).

WEIGLE, J. M., "Groundwater Contamination by Highway Salting." *Hwy. Res. Record No. 193* (1967) p. 34.

"Winter Maintenance Practices in Canada—1963." *Tech. Publ. No. 20,* Canadian Good Roads Assn. (Jan. 1968).

WOOD, FRANK, "Survey of Salt, $CaCl_2$ and Abrasives Use for Streets and Highway Deicing in the United States and Canada, 1966-67." Salt Institute, Alexandria, Va.

WRY, J. M., JR., "Value of Early Planning Proved in November Storm." *Better Roads,* Vol. 39, No. 3 (Mar. 1969).

APPENDIX B

QUESTIONNAIRE SUBMITTED TO STATES THROUGH AASHO

To obtain the viewpoints in the United States on matters regarding interchange snow and ice control, a questionnaire was distributed through the AASHO Committee on Maintenance and Equipment. A response was obtained from 39 of the 52 questionnaires mailed. Eight questions were included for consideration and comment; answers and comments are summarized in the following pages. Table B-1 is a compilation of the response by state.

1. Do you consider interchange snow and ice control to be a separate and significant problem area in your winter maintenance program?

Yes 18
No 17 *
Other 4 **

* 13 without major snowfall or without urban interchanges in snowbelt.
** Without major snowfall or without interchanges.

TABLE B-1

COMPILATION OF RESPONSES TO AASHO QUESTIONNAIRE TO STATES

State	Question Number 1			2			3			4			5			6			7			8		
	Yes	No	Other	Yes	No	Other	Yes	No	Other	Yes	No	Other	Yes	No	Other	Yes	No	Other	Yes	No	Other	Yes	No	Other
Alabama																								
Alaska			X			X			X			X			X			X			X			X
Arizona	X			X				X			X			X		X				X			X	
Arkansas																								
California		X			X			X		X				X			X			X			X	
Colorado	X				X			X		X				X			X			X			X	
Connecticut		X			X			X		X				X			X			X		Xa		
Delaware																								
Florida			X			X			X			X			X			X			X			X
Georgia		X			X			X			X			X			X			X			X	
Hawaii																								
Idaho	X			X				X		X				X			X				X	Xa		
Illinois	X				X			X		X				X			X			X			X	
Indiana	Xa				X			X			X			X			X			X			X	
Iowa	X			Xa				X			X			X		Xa				Xa			X	
Kansas																								
Kentucky		X		Xa				X		X				X			X			X			X	
Louisiana		X			X			X			X			X			X			X			X	
Maine																								
Maryland	Xa				X			X		X				X			X			X			X	
Massachusetts	X			Xa				X		X				Xa		Xa				X			X	
Michigan	X			Xa				X			X			X			X			X			X	
Minnesota	X			X				X			X			X			X			X				X
Mississippi																								
Missouri	Xa			Xa				X			X			X		Xa				X			X	
Montana	X				X			X		X				X			X			X			X	
Nebraska		X			X			X			X			X		Xa				X			X	
Nevada																								
New Hampshire																								
New Jersey			Xa	Xa				X		X				X		Xa				X			X	
New Mexico																								
New York	X				X			X		X				X			X			X			X	
North Carolina		X			X			X		X				X		X				X			X	
North Dakota																								
Ohio		X		Xa				X			X			X			X			X			X	
Oklahoma		X			X			X		X				X			X		Xa				Xa	
Oregon	X				X			X			X			X			X			X			X	
Pennsylvania	X				X			X		X				X			X			X			X	
Rhode Island																								
South Carolina		X			X			X			X			X			X			X			X	
South Dakota		X			X			X			X			X			X				X			X
Tennessee		X			X			X			X			X			X			X			X	
Texas		X			X			X		X				X			X			X			X	
Utah		X			X			X			X			X			X			X			X	
Vermont	X			X					Xa	X				X		X				X			X	
Virginia			Xa	Xa			Xa			X				X			X			X			X	
Washington		X			X		Xa			Xa				X			X			X			X	
West Virginia																								
Wisconsin		X			X			X		X			Xa				X			X			X	
Wyoming	X				X			X			X			X			X		Xa				X	
District of Columbia	X			X				X		X				X			X			X		Xa		
Puerto Rico		X			X			X			X			X			X			X			X	
Totals	18	17	4	13	24	2	2	34	3	20	17	2	1	36	2	8	29	2	2	33	4	3	32	4

a = Comment

Comments:

Alaska—No interchanges.

Florida—No snow.

Indiana—A problem in areas with 8- to 10-in. curb and much guardrail. Current design calls for no curbs or 4-in. rolled curb on ramps. Slopes reduced to 4 on 1 or flatter.

Maryland—A problem in urban areas.

Missouri—A problem in urban areas only.

New Jersey—Recognized as a significant problem but not considered separately.

Virginia—A problem in urban areas only.

2. Do you provide special equipment, materials, or procedures exclusively for interchanges?

Yes 13
No 24
Other 2

Comments:

Iowa—Conveyor-type snow loaders (2), and truck self-loaders for bridges.

Kentucky—In isolated cases.

Massachusetts—Power-wagons, short wheel base, 4-wheel drive capable of handling 10-ft plow.

Michigan—Equip trucks of 19,500 GVW with underbody plow blades.

Missouri—Special procedures in urban areas but no special equipment or materials.

New Jersey—Special equipment required in some areas to maneuver short radius curves. No special materials or procedures.

Ohio—Power reversible plows used in interchange and main line.

Virginia—Special crossovers used exclusively for snow removal.

3. Have you developed and adopted special design criteria for interchanges specifically related to snow and ice control?

Yes 2
No 34
Other 3

Comments:

Vermont—To some extent.

Virginia—Special crossovers used exclusively for snow removal.

Washington—Effort made to flatten grades and place structures on tangent.

4. Does your formal plan review procedure for new highway interchange designs include a review for maintainability by knowledgeable maintenance engineers?

Yes	20
No	17
Other	2

Comments:

Washington—Informal review at District level.

5. Do you maintain any separate records of manpower, materials, and/or equipment utilization in snowstorm operations in interchanges?

Yes	1
No	36
Other	2

Comments:

Massachusetts—Information to be available at end of 1970 fiscal year snow season.
Wisconsin—For one large directional interchange.

6. Are you currently conducting or have you recently conducted any study, research, or special analysis of snow and ice control at interchanges?

Yes	8
No	29
Other	2

Comments:

Iowa—Conducted study related to median crossovers.
Massachusetts—Ideas tried; crossovers seem to be the answer but are dangerous.
Missouri—Procedures established for each interchange on individual basis by District. No special research or analysis on general basis.
Nebraska—Recent limited study.
New Jersey—An electrically heated pavement was constructed on a problem ramp.

7. Do you know of any additional factors or problems affecting snow removal and ice control at interchanges that are not covered in the attached summary report?

Yes	2
No	33
Other	4

Comments:

Iowa—Big problem is deadheading due to lack of crossovers.
Oklahoma—Report does not consider different kinds of storms. (Note: Not considered to be a problem unique to interchanges.)
Wyoming—Fencing and cattle guards on rural interchange.

8. Do you have any suggested solutions or comments not discussed in the report?

Yes	3
No	32
Other	4

Comments:

Connecticut—Recommend use of hydraulically controlled reversible snowplows.
Idaho—Sight distance on diamond interchanges is the greatest hazard to trucks.
Oklahoma—Agrees with report conclusion: "Do the best you can with what you have, provided planning has been sound."
District of Columbia—Plow and remove drifts with front-end loaders.

APPENDIX C

EQUIPMENT QUESTIONNAIRE

1. Do you have any suggestions for new or innovative equipment for snow and ice control?

2. It has been suggested that standard hydraulic elements for snow and ice control equipment (plow lifts, spreader belts, spinners, etc.) be adopted by the American Association of State Highway Officials to simplify the compatibility of different makes and models of equipment, to relieve the spare parts inventory problem, and to simplify the training of operators and mechanics. Drawings and specifications of the standard parts would be available to all manufacturers. Items suggested for standardization follow:

Pump
Hose
Fittings
Rams
Location of controls:

In control box
In vehicle cab

a. Is it feasible?
b. Do you recommend it? Reason?
c. Other comments or suggestions.

APPENDIX D

REDUCTION OF PLOW-PATH WIDTH ON RAMPS

Some concern was expressed by maintenance engineers that when short-radius curves on interchange ramps are plowed the effective plow-path width is decreased significantly. A brief study of the problem indicates that, in reality, the reduced plow path caused by the ramp curvature is nominal.

As an example, to show the extreme situation that may occur, a minimum ramp radius is selected. The following geometric design guidelines are presented in AASHO's *Policy on Geometric Design of Rural Highways.*

HIGHWAY DESIGN SPEED (MPH)	RAMP DESIGN SPEED (MPH)		CORRESPONDING MINIMUM RADIUS (FT)	
	DESIR-ABLE	MIN.	DESIR-ABLE	MIN.
70	60	30	1,040	230
75	60	35	1,040	300
80	65	40	1,260	430

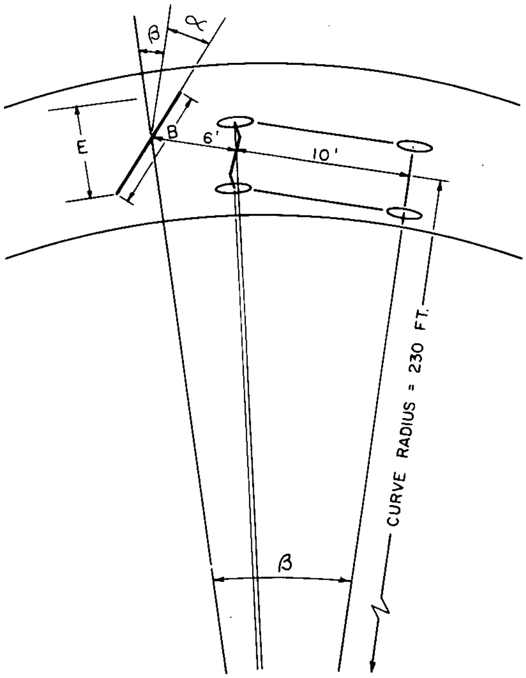


Figure D-1. Reduction of plow path width on ramps.

For this analysis, assume a minimum ramp radius of 230 ft.

Assume snowplowing equipment as follows:

Truck:

1. 21,000 GVW vehicle, or a 2½-ton 4 × 4.
2. 10 ft between axles.
3. 6 ft from front axle to center-line plow blade.

Plow blade:

1. 10-ft moldboard length.
2. 30° angle of cut.

Tangent:

In Figure D-1 the angle between blade center position and full angle of cut is designated α and is equal, in this example, to 30°.

For a 10-ft blade width, *B*, and plowing *on tangent* at a full 30° angle of cut, the effective plow width, E_T, is:

$E_T = B \cos \alpha = 10 \cos 30°$

$E_T = 8.66$ ft

This amounts to a 13 percent reduction in plow blade width.

Curve:

The increase in plow angle caused by the ramp curvature is designated β and is equal to the central angle between the rear axle and plow center line. β is computed as follows:

$$\tan \beta = \frac{10 + 6}{230} = 0.0695$$

$$\beta = 3° \, 59', \text{ say } 4°$$

Therefore: $\alpha + \beta = 30° + 4° = 34°$

When one is plowing a 230-ft-radius curve, the effective plow width, E_c, is:

$E_c = B \cos (\alpha + \beta) = 10 \cos 34°$

$E_c = 8.29$ ft

Therefore, the decrease in effective plow width caused by the curve is 0.37 ft, about 4½ in., or a reduction of 3.7 percent. Total decrease in plow width on the curve is 17 percent.

If the plow blade is rotated so that plowing is to the low or left side of the ramp rather than to the right side, calculations are:

$E_{CL} = B \cos (\alpha - \beta) = 10 \cos (34° - 4°)$

$E_{CL} = 8.99$ ft

Plowing in this manner results in a total reduction in plow width of only 10 percent. For either situation, the most feasible approach to increasing plow-path width for a given plow blade is to plow with the smallest angle of cut practical for the existing snow and plow speed conditions.

APPENDIX E

IDENTIFICATION OF CRITICAL INTERCHANGE

Many problems influence and limit the effectiveness of ice and snow removal in interchange areas. Various operational and design procedures have been suggested to cope with the problems. The changes in operations may represent additional costs. It is appropriate, therefore, to develop criteria that can be used to evaluate the relative operational and economic impact of any interchange problem. This will allow warrants to be established for implementing operational changes.

Interchanges exist to provide entry and exit of main-line traffic. A well-designed facility provides this function with a minimum of interference with the main-line traffic. If the presence of ice and snow in the interchange area overly restricts traffic movement, its function may be impaired to the point where interchange traffic interferes greatly with main-line traffic. This is an undesirable situation and the degree of interference could be the criteria needed to establish warrants for implementing various changes in maintenance operations.

OPERATIONAL IMPACT

The ramps in an interchange are normally designed to accommodate the 30th highest hourly volume of some future year (usually 20 years). This design volume should be less than or equal to the design capacity of the ramp. The design capacity may be controlled by either the ramp proper or the ramp terminal area. When capacity is controlled by the ramp proper, curvature, gradient and proportion of trucks are the significant variables. The ramp capacity in terminal areas is more complex, depending not only on design, but also on the traffic movements in the main-line area. In either case, the procedures for establishing the design capacity for interchange ramps are well documented and therefore are not reiterated here. This discussion is confined to presenting a procedure for evaluating the consequences of various cycles of effective ice and snow removal in interchange areas.

HRB Spec. Report 87, "Highway Capacity Manual—1965," states that, "In most cases a design will be considered satisfactory if it permits operation at level C, representing the relatively free flow, or better." The following analysis is presented with this criterion in mind where the objective is to establish a relationship between snowstorm conditions, maintenance operational cycles, and traffic volume. If any combination of these elements produces operating conditions below a C level of traffic service, the ramp or associated interchange is potentially critical to total traffic movements. Such interchanges may warrant special consideration during their design, or when developing operational procedures for eliminating snow and ice conditions.

Limited information exists on the relationship between ice and snow conditions and traffic movements. Pertinent information was presented in the 1965 APWA report, *Snow Removal and Ice Control in Urban Areas.* In that report a series of curves were presented that related varying snowstorm conditions to vehicle average over-all speed. The application of these curves to vehicle speeds in interchanges is based on the following quote from that report: "When it is snowing, traffic is slowed; the rate of slowing appears to be independent of normal traffic speed." The assumption being made in this analysis is that any speed factor based on the snowstorm applies, regardless of the vehicle speed on an interchange ramp. For example, if it is determined that the snow and ice condition generates a speed reduction or "snowstorm speed factor" of 0.75, this factor can be applied to any of the following:

1. Spot speed.
2. Average spot speed.
3. Over-all travel speed.
4. Average over-all travel speed.
5. Space mean speed.
6. Running speed.
7. Free-flow operating speed.

Therefore, snowstorm speed factors are developed to predict average vehicle speeds in ramp areas under various storm conditions. These speeds are then used to analyze either the operating characteristics or the economic impact of a snowstorm condition.

The snowstorm speed factor curves in the cited APWA report were presented for a range of snowfall intensities, temperature conditions, and snowstorm conditions. Because the objective in analyzing an interchange is to establish warrants for additional investment, it is necessary to establish the type or level of snowstorm condition that can be adequately handled with present maintenance procedures. This is done by establishing storm speed factors for the most severe storm conditions anticipated.

A series of curves were developed to reflect the reduced operating conditions to be associated with any intensity of continuous snowfall, and for temperatures remaining below 25°F. The general relations presented in the APWA report were used to control the shape and the maximum speed reduction values on the curves, which are shown in Figure 21. The influence on vehicle speed shown in the curves reflects a constant snowfall intensity, an infinite storm duration, and no maintenance operations.

The first objective will be to establish the level of snowstorm intensity that can be handled using present maintenance procedures. To do this, it will be necessary to establish a snow and ice maintenance cycle (i.e., the time lapse between the completion of ramp snow removal operations). For the purpose of the analysis it is assumed that the completion of the removal operation is instantaneous. This is shown in Figure 22, where the curve drops to a minimum assumed snowstorm speed factor of 0.80 applicable to any snowing condition. This somewhat unrealistic procedure can be rationalized in the selection of maintenance cycle time. For example, if there are delays or problems that prolong the removal operation, the cycle may be modified.

The actual influence of a snowstorm on traffic movements varies widely during the storm. Therefore, this analysis is limited to the investigation of the worst situation. This probably occurs between maintenance cycles and during the most intense snowfall period. Accordingly, the assumptions made in developing an average snowstorm speed factor for this period are:

1. The maintenance cycle is the period in hours between the completion of one snow removal operation and the following snow removal operation.
2. The snowfall intensity is a constant during the entire maintenance cycle.
3. The minimum snowstorm speed factor that can be achieved following the completion of a maintenance cycle is 0.80.

Based on the foregoing assumptions and the snowstorm speed factor curves shown in Figure 21, average factors were determined for various maintenance cycles and snowfall intensities (Table E-1).

To establish if a particular ramp and/or interchange area is critical, the speed factor must be applied to the ramp's capacity. This is accomplished using the relationship:

$$C_f = (-0.3/F + 1.3)C$$

in which:

C_f = factored capacity;
F = snowstorm speed factor; and
C = ramp design capacity at traffic service level C.

This conversion is given in Table E-2 for a range of design capacities and snowstorm speed factors.

If the resulting factored capacity falls below the maximum traffic volume expected during the analysis period, a critical situation is indicated.

Example 1

Objective: Determine the maximum volume of traffic that can be handled by a ramp for a given storm intensity, maintenance cycle, and ramp design capacity.

Given:

1. 1.0-in. snowfall intensity.
2. 2½-hr maintenance cycle.
3. 600 vph ramp design capacity.

1. Enter Table E-1 with a 1-in. snowfall intensity and a 2½ hr maintenance cycle, and find the associated snowstorm speed factor.

Snowstorm speed factor = 0.60

2. Enter Table E-2 with a snowstorm speed factor of 0.60 and a design capacity of 600 vph, and find the corresponding factored capacity that equals 480 vph.

TABLE E-1

SNOWSTORM SPEED FACTORS

MAINT CYCLE HOURS	SNOWFALL INTENSITY INCHES/HOUR .25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	SNOWSTORM SPEED FACTOR									
0.25	.75	.74	.73	.72	.72	.71	.70	.69	.69	.68
0.50	.76	.74	.73	.72	.71	.69	.68	.67	.66	.65
0.75	.75	.73	.72	.70	.69	.67	.66	.64	.63	.62
1.00	.75	.72	.70	.68	.67	.65	.64	.62	.61	.59
1.25	.74	.71	.69	.67	.65	.63	.61	.60	.59	.57
1.50	.74	.70	.67	.65	.63	.61	.60	.58	.57	.55
1.75	.73	.69	.66	.64	.62	.60	.58	.57	.55	.54
2.00	.72	.68	.65	.62	.60	.59	.57	.56	.54	.53
2.25	.72	.67	.64	.61	.59	.57	.56	.55	.53	.52
2.50	.71	.66	.63	.60	.58	.56	.55	.54	.53	.52
2.75	.71	.66	.62	.59	.57	.56	.54	.53	.52	.51
3.00	.70	.65	.61	.59	.56	.55	.54	.53	.52	.51
3.25	.70	.64	.61	.58	.56	.54	.53	.52	.51	.50
3.50	.69	.64	.60	.57	.55	.54	.53	.52	.51	.50
3.75	.69	.63	.59	.57	.55	.53	.52	.51	.51	.50
4.00	.69	.63	.59	.56	.54	.53	.52	.51	.50	.50
4.25	.68	.62	.58	.56	.54	.53	.52	.51	.50	.49
4.50	.68	.62	.58	.55	.53	.52	.51	.51	.50	.49
4.75	.68	.62	.58	.55	.53	.52	.51	.50	.50	.49
5.00	.68	.61	.57	.55	.53	.52	.51	.50	.49	.49

TABLE E-2

FACTORED CAPACITY

DESIGN CAPACITY	SNOWSTORM SPEED FACTOR .40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95
	FACTORED CAPACITY											
200	110	126	140	150	160	167	174	180	185	189	193	196
250	137	158	175	188	200	209	217	225	231	236	241	246
300	165	190	210	226	240	251	261	270	277	284	290	295
350	192	221	245	264	280	293	305	315	323	331	338	344
400	220	253	280	301	320	335	348	360	370	378	386	393
450	247	285	315	339	360	377	392	405	416	426	435	442
500	275	316	350	377	400	419	435	450	462	473	483	492
550	302	348	385	415	440	461	479	495	508	520	531	541
600	330	380	420	452	480	503	522	540	555	568	580	590
650	357	411	455	490	520	545	566	585	601	615	628	639
700	385	443	490	528	560	586	610	630	647	662	676	688
750	412	475	525	565	600	628	653	675	693	710	725	738
800	440	506	560	603	640	670	697	720	740	757	773	787
850	467	538	595	641	680	712	740	765	786	805	821	836
900	495	570	630	679	720	754	784	810	832	852	870	885
950	522	601	665	716	760	796	827	855	878	899	918	935
1000	550	633	700	754	800	838	871	900	925	947	966	984
1050	577	665	735	792	840	880	915	945	971	994	1015	1033
1100	605	696	770	830	880	922	958	990	1017	1041	1063	1082
1150	632	728	805	867	920	964	1002	1035	1063	1089	1111	1131
1200	660	760	840	905	960	1006	1045	1080	1110	1136	1160	1181
1250	687	791	875	943	1000	1048	1089	1125	1156	1183	1208	1230
1300	715	823	910	980	1040	1090	1132	1170	1202	1231	1256	1279
1350	742	855	945	1018	1080	1131	1176	1215	1248	1278	1305	1328
1400	770	886	980	1056	1120	1173	1220	1260	1295	1325	1353	1377
1450	797	918	1015	1094	1160	1215	1263	1305	1341	1373	1401	1427
1500	825	950	1050	1131	1200	1257	1307	1350	1387	1420	1450	1476
1550	852	981	1085	1169	1240	1299	1350	1395	1433	1467	1498	1525
1600	880	1013	1120	1207	1280	1341	1394	1440	1480	1515	1546	1574
1650	907	1045	1155	1245	1320	1383	1437	1485	1526	1562	1595	1623
1700	935	1076	1190	1282	1360	1425	1481	1530	1572	1610	1643	1673
1750	962	1108	1225	1320	1400	1467	1525	1575	1618	1657	1691	1722
1800	990	1140	1260	1358	1440	1509	1568	1620	1665	1704	1740	1771

Therefore, if the maximum traffic volume in the ramp area exceeds 480 vph at any time during the storm, a critical condition may exist because the service level on the main-line expressway will be reduced below service level C.

Example 2

Objective: Determine the minimum critical snowfall intensity for a given design capacity, maximum traffic volume, and maintenance cycle on a ramp.

Given:

1. 600 vph ramp design capacity.
2. 500 vph maximum traffic volume.
3. 2½-hr maintenance cycle.

1. Enter Table E-2 with a 600 vph design capacity and find the snowstorm speed factor associated with a 500 vph factored capacity.

Storm speed factor (by interpolation) =

$$0.65 - \frac{(503 - 500)}{(503 - 480)} \times (0.65 - 0.60) = 0.644$$

2. Enter Table E-1 with a 2½-hr maintenance cycle and find the snowfall intensity associated with a 0.644 snowstorm speed factor.

Snowfall intensity (by interpolation) =

$$0.75 - \frac{(0.644 - 0.630)}{(0.660 - 0.630)} \times 0.25 = 0.63 \text{ in./hr}$$

Example 3

Objective: Determine the maintenance cycle required to handle a given snowfall intensity, design capacity and maximum traffic volume on a ramp.

Given:

1. 700 vph ramp design capacity.
2. 600 vph maximum traffic volume.
3. 1½-in. snowfall intensity.

1. Enter Table E-2 with a 700 vph design capacity and find the snowstorm speed factor associated with a 600 vph factored capacity.

Storm speed factor (by interpolation) =

$$0.65 + \frac{(610 - 600)}{(610 - 586)} \times (0.05) = 0.671$$

2. Enter Table E-1 with a 1½-in. snowfall intensity and a snowstorm speed factor of 0.671 and find the corresponding maintenance cycle.

Maintenance cycle =

$$0.75 + \frac{(0.671 - 0.670)}{(0.690 - 0.670)} \times (0.25) = 0.756 \text{ hr}$$

ECONOMIC IMPACT

Procedures have been developed to evaluate the relative operational impact of reduced traffic capacity on an interchange ramp. As a result of reduced operating speeds in the ramp area, the reduction in ramp capacity causes increased vehicle operating and time costs.

To plan and budget effective snow removal and ice control operations, it is necessary to measure the relative economic impact of these problems on interchange operations. Justification or warrants for changes in the snow removal plan can then be based on the economics of the situation; i.e., costs associated with delay-time may then be compared with the additional cost of increased snow removal activity.

Budgeting of expenditures on snow removal operations cannot be realistically based on critical snowfall or peak traffic periods. Needless expenditure will result by having excess materials, equipment, and personnel on hand during the snow season with limited operations to perform. Normal snow conditions for the region in question must be used as a base for budget planning.

With this in mind, the reduced vehicle speed (i.e., snowstorm speed factor) was determined over a 24-hr period under various storm conditions for selected maintenance cycles. The objective was to establish the relationship of storm conditions and duration to average vehicle speed in the ramp area over 24 hr. These snowstorm speed factors can then be used to analyze the relative vehicle operating and time costs for different maintenance cycles. The 24-hr period was selected because of its compatibility with the readily available average daily traffic.

The assumptions cited in the previous discussion remain valid. One additional assumption was made: The period between the start of the storm and the completion of the first snow removal operation will equal one-half of the maintenance cycle.

Figure 22 shows the curve relating snowstorm speed factor with time into the storm. The curve is presented for a constant snowfall intensity of 2.00 in. per hour (high intensity used to accentuate the effects), a storm duration of 6 hr, and a 2-hr maintenance cycle.

Summation of the total effect of the storm over 24 hr and division by 24 yields the average snowstorm speed factor. These factors are given in Tables E-3 through E-6 for 1-, 2-, 3-, and 4-hr maintenance cycles, respectively. The difference between corresponding factors for any two cycles is the increase (or decrease) in average ramp operating speed to be realized by changes in frequency of plowing operations.

There is an operational benefit (i.e., higher speeds) to be derived by the highway user when plowing operations are conducted at a 2-hr interval, for example, rather than at a 4-hr interval. The economics of such operations may be determined by establishing the dollar value of time saved by the motorist compared to the increased cost of the additional maintenance operations.

User Cost

Assume a main-line average daily traffic (ADT) of 30,000 and assume that 20 percent of these vehicles will operate on the interchange ramps. Assume further an interchange with 1 mile of ramps:

$$30{,}000 \text{ ADT} \times 20\% = 6{,}000 \text{ ADT per ramp mile}$$

The 1960 edition of AASHO's *Road User Benefit Analysis for Highway Improvements* ("Redbook") presents a value of $1.55 per hour or $0.0259 per minute of time for passenger cars. Data collected by Stanford Research Institute and presented in HRB literature present time costs as a function of family income and amount of

TABLE E-3

SNOWSTORM SPEED FACTORS— 1-HR MAINTENANCE CYCLE

DURATION	SNOWFALL INTENSITY INCHES/HOUR									
HOURS	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	SNOWSTORM SPEED FACTOR									
1.00	.98	.96	.94	.93	.93	.93	.93	.92	.92	.92
2.00	.93	.92	.92	.92	.92	.91	.91	.91	.91	.90
3.00	.92	.91	.91	.91	.90	.90	.90	.89	.89	.89
4.00	.91	.90	.90	.89	.89	.88	.88	.88	.87	.87
5.00	.90	.89	.88	.88	.87	.87	.86	.86	.86	.85
6.00	.89	.88	.87	.87	.86	.85	.85	.84	.84	.84
7.00	.87	.87	.86	.85	.85	.84	.83	.83	.82	.82
8.00	.86	.85	.85	.84	.83	.83	.82	.81	.81	.80
9.00	.85	.84	.83	.83	.82	.81	.80	.80	.79	.78
10.00	.84	.83	.82	.81	.80	.80	.79	.78	.77	.77
11.00	.83	.82	.81	.80	.79	.78	.77	.77	.76	.75
12.00	.82	.81	.80	.79	.78	.77	.76	.75	.74	.73
13.00	.82	.80	.79	.78	.77	.76	.75	.74	.73	.72
14.00	.81	.79	.78	.77	.75	.74	.73	.72	.71	.71
15.00	.80	.78	.77	.76	.74	.73	.72	.71	.70	.69
16.00	.79	.77	.76	.75	.73	.72	.71	.70	.69	.68
17.00	.79	.77	.75	.74	.72	.71	.70	.69	.68	.66
18.00	.78	.76	.74	.73	.71	.70	.69	.68	.66	.65
19.00	.78	.75	.74	.72	.71	.69	.68	.67	.65	.64
20.00	.77	.75	.73	.71	.70	.68	.67	.66	.64	.63
21.00	.77	.74	.72	.71	.69	.68	.66	.65	.63	.62
22.00	.76	.74	.72	.70	.68	.67	.65	.64	.62	.61
23.00	.76	.74	.71	.70	.68	.66	.65	.63	.62	.60
24.00	.76	.73	.71	.69	.67	.65	.64	.62	.61	.59

TABLE E-4

SNOWSTORM SPEED FACTORS— 2-HR MAINTENANCE CYCLE

DURATION	SNOWFALL INTENSITY INCHES/HOUR									
HOURS	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	SNOWSTORM SPEED FACTOR									
1.00	.98	.96	.93	.92	.91	.91	.90	.90	.90	.89
2.00	.93	.92	.91	.91	.90	.90	.89	.89	.89	.89
3.00	.92	.91	.91	.90	.90	.90	.89	.89	.89	.89
4.00	.90	.89	.88	.87	.87	.86	.86	.86	.85	.85
5.00	.90	.89	.88	.87	.87	.86	.86	.85	.85	.85
6.00	.88	.86	.85	.84	.84	.83	.82	.82	.81	.81
7.00	.88	.86	.85	.84	.83	.83	.82	.82	.81	.81
8.00	.85	.84	.82	.81	.80	.79	.79	.78	.78	.77
9.00	.85	.84	.82	.81	.80	.79	.79	.78	.77	.77
10.00	.83	.81	.79	.78	.77	.76	.75	.74	.74	.73
11.00	.83	.81	.79	.78	.77	.76	.75	.74	.74	.73
12.00	.81	.79	.77	.75	.74	.73	.72	.71	.70	.70
13.00	.81	.78	.77	.75	.74	.73	.72	.71	.70	.69
14.00	.79	.77	.74	.73	.71	.70	.69	.68	.67	.66
15.00	.79	.76	.74	.72	.71	.70	.69	.68	.67	.66
16.00	.78	.75	.72	.70	.69	.67	.66	.65	.64	.63
17.00	.78	.74	.72	.70	.68	.67	.66	.65	.64	.63
18.00	.76	.73	.70	.68	.66	.65	.63	.62	.61	.60
19.00	.76	.73	.70	.68	.66	.64	.63	.62	.61	.60
20.00	.75	.71	.68	.66	.64	.62	.61	.60	.58	.57
21.00	.75	.71	.68	.66	.64	.62	.61	.59	.58	.57
22.00	.74	.70	.67	.64	.62	.60	.59	.57	.56	.55
23.00	.74	.70	.67	.64	.62	.60	.59	.57	.56	.55
24.00	.73	.69	.66	.63	.61	.59	.57	.56	.54	.53

TABLE E-5

SNOWSTORM SPEED FACTORS— 3-HR MAINTENANCE CYCLE

DURATION	SNOWFALL INTENSITY INCHES/HOUR									
HOURS	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	SNOWSTORM SPEED FACTOR									
1.00	.98	.96	.93	.91	.90	.90	.89	.88	.88	.87
2.00	.93	.90	.89	.88	.87	.87	.86	.86	.86	.85
3.00	.91	.89	.88	.87	.87	.86	.86	.86	.85	.85
4.00	.90	.89	.88	.87	.87	.86	.86	.86	.85	.85
5.00	.88	.86	.85	.84	.83	.82	.82	.82	.81	.81
6.00	.87	.85	.83	.82	.82	.81	.80	.80	.80	.79
7.00	.87	.85	.83	.82	.81	.81	.80	.80	.79	.79
8.00	.84	.82	.80	.79	.78	.77	.76	.76	.75	.75
9.00	.83	.81	.79	.77	.76	.75	.75	.74	.74	.73
10.00	.83	.80	.78	.77	.76	.75	.74	.74	.73	.73
11.00	.81	.78	.75	.74	.73	.72	.71	.70	.69	.69
12.00	.80	.77	.74	.72	.71	.70	.69	.69	.68	.67
13.00	.80	.76	.74	.72	.71	.70	.69	.68	.68	.67
14.00	.78	.74	.71	.70	.68	.67	.66	.65	.64	.64
15.00	.77	.73	.70	.68	.67	.65	.64	.64	.63	.62
16.00	.77	.73	.70	.68	.66	.65	.64	.63	.63	.62
17.00	.75	.71	.68	.66	.64	.63	.62	.61	.60	.59
18.00	.75	.70	.67	.64	.63	.61	.60	.59	.58	.58
19.00	.74	.70	.67	.64	.62	.61	.60	.59	.58	.57
20.00	.74	.69	.65	.63	.61	.59	.58	.57	.56	.55
21.00	.73	.68	.64	.61	.59	.57	.56	.55	.54	.53
22.00	.73	.67	.64	.61	.59	.57	.56	.55	.54	.53
23.00	.72	.67	.63	.60	.58	.56	.55	.54	.53	.52
24.00	.71	.65	.61	.58	.56	.54	.53	.52	.51	.50

TABLE E-6

SNOWSTORM SPEED FACTORS— 4-HR MAINTENANCE CYCLE

DURATION	SNOWFALL INTENSITY INCHES/HOUR									
HOURS	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	SNOWSTORM SPEED FACTOR									
1.00	.98	.96	.93	.90	.89	.88	.88	.87	.86	.86
2.00	.93	.88	.87	.86	.85	.84	.84	.83	.83	.82
3.00	.89	.87	.86	.85	.84	.83	.83	.83	.82	.82
4.00	.88	.86	.85	.84	.83	.83	.83	.83	.82	.82
5.00	.88	.86	.85	.84	.83	.83	.83	.83	.82	.82
6.00	.88	.86	.85	.84	.83	.83	.83	.83	.82	.82
7.00	.84	.81	.80	.78	.77	.77	.76	.76	.75	.75
8.00	.83	.80	.78	.77	.76	.75	.75	.75	.74	.74
9.00	.83	.80	.78	.77	.76	.75	.75	.74	.74	.74
10.00	.83	.80	.78	.77	.76	.75	.75	.74	.74	.74
11.00	.79	.76	.73	.71	.70	.69	.69	.68	.68	.67
12.00	.78	.75	.72	.70	.69	.68	.68	.67	.67	.66
13.00	.78	.74	.72	.70	.69	.68	.67	.67	.67	.66
14.00	.78	.74	.72	.70	.69	.68	.67	.67	.67	.66
15.00	.75	.71	.68	.66	.64	.63	.62	.61	.61	.60
16.00	.75	.70	.67	.64	.63	.62	.61	.60	.60	.60
17.00	.74	.70	.66	.64	.63	.61	.61	.60	.60	.60
18.00	.74	.70	.66	.64	.62	.61	.61	.60	.60	.60
19.00	.73	.67	.63	.61	.59	.57	.56	.56	.55	.54
20.00	.72	.66	.62	.60	.58	.56	.55	.55	.54	.54
21.00	.72	.66	.62	.59	.57	.56	.55	.55	.54	.54
22.00	.72	.66	.62	.59	.57	.56	.55	.55	.54	.54
23.00	.71	.65	.61	.58	.56	.54	.53	.53	.52	.52
24.00	.69	.63	.59	.56	.54	.52	.51	.51	.50	.49

time saved. It was reported that the value of time is higher for motorists with a higher income. For a motorist at the $9,000 family income level who saves 10 min during a commuter trip, the average hourly value for time is $1.42 per person per hour. Assuming the AASHO figure of 1.8 persons per vehicle, the value of time is $2.56 per hour per vehicle or $0.0426 per minute.

For example, assume that vehicles under severe snow and ice conditions are forced to negotiate the ramps at 20 mph rather than the normal 40 mph. This results in a loss of 1.5 min per mile and, at $0.0426 per minute, a cost to the motorist of $0.064 per vehicle per mile. For the 6,000 ADT in the interchange, the total cost for delay will be $384 per ramp-mile per day.

Maintenance Cost

The maintenance cost associated with plowing during a normal snow season on a per mile per cycle basis is developed by assuming:

1. Total expenditure for snow and ice control of $1,000 to $2,000 per mile per season.
2. 10 storms per season.
3. 1 storm per day.

The range in maintenance cost will then be $100 to $200 per mile per day.

To develop average per cycle cost of plowing, assume a duration of 8 hr per storm per day and a maintenance cycle of 2 hr (i.e., five maintenance cycles per storm). Total cost is then $20 to $40 per mile per cycle.

For example, enter Table E-4 (2-hr maintenance cycle) with a storm duration of 3 hr and a snowfall intensity of 2.00 in. per hour to obtain a snowstorm speed factor of 0.89. Entering Table E-6 (4-hr maintenance cycle) with the same input yields a snowstorm speed factor of 0.83. The difference between these factors is 0.06, or 6 percent.

For this example, and by plowing at 2-hr intervals rather than 4-hr intervals, vehicle speeds on the ramp will be increased by 6 percent maximum. Therefore, the total benefit to the user will be a 6 percent reduction in cost of delay which, from the previous example, will amount to approximately $23 per ramp mile *per day* for the 6,000 ADT level.

At a cost of $20 to $40 per ramp mile *per maintenance cycle,* it is difficult to justify more frequent plow operations for the example situation entirely on the economics of reduced delay time.

APPENDIX F

ECONOMIC ANALYSIS OF MEDIAN CROSSOVERS

An analysis of an example interchange (New York Southern Tier Expressway, Stanton Hill Road Interchange) for consideration of the impact of design features on snow removal operations was undertaken. Costs versus benefits of median crossovers, provision for drainage of snow storage areas, and potential for hazardous drifting were examined.

The interchange is remote from any other and maintenance vehicle deadhead time was considered prohibitive without turnarounds close to the interchange. Median crossover locations were selected for convenience, adequate sight distance for crew safety when crossing, and adequate drainage. The related constructions costs for two median crossovers are as follows:

Earthwork and drainage:

Station 230 + 00 EBL:

2,740 cu yd of fill @ $1.50/cu yd = $4,110

Corrugated metal drain, 12″, 100 ft @ $4.91/ft = 491

Galvanized metal and section, 12″, 2 @ $31.71 = 63

Station 267 + 00 EBL:

152 cu yd of fill @ $1.50/cu yd (no drain required, crossover located at ditch check) = 228

Subtotal, earthwork and drainage, approx. $5,000

Pavement:

Subbase:

Granular materials, 12-in. depth

220 linear ft × 26 ft width × 1 ft = 220 cu yd

220 cu yd @ $4.65/cu yd = $1,020

Base course:

Asphaltic concrete, Type 1A, 3-in. depth

220 × 18 × 0.25 = 1,000 cu ft

1,000 cu ft × 145 lb/cu ft = 72.5 tons

72.5 tons @ $10.45/ton = 760

Surface:
Asphaltic concrete, Type 1A, 2-in. depth
220 × 14 × 2/12 = 513 cu ft
513 cu ft × 145 lb/cu ft = 37.2 tons
37.2 tons @ $10.45/ton = 388
Subtotal (approx.) $2,500

Total construction cost for two median crossovers $7,500

An analysis of the cost for deadhead time *without* median crossovers was performed. Assuming a complement of two trucks with plows and chemical spreaders, examination of one possible approach to plowing the interchange resulted in total deadhead of 17 miles. This occurs principally because a round trip of 17.8 miles is needed just to plow less than 1 mile in the interchange area. (Deadhead with crossovers is essentially zero miles.)

COST-BENEFIT 1

The cost for deadheading is based on the following assumptions:

1. 20 storms per year (U.S. Weather Bureau data for central New York).
2. 3 passes per storm.
3. 40-year service life for the interchange.
4. $0.24 per mile driver and equipment deadhead cost.*

Therefore:

3 × $0.24 × 17 = $12.20 per storm
20 × $12.20 = $245 per season

The previously determined construction cost for two median crossovers installed after original highway construction is $7,500. Amortized over 40 years this would be $188 per year.

$$\text{Benefit/cost ratio} = \frac{\$245}{188} = 1.3$$

Maintenance and resurfacing costs over the life of the crossovers are not included. However, yearly maintenance costs may be offset by yearly benefits of convenience to maintenance crews working on the interchange. Additional benefits during snow and ice conditions are obtained by having all lanes of the interchange open to traffic sooner than if the crossovers were not available.

The benefits to be derived by crossovers, in this case, justify the additional cost principally because travel to adjacent interchanges for turnarounds is excessive.

COST-BENEFIT 2

Compilation of maintenance cost data for the State of New York indicated a per-mile cost of $4,000 for labor, equipment, and material for snow removal operations (including chemical spreading) in *urban* areas. In *rural* areas the total cost per mile was $2,400 (per season).

* Heavy truck, 5-6 ton	$4.66
Plow attachment (not included)	
Operator wages	2.60
Total cost/hr	$7.26

At deadheading speed of 30 mph, cost is $\frac{\$7.26}{30} = \$0.24$/lane-mile.

Dividing by two (to obtain the cost per directional roadway) and reducing the cost by 25 percent for materials and 10 percent for other snow operations (i.e., charges not related to the use of crossovers, such as erecting snow fences) results in a cost of $1,300 per mile for urban areas and $780 per mile for rural areas.

This cost reflects the total statewide expenditures chargeable to snow and ice and therefore includes all trucks operating within the system. The cost consists of plowing and chemical spreading operations whether performed separately or simultaneously, and includes only production time, not deadheading.

Operating speed while deadheading in rural areas is assumed to be double the plowing speed and therefore the time cost while deadheading is reduced by half, making it $390 per mile for rural areas.

Installation of median crossovers will eliminate approximately 17 miles of deadheading and will result in savings of 17 × $390, or $6,630 during the snow season.

The benefit to be derived, therefore, by providing median crossovers is $6,630 per season versus approximately $200 per year amortized construction cost. Admittedly, this cost neglects the potential cost of accidents at median crossovers, which may be significant in some areas.

DRAINAGE OF SNOW STORAGE AREAS

The median of this example interchange is generally of 60 ft width, depressed, well-drained, and should provide sufficient snow storage and drainage.

Gores and lane separators at the ramps are paved and flush and, if plowed, drainage should be no problem. However, when windrows are allowed to remain and melt, cross pavement drainage will occur. Drains are needed in the gore to accommodate this melt water.

Construction costs are as follows:

12-in. corrugated metal pipe, Ramp	"F"	47 ft
	"G"	41
	"H"	47
	"I"	41
Total		176 ft

Excavation, 3 ft × 2 ft × 176 ft = 40 cu yd @ $8.40/cu yd	= $ 336
Corrugated metal pipe, 176 ft @ $4.91/ft	= 865
Metal end sections, 8 each, @ $31.71	= 254
Metal frame and grate, 4 each, 16 sq ft @ $24.60/sq ft	= 394
Stone fill slope protection as required	= 100
Approximate total cost	$2,000

If the gore and windrows are not plowed, the possibility exists of reduced sight distance at the entrance ramps. On superelevated ramps the pavement slope is carried for 2 ft on the shoulder beyond pavement edge, creating the problem of drainage across the ramp when snow is allowed to remain and melt in this area. However, no difficulty should exist if the shoulder is plowed before significant melting occurs.

Safety is the principal benefit provided by drainage of ramp separations, gores, and snow storage.

SAFETY

Based on figures for 1966 from the National Safety Council, the cost due to one fatality was $186,500. The fatality rate on Interstate highways was 2.6 per 100 million vehicle-miles in 1965. For a 5-mile section of 4-lane highway with a 6,000 ADT, the fatality rate would convert to one death every 3.5 years, or an economic loss per year of $53,400. For a 1-mile section, the economic loss would be $10,700 per year.

Compared with the $2,000 to $4,000 initial cost of installing gore drains, the increased expenditure would be worthwhile if just one fatality were prevented every 3 to 4 years. No actual data are available on how many fatalities would be prevented by construction of gore drains. However, improved operating safety for such nominal cost seems justified.

Admittedly, it is not valid to compare the cost of constructing interchange gore drains with the user benefit to be obtained by a reduction of main-line accident rate. However, the preceding figures are quoted to indicate the relative dollar value of the two items.

DRIFTING

Having been designed and constructed before the 1968 Safety Standards were issued, this highway interchange generally carries 1 on 5 slopes except near bridges, box culverts, etc., where it transitions to 1 on 2. Slopes of 1 on 2 used near bridges in the interchange may result in drifting under certain wind and snow conditions. Assuming prevailing winds from the northwest and west, several locations were examined.

Areas of high fill (more than 15 ft on the main pavement) may cause drifting in the ramp separations but should present no problem to plowing. Flattening of slopes would not be justified until an actual problem is encountered that cannot be foreseen at this time. In most instances sufficient right-of-way is available, however, for only limited change in slope.

APPENDIX G

ECONOMIC ANALYSIS OF SLOPE MODIFICATION

Drifting has been identified as a significant problem in areas of heavy snowfall and high prevailing winds. Several solutions are available such as the use of snow fence, planting of tree or shrub windbreaks, or modification of the side slopes to eliminate drifting. A New York interchange (Chautauqua Lakeway with New York Route 5 and New York Route 30) was selected for comparison of the reduced maintenance expenditures for snow and ice control with the additional construction cost for flattened slopes in fill sections.

AASHO design policy recommends a 2 on 1 slope for fills of more than 15 ft. Assuming that an average ramp has 400 ft of 2 on 1 slope for fills of 15 to 30 ft, the increased cost in order to flatten the slopes to 4 on 1 (Fig. G-1) was calculated.

$$\text{Volume of fill per mile} = \frac{450 + 1{,}800}{2} \times \frac{5{,}280}{27}$$

$- 220{,}440$ cu yd

Construction cost per mile = 220,440 cu yd × $1.50 = $330,660

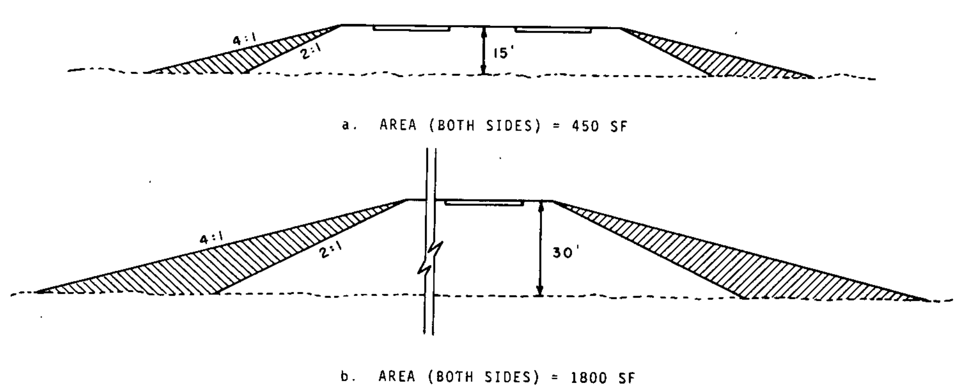


Figure G-1. Slope modification details.

For one diamond interchange with four 400-ft ramps:

$$\$330,660 \times \frac{1,600}{5,280} = \$100,000$$

Subtract $5,000 per ramp for guardrail.

Total investment = $100,000 −($5,000/ramp × 4)= $80,000

Cost per ramp = $20,000

Assume that the ramps are the critical drift areas and that the main line can withstand more snow before requiring plowing. A call for plowing the ramps, however, means that the main line will also be plowed. Further assume that after slope modification the required ramp plowing will be reduced by half. Considering the example interchange, the trumpet interchange at NY 5 and the diamond interchange at NY 20 could be considered as a unit with a turnaround about 2,300 ft southeast of NY 20 and a turnaround approximately 2,000 ft northwest of NY 5. Although not exactly comparable, for an approximation assume 8 ramps with slope modifications costing $20,000 each, 8 × $20,000 = $160,000 additional investment. Amortized over a 40-year life, investment would be $4,000 per year, not including initial cost of right-of-way, seeding, or annual cost of mowing.

Average plowing costs for the State of New York, including operator wages, equipment, and materials, are approximately $2,000 per center-line mile per year. Assume that the entire roadway between the two interchanges will be plowed when the ramps require plowing. This will require that 10,000 ft of roadway be plowed. The cost is:

$$\$2,000 \times \frac{10,000}{5,280} = \$3,790 \text{ per year}$$

If plowing requirements are reduced by 50 percent by the slope modification, the benefit or reduced cost realized by this addition is $1,895. The benefit/cost ratio will then be: $\frac{1,895}{3,790} = 0.50$.

The cost of modifying the slopes to reduce snowplowing requirements is therefore prohibitive. Because the analysis assumes that a bare pavement policy is maintained, it is assumed that there is no extreme inconvenience or economic loss to the driving public and therefore no such cost has been included.

Slopes of 6 on 1 in fill areas would require even greater right-of-way and greater construction costs, making the investment even less attractive.

The problem of drifts in cut areas is more costly, partly because the required slope to eliminate drifting is 6½ on 1 and partly because the storage area is reduced. The recent policy of holding a 6 on 1 slope for 30 ft beyond the edge of pavement primarily for safety reasons has a beneficial side effect of more storage room for plowed snow in cuts. It also provides a place for drifts to form off the traveled way. To flatten cut slopes to 6½ on 1 would be prohibitive in urban areas because of the high cost for earthwork and right-of-way. The present trend of flattening to a 3 on 1 slope and eliminating bench ditches may be effective in reducing the drifting problem.

APPENDIX H

SNOWMELT DRAINAGE

Characteristics of snow, density, and water content, for example, materially affect the effort required to remove snow from interchange ramps and will also affect the requirements for drainage. Many variables control the thermal and mechanical properties of snow. Meteorological conditions at the time of snowfall, such as air temperature, wind velocity, and humidity, affect the type of snow and the rate of snowfall. Conditions on the highway after deposition, such as the amount of handling or compaction by plowing and traffic, also affect snow characteristics.

SNOW DENSITY AND WATER EQUIVALENT

The depth of snowmelt in inches for a given depth of snow on the ground is termed "water equivalent"; for example, 3.0 in. of water per 30 in. of snow. The ratio of water equivalent to depth of snow is commonly termed snow density; i.e.,

$$\text{Density} = 3.0 \text{ in.}/30 \text{ in.} = 0.10$$

Average densities generally recognized for snow on the ground are:

0.05	Freshly fallen snow at high altitudes.
0.10	Average for freshly fallen snow.
0.2 to 0.3	Late-winter snow 1 or 2 ft in depth.
0.4 to 0.6	Common in regions of heavy snow accumulation by the time of spring thaw.
0.8 to 0.9	Compacted snow in glaciers.

Note: Strictly speaking, the depth of water per unit depth of snow is termed specific gravity and is dimensionless. Density is defined as mass per unit volume (i.e., the ratio of the weight of a quantity of snow to its volume) and averages 6.2 lb/cu ft (0.10) for dry, undisturbed snow.

The lower values will be encountered when the snow is dry and undisturbed by traffic or plowing operations. Agitation by the wind and traffic or air temperatures at or above the melting point will result in a wet snow and higher densities.

U.S. Weather Bureau *Technical Paper No. 50,* "Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States," presents data on the maximum observed water equivalent for snow on the ground during each half of March for nine years on record. The average density or ratio of water equivalent to depth of snow cover was computed to be 0.23 for the first half of March and 0.22 for the second half. These values are higher than the previously cited average for freshly fallen snow for two reasons: (1) they represent "snow cover," which includes freshly fallen snow and/or snow that has been on the ground for a while, and (2) snow cover in March is likely to have a fairly high water equivalent because of warmer temperatures and frequent melting.

Data on water equivalents are available on an hourly basis through the U.S. Weather Bureau for all first-order reporting stations throughout the U.S. Data for a particular area may be used to determine whether snowfall would be the critical factor controlling highway drainage requirements.

In the absence of such data, a general calculation may be made as follows.

As an example calculation for water equivalent, assume a 3-hr-duration snowstorm at a constant snowfall intensity or rate of 1.5 in. per hour. This would yield an approximate snow depth of 4.5 in., assuming a ground temperature of 32°F or less. At a density of 0.10 in. of water per inch of snow depth, the 3-hr accumulation would yield 0.45 in. of water for a water equivalent of 0.15 in. per hour.

SNOWFALL RATE

The American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) obtained data from the U.S. Weather Bureau in 1949 for a project on pavement snow melting systems. Results of this study are published periodically in the ASHRAE *Guide and Data Book,* Volume 2, "Applications."

Temperature, snowfall rate, and water equivalent information had been collected four times daily from November to February from 1940 to 1949 for 10 selected cities. These data were evaluated to determine the number of readings at various snowfall rates with maximum temperature below freezing in a 6-hr period. The weighted snowfall rate in equivalent inches of water per hour was reported as follows:

CITY	SNOWFALL RATE IN EQUIVALENT INCHES OF WATER PER HOUR
Albany, N.Y.	0.16
Asheville, N.C.	0.08
Billings, Mont.	0.08
Bismarck, N.D.	0.08
Cincinnati, Ohio	0.08
Cleveland, Ohio	0.08
Evansville, Ind.	0.08
Kansas City, Mo.	0.16
Madison, Wisc.	0.08
Portland, Maine	0.16
Average	0.10

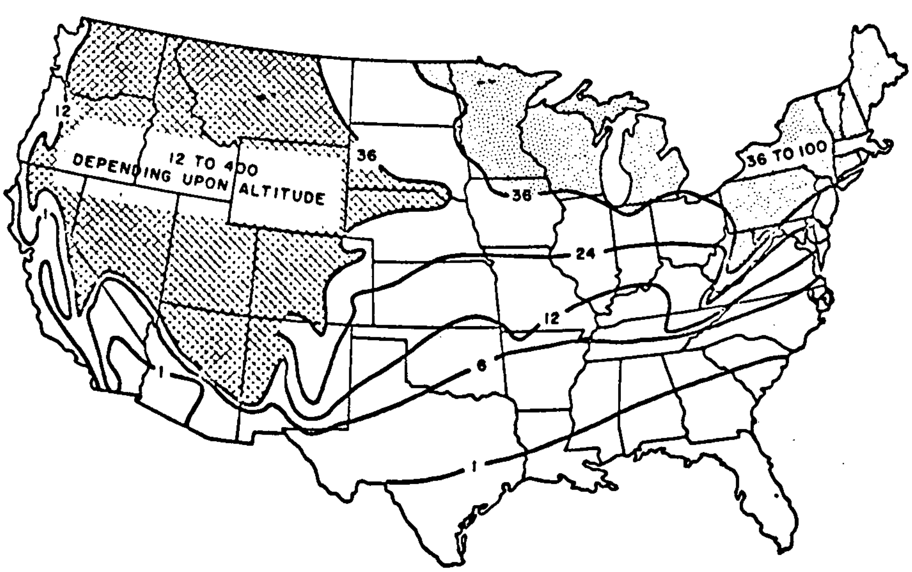


Figure H-1. Mean annual snowfall in inches (U.S. Department of Commerce).

TABLE H-1

GENERAL INFORMATION ON SNOWFALL IN THE UNITED STATES

City	Approx. mean no. of days per year w/1 in. or more snow on ground	Mean no. of in. per year of snowfall	Greatest snowfall in 24 hr (in.)	Greatest depth of snow on ground (in.)	Mean no. of days per year w/snowfall of 1 in. or more
Albuquerque, N. Mex.	20	8.6	6.8	6.8	4
Amarillo, Texas	15	19.2	20.6	13.5	6
Boston, Mass	70	42.5	16.5	23.0	10
Buffalo-Niagara Falls, N. Y.	95	74.4	24.3	32.0	22
Burlington, Vt.	140	65.4	24.2	27.0	20
Caribou-Limestone, Maine	110	102.3	18.2	51.0	31
Cheyenne, Wyo.	100	56.4	16.5	21.0	17
Chicago, Ill.	70	33.8	14.9	24.7	10
Colorado Springs, Colo.	40	24.3	23.0	32.6	17
Columbus, Ohio	50	21.7	11.9	13.5	6
Detroit, Mich.	85	39.8	24.5	26.0	13
Duluth, Minn.	140	54.9	23.0	38.6	16
Falmouth, Mass.	30	21.2	15.0	18.2	35
Great Falls, Mont.	100	53.5	11.0	18.3	20
Hartford, Conn.	65	40.5	19.0	32.8	11
Lincoln, Nebr.	40	26.3	12.4	17.1	9
Memphis, Tenn.	10	5.2	18.0	10.2	2
Minneapolis-St. Paul, Minn.	110	42.2	16.2	31.0	12
Mountain Home, Idaho	50	17.7	13.0	18.0	8
New York, N. Y.	35	30.9	25.8	24.0	8
Ogden, Utah	55	88.7	15.3	23.0	18
Oklahoma City, Okla.	20	8.0	11.3	10.5	3
Philadelphia, Pa.	35	21.5	21.0	26.0	6
Pittsburgh, Pa.	70	34.7	17.5	23.0	11
Portland, Oreg.	10	12.6	16.0	19.0	4
Rapid City, S. Dak.	100	33.2	18.3	18.0	34
Reno, Nev.	30	28.4	22.5	30.0	6
St. Louis, Mo.	40	17.3	20.4	15.6	5
Salina, Kans.	33	17.9	12.3	12.0	4
Sault Ste. Marie, Mich.	130	83.5	14.3	36.2	29
Seattle-Tacoma, Wash.	20	11.7	21.5	29.0	2
Spokane, Wash.	65	38.2	13.0	29.0	33
Washington, D. C.	30	19.9	25.0	34.2	6

*From Chapman, Air Conditioning, Heating and Ventilating, vol. 54, no. 8, Aug 1957.

TABLE H-2

ELEVATION CORRECTION FOR SOLAR RADIATION (FOR EACH 2,000 FT ABOVE SEA LEVEL, RADIATION VALUES DERIVED FROM FIG. H-2 SHOULD BE INCREASED BY THE PERCENTAGE INDICATED FOR DATE AND LATITUDE)

DATE *Read Down December to June*	NORTH LATITUDE									DATE *Read Up June to December*
	40°	50°	60°	66°	70°	75°	80°	85°	90°	
	Percentage Increase Per 2000' elevation									
11/23-12/21	4	5	8			*Sun*				11/23-12/21
12/22-1/21	3	4	7	10			*Below*			1/5-11/22
1/22-2/8	3	3	5	9	11			*Horizon*		10/21-11/4
2/9-2/23	3	3	4	6	7	10				10/7-10/20
2/24-3/8	2	3	4	4	5	7	12			9/24-10/6
3/9-3/21	2	3	3	4	4	5	7	11		9/11-9/23
3/22-4/3	2	3	3	3	4	5	6	8	7	8/28-9/10
4/4-4/16	2	3	3	3	3	4	6	5	4	8/13-8/27
4/17-5/1	2	2	3	3	3	4	4	3	3	7/24-8/12
5/2-5/21	2	2	3	3	3	3	3	3	2	6/22-7/23
5/22-6/21	2	2	3	3	3	2	2	2	1	5/22-6/2

66° *Arctic Circle*

These values are comparable to the 0.15 per inch per hour developed in the previous example.

Information on typical snowfall conditions for the U.S. and for various cities is shown in Figure H-1 and given in Table H-1, respectively.

NOMOGRAPH AND ITS USE

Table H-2 and Figures H-2 and H-3 show a nomograph for the determination of equivalent melt in inches or centimeters per day. The nomograph and the explanation of its use are abstracted from *Research Paper 8*, "Nomographs for Computation of Radiation Heat Supply," U.S. Army Snow, Ice and Permafrost Research Establishment, Corps of Engineers, 1954.

The simplest way to explain the use of the nomograph is to set up an example problem and follow it through each of the charts. For the purpose of illustrating the procedure, the following conditions are assumed:

1. Date—10 April
2. Latitude—45° North
3. Sky condition (cloud cover)—5/10
4. Elevation of site—4,000 ft MSL
5. Age of snow surface (time since end of last snowfall)—3 days
6. Maximum daily temperature— + 12°F
7. Density of snow—30%

The heavy dashed line, marked Ia, Ib, IIa, IIb, and IIc, shows the steps to be used in following these conditions through Figures H-2 and H-3. Figure H-2 is entered at the bottom at the 10 April date, proceeding upward (line Ia) to the 45° point, midway between the curves for 40° and 50° north latitude, moving horizontally (line Ib) to the intersection with the sky-condition lines, and then downward parallel to the closest diagonal line to the 5/10 cloud-cover line. A value of 490 cal/cm^2-day is indicated as the total available solar radiational heat supply at sea level for a condition of 5/10 average cloud cover for the day. To correct at this point for elevation, reference is made to Table H-2.

For the latitude of 45°N, and the period between 3 April and 16 April, the correction, determined from Table H-2, is between 2 and 3 percent, or 2.5 percent per 2,000 ft. At 4,000 ft, therefore, a correction of 5 percent must be added to the indicated available radiation. The corrected value for the total daily solar and sky radiation received by a horizontal surface at this site would then be $490 + (490 \times 0.05) = 514.5$ cal/cm^2.

To determine the actual amount of the radiational heat that may be absorbed by the snow, the correction for elevation should be made graphically; and Figure H-3 is entered by proceeding horizontally (line IIa) from the original value of 490 cal on Figure H-2 to an intersection with the 5 percent elevation correction curve on Figure H-3. At this point a correction for the albedo (or reflectance) of the snow surface must be introduced. For a 3-day-old snow surface that has not been subject to temperatures above freezing, a 75 percent albedo is indicated by the graph inserted in Figure H-3. From the 5 percent elevation correction, it is necessary to move upward (line IIb) to the point representing 75 percent albedo within the family of dashed lines for the albedo of the snow surface. By proceeding horizontally from this point (line IIc), the total amount of solar radiation absorbed by the snow cover is determined to be 125 cal/cm²-day.

A portion of the solar radiation absorbed by the snow cover is lost by back (long-wave) radiation to the sky. The less the cloud cover, the greater the loss by day and by night. To obtain the net heat balance for the conditions set up in the example problem, line IIc must be extended horizontally to the sky-condition lines, then projected downward parallel to the diagonal lines to the 5/10 cloud cover line. At this point, a net radiational heat gain by the snow cover of 40 cal/cm² for the 24-hr day is shown.

The amount of melt water produced by this heat supply when the snow temperature is 0°C is indicated on the equivalent melt line to be 0.5 cm, or 0.2 in. of liquid per 24-hr day.

DRAINAGE OF SNOWMELT

In areas of heavy snowfall and high accumulation during the snow season, water as snowmelt (rather than rainfall) may be the critical factor governing design of drainage facilities for highway gores and snow storage areas. Each

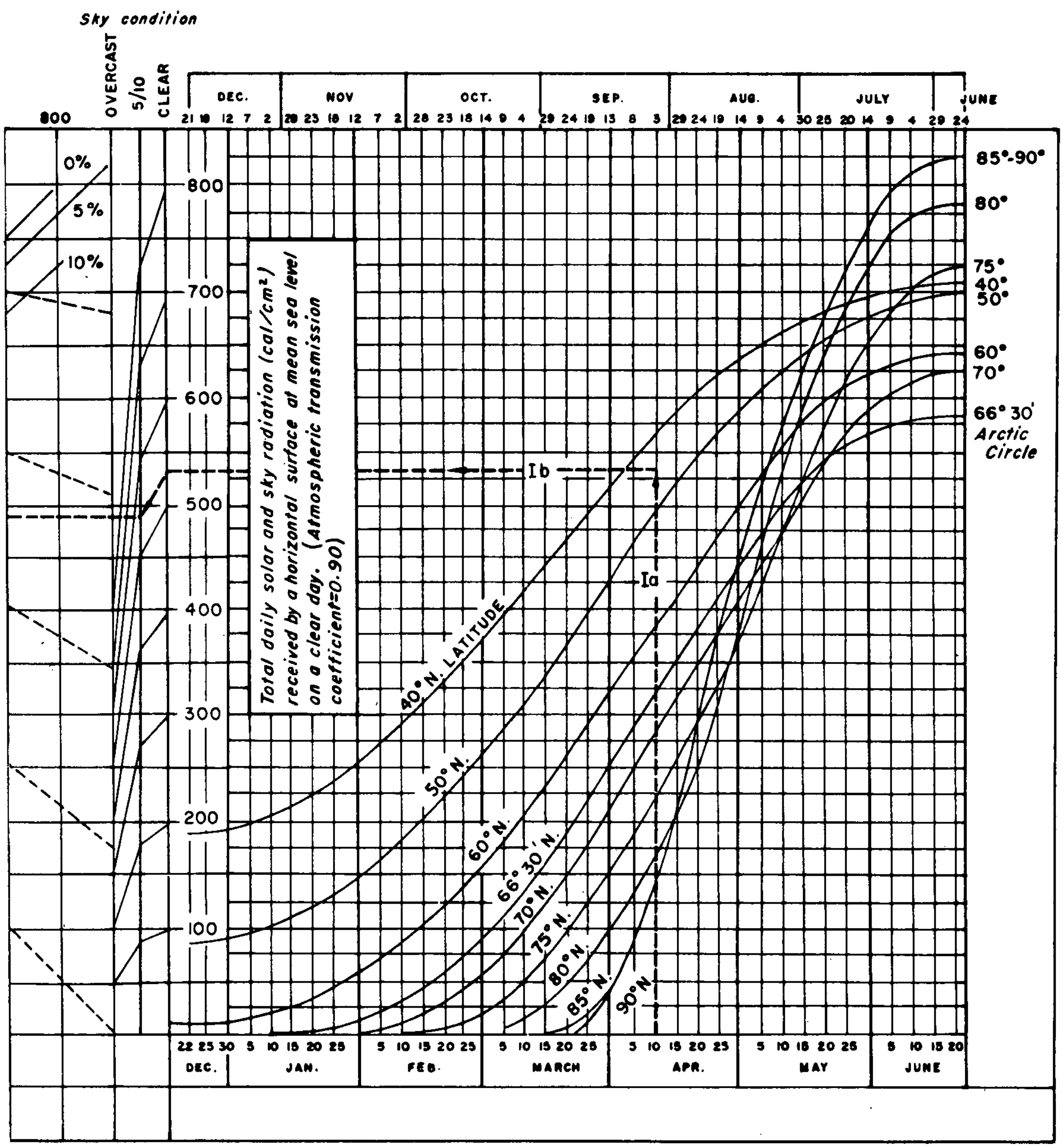


Figure H-2. Solar radiation heat supply.

interchange must be analyzed during the design phase to assure that if snowmelt is excessive it can be adequately handled by the drainage system.

The following is an example illustrating the computations necessary to determine the criticality of snowmelt.

RAINFALL RUNOFF

When one is determining the runoff from rainfall for small areas of 200 acres and less, the rational method is applicable; i.e.,

$$Q = CIA \quad \text{(H-1)}$$

in which

Q = runoff, cfs, for total drainage;
C = runoff coefficient, ratio of runoff to rainfall;
I = intensity of rainfall, in. per hr; and
A = drainage area, acres.

For Interstate highway drainage design, a 50-year rainfall frequency or return period is generally specified. An average 50-year design intensity for a duration of 1 hr may be 3.0 in. per hour. Intensities of 10 in. per hour occur for very brief durations only (5 min or less). For an example critical situation an intensity of 6 in. per

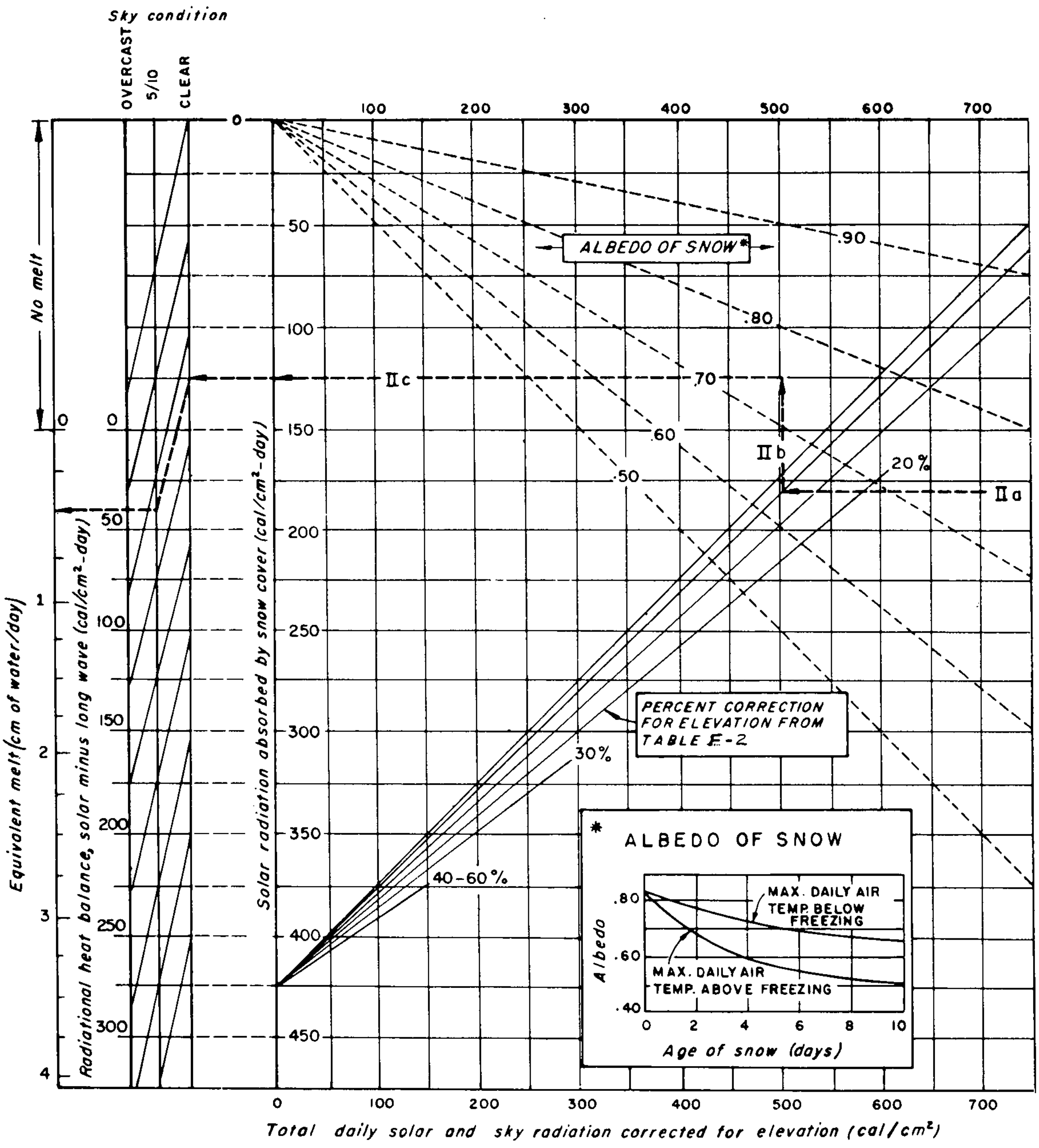


Figure H-3. Net radiational heat balance of snow cover.

hour will be used. A rainfall runoff coefficient of 0.7 will be used based on a composite of 0.8-0.9 for concrete and asphalt pavement and 0.5-0.7 for steep grassy areas (2 on 1 slope). Assume a drainage area of 2 acres.

$$Q = 0.7 \times 6.0 \times 2.0 = 8.4 \text{ cfs}$$

The rational method may be crosschecked by using the equation developed by C. F. Izzard of the Bureau of Public Roads; i.e.,

$$Q \text{ (design)} = RF \times LF \times FF \times Q \qquad \text{(H-2)}$$

in which:

Q (design) = runoff, cfs, for total drainage;
RF = rainfall factor;
LF = land-use and slope factor;
FF = frequency factor; and
Q = peak rate of runoff, cfs, $(9.0 \times \text{area})^{0.667}$

For a location in central Wisconsin (45° North latitude):

$RF = 0.8$
$LF = 1.2$ for cultivated steep (greater than 2 percent) slopes
$FF = 1.2$ for 50-year frequency
$Q = 6.87$ cfs

Therefore:

$$Q \text{ (design)} = 0.8 \times 1.2 \times 1.2 \times 6.87 = 7.9 \text{ cfs}$$

SNOWMELT RUNOFF

Referring to the rational equation, $Q = CIA$, if snowmelt runoff is assumed to occur on frozen ground, the runoff coefficient, C, will approach 0.9. Melting at the rate of 4.7 in. per hour would thus be needed to produce equal runoff, Q, of 8.4 cfs as obtained from rainfall. This rate of melting is unlikely under natural field conditions. A rate of 1.5 in. per day (as indicated by the nomograph, Fig. H-3) is the maximum likely to result, even with temperatures above freezing. Therefore, for the example situation, rainfall will be the controlling drainage design factor.

In areas not covered by the nomograph (below 40° North latitude), the rate of snow melting may increase. However, the resulting increased runoff may be counteracted by a reduced snow accumulation, and, therefore, the snowmelt in these southern areas is not likely to be critical.

APPENDIX I

EVALUATION FORMS

The Operations Evaluation Form (Fig. I-1) and the Design Evaluation Form (Fig. I-2) are presented as aids to the maintenance and design engineer so that consideration may be given to the requirements for interchange snow removal and ice control and so that potential problems and solutions may be identified.

The evaluation form is suitable for use in evaluating existing or planned interchanges. When the form is applied to an existing interchange, and combined with reports of current maintenance problems, the undesirable features of the interchange may be isolated for further study or modification. Conversely, the desirable interchange features, which may be incorporated into future operations and designs, will be identified.

The evaluation form, used to analyze interchanges under design, can serve as a basis for determining the suitability of design alternatives. The preferred design will use design standards that reduce maintenance problems to a minimum, other considerations being equal.

Operational or design standards, where applicable, are recommended on the form. The existing condition or "standard used" is to be entered on the form for comparison with the "recommended standard."

A rating procedure similar to that used in AASHO's *Policy on Geometric Design of Rural Highways* for interchange comparative analysis is recommended wherein each interchange feature is rated by a relative scale (i.e., 1—best with respect to the recommended standard; 2—next best; 3—less desirable than 2; etc.).

A numerical rating is suggested so that values for all items may be combined into a single numerical rating for the entire interchange. When one is evaluating operational or design alternatives, the best interchange from the standpoint of snow and ice control will be the one with the lowest numerical rating. Such a rating procedure is applicable to either existing or planned interchanges. Other rating procedures (for example, a "Yes" or "No" answer to the question) may be applied as desired.

Admittedly, some items included for evaluation have no recommended standards or objective measures and must therefore be rated from a subjective point of view. This procedure will create limited variation if guidelines, as developed, are kept in mind. For existing interchanges, knowledge of the relative degree of success of current snow removal operations will, of course, be helpful in the evaluation process.

The spaces for recording interchange type, mileage, weather, and traffic are included so that basic information concerning the interchange will be uniformly documented.

OPERATIONS EVALUATION FORM

Location__________ Route__________ Interchange__________

Evaluation by__________ Date__________

	Recommended Standard	Standard Used	Rating
PHYSICAL CONDITION			
1. Interchange type	Full movement		
2. Ramp mileage, total (lane mile)	Not applicable		
3. Distance to next interchange or crossover for each leg	N/A		
N			
S			
E			
W			
4. Number of structures	N/A		
ENVIRONMENT			
1. Classification of adjacent land use	N/A		
2. Weather			
a. Average annual snowfall	N/A		
b. Average annual number of storms (1" or greater)			
c. Average maximum snowfall in 24 hours			
e. Average snowfall intensity (inches per hour)			
f. Prevailing wind			
Speed			
Direction			
3. Traffic	N/A		
a. Traffic per ramp			
(1) Design capacity(VPH)			
Ramp A			
Ramp B			
Ramp C			
Ramp D			
(2) Average daily traffic			
Ramp A			
Ramp B			
Ramp C			
Ramp D			
ORGANIZATION			
1. Number of equipment units assigned to interchange?	Varies by complexity		
2. Additional lane miles (outside of interchange) assigned to above units?			
3. Average lane-mile assignment per equipment unit for	20-40 miles		
Plowing	(Varies by coverage requirements)		
Spreading			
Deadheading			
Total per run			
4. Average time of complete coverage per equipment run	2-3 hours (varies by priority)		
Full interchange			
5. Cooperative arrangements with adjacent highway jurisdictions	Complete coverage w/no duplication		
PROCEDURES			
1. Pre-planned, pre-assigned routes?	Written, posted		
2. Plowing speeds established?	20-40 mph		
3. Number of plows in echelon on ramps	2 maximum		
4. Wings used?	As required		

	Recommended Standard	Standard Used	Rating
PROCEDURES (cont'd)			
5. Blowers/loaders used?	If available		
6. Windrow prevention plan?	As required		
7. Material usage prescribed per lane-mile			
a. $CaCl_2$	As required		
b. NaCl	As required		
c. Fine aggregate or cinders	As required		
8. Material stockpiled for interchange (quantity in tons)	As required		
a. $CaCl_2$			
b. NaCl			
c. FA or cinders			
9. Coverage frequency?	Varies by storm		
10. Stockpile location, miles from interchange?	Near as possible		
11. Critical areas and obstructions marked before storm?	Signs, delineator extensions		
CLEANUP			
1. Snow storage sites provided?	Off traveled pavement		
2. Critical areas requiring special snow removal (number)?	Varies by complexity		
3. Drainage check plan?			
EMERGENCY PLANS			
1. Number of standby units of equipment per interchange?			
a. owned			
b. contracted	As required		
2. Supplemental personnel on call (number)?			
a. employees	Pre-arranged		
b. contract			
3. Relief plan or two-shift for long storms?	Pre-planned. Maximum 12 hr. shift		

Figure I-1. Operations evaluation form.

DESIGN EVALUATION FORM

Location__________ Route__________ Interchange__________

Evaluation by__________ Date__________

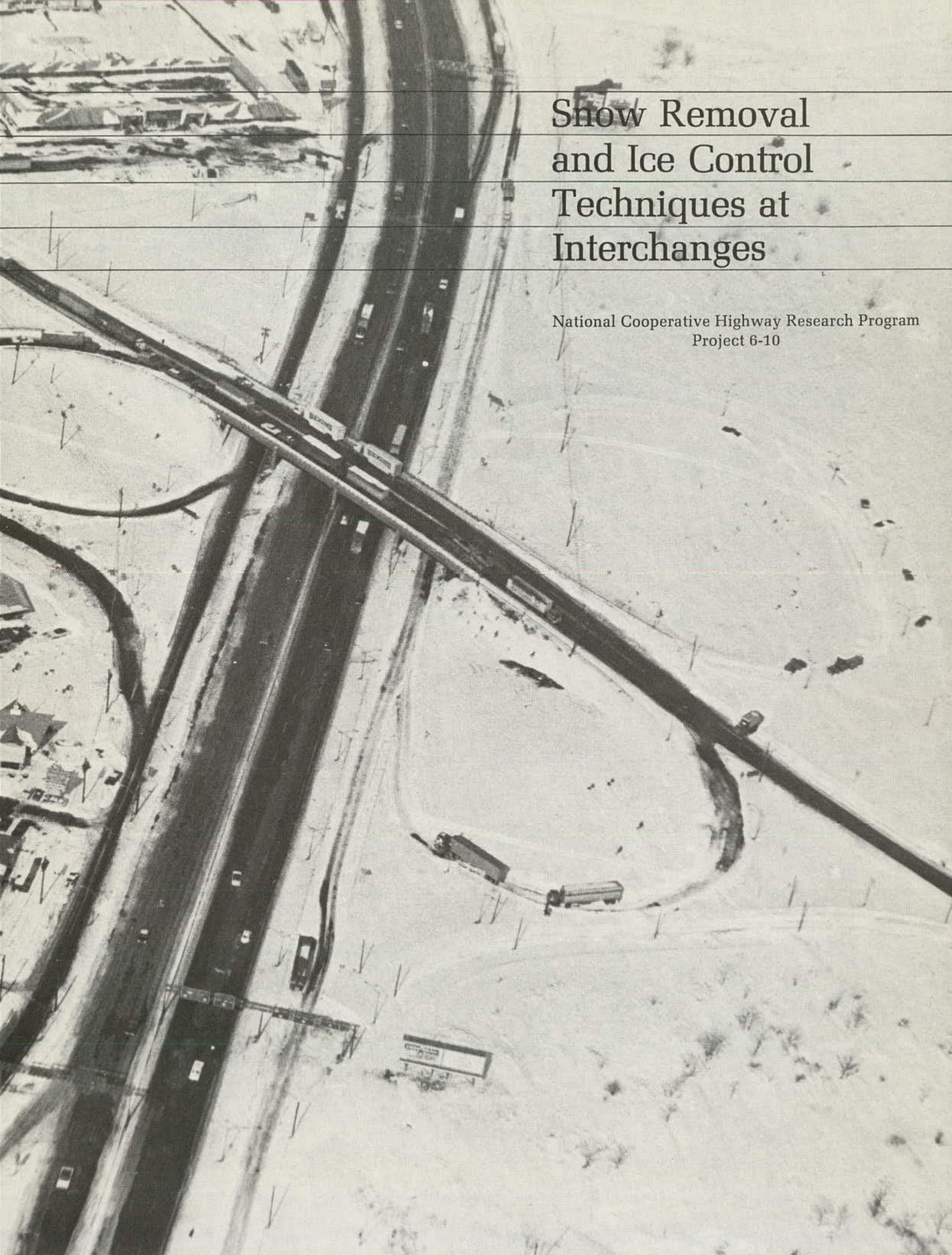
	Recommended Standards	Standard Used	Rating
TYPE AND LOCATION OF INTERCHANGES			
1. Have snow and ice control operations been given consideration in selecting interchange type?	As required	______	____
2. Is interchange planned to reduce drifting, and to achieve maximum effective use of terrain features in controlling snow and ice?	As required	______	____
GEOMETRICS			
1. Are grades on the ramps designed so that plows can maintain adequate travel speed?	5% maximum 1% minimum	______	____
2. Have snow storage and drainage requirements been accommodated?	As required	______	____
3. Are cross sections rounded where necessary to eliminate drifting?	50 foot radius	______	____
4. Is southern exposure to the sun provided on the ramps to promote snow melting?	Flatten slopes if necessary	______	____
5. Is proper superelevation provided in areas of heavy snow and ice to prevent side slipping of slow moving vehicles?	0.08 maximum 0.02 minimum	______	____
6. Are slope breaks at the shoulder adequate for drainage and safety?	0.06 maximum	______	____
7. Are side slopes designed to reduce drifting and increase safety?	Varies with cross section	______	____
STRUCTURES			
1. Is adequate temporary snow storage area provided on bridge decks?	Shoulders or sidewalks	______	____
2. Are features needed on structures to prevent casting of snow through bridge parapets or guardrails?	Barriers or baffles as required	______	____
APPURTENANCES			
1. Have delineators, signs, lighting and other appurtenances been located to permit snow plowing, storage and removal without obstruction?	As required	______	____
2. Have signs and lights been located to remain clear of snow cast by plows or blowers, where possible?	As required	______	____
3. Have guardrail sections and signs been designed and located to minimize snow drifting problems?	Streamlined, open and located as required	______	____
LANDSCAPING			
1. Are wind obstructions in the interchange that may cause drifting, such as trees or shrubs, properly located or removed.	As required	______	____
2. Are plantings located to be free of brine spray or runoff damage?	As required	______	____

	Recommended Standard	Standard Used	Rating
DRAINAGE			
1. Are drains provided in gores and other areas where snow will be stored to reduce cross-pavement drainage from snow melt?	As required	______	____
2. Are curb or gutter drains designed and located for ease of cleaning and for minimum obstruction to plowing operations?	Mounted flush and in plowed pavement	______	____
3. Are drains designed to function at or below freezing temperatures for extended periods?	Sized to accommodate ice formation	______	____
MAINTENANCE OPERATIONS			
1. Can special ramps or connections be provided within the interchange for the use of snow plowing equipment?	Inconspicuous ramps or turnarounds	______	____
2. Can areas and access be provided for equipment and/or material storage for snow and ice control?	As required	______	____

Figure I-2. Design evaluation form.

APPENDIX J

MAINTENANCE AND DESIGN MANUAL FOR INTERCHANGE SNOW REMOVAL AND ICE CONTROL



Snow Removal and Ice Control Techniques at Interchanges

National Cooperative Highway Research Program
Project 6-10

Maintenance and Design Manual for
Interchange Snow Removal and Ice
Control

I. INTRODUCTION

II. MAINTENANCE OPERATIONS

A. Plowing Operations
B. Chemical Spreading
C. Clean-Up Operations

III. INTERCHANGE DESIGN

A. Geometrics
   1. Cross Section
   2. Crossovers
   3. Side Slopes
   4. Snow Storage

B. Drains
C. Guardrail
D. Appurtenances
E. Structures
F. Maintenance
   Storage Yards

Introduction

This manual is presented for use in planning and conducting snow removal and ice control maintenance operations in highway interchange areas. In addition, the information and guidelines contained herein are intended for use in designing highway interchanges to reduce the need for snow removal and to accommodate snow removal and ice control operations when required.

Maximum emphasis is given to typical conditions of both good and poor operations and design criteria through the use of illustrations and diagrams. A minimum of text is included.

Primary attention is paid to high-classification highway interchanges which accommodate large traffic volumes and are relied upon by the traveling public to continually provide a high level of service.

This manual is directed to all agencies whether state, county, town or private, which have responsibility for the efficient, orderly and economical control of snow and ice on highways. In a peripheral nature, numerous observations and recommendations are applicable to airfields as well.

There is nothing about the suggestions presented within this manual which will assure easy snow removal for all interchanges. Each interchange, in fact each and every interchange ramp, is unique and must be designed and maintained as conditions dictate.

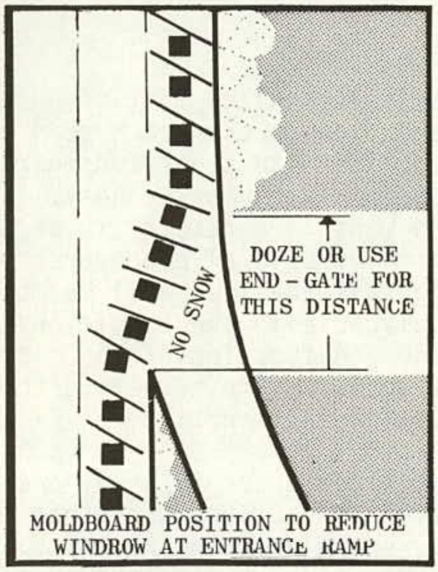
It is recognized that some recommendations presented herein may conflict with other considerations, such as safety or economy. Sound judgment is necessary in deciding which of several procedures or design alternatives will be most applicable to the conditions at hand. A function of the manual is to assist in selecting the most suitable alternative.

Users are urged to apply the manual in an active, concerned effort to reduce existing problems. From such a concern, improved interchange designs and maintenance operations for snow removal and ice control will result.

MAINTENANCE OPERATIONS

A. Plowing Operations
B. Chemical Spreading
C. Clean-Up Operations

Maintenance Operations — A. Plowing Operations



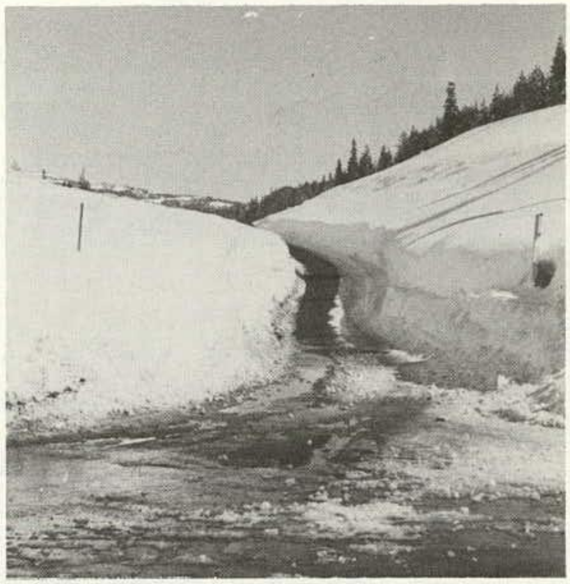
MOLDBOARD POSITION TO REDUCE WINDROW AT ENTRANCE RAMP

Windrows resulting from plowing across entrance or exit ramps present an unexpected obstacle to the vehicle driver and a definite safety hazard. Solutions include:

1. Use of an end-gate on plow moldboard to stop discharge in gore area.

2. Rotate plow to doze and carry snow across gore as shown in the diagram.

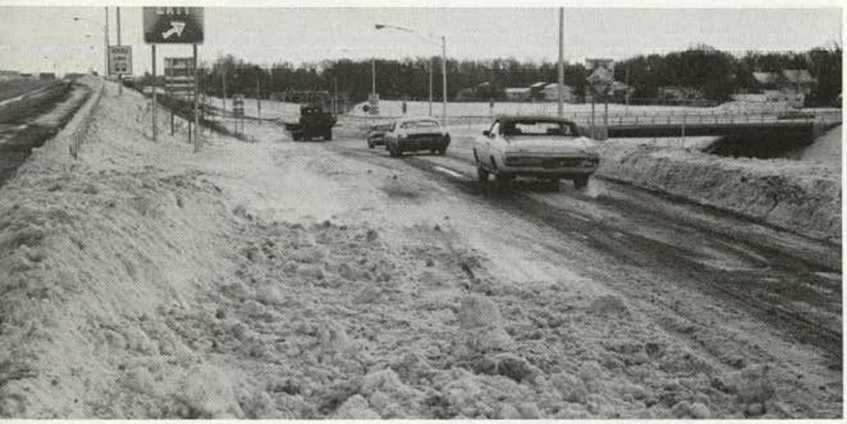
In areas of heavy snow accumulation, windrows on the entrance or exit ramp can obstruct driver sight distance and create a severe safety hazard. Such areas should be of first priority for clean-up operations.



The existence of parallel windrows on either side of the traveled pavement severely restricts snow storage for future storms.

A. Plowing Operations

If gore areas are of limited snow storage capacity, the plows may attempt to push more snow than the blade will handle. The result will be snow dropped onto the pavement. Plow speed and moldboard angle sufficient to obtain snow cast are necessary.



When plowing, difficulty may be encountered negotiating small radius ramp curves, especially with the larger equipment. Plow operators failing to follow the ramp pavement when plowing may wander off onto the shoulder. Traffic will follow the plowed path resulting in unnecessary use of the exposed shoulder. The solution: Effort by the operator to remain on the pavement by using the delineators.

On superelevated ramps, snow should be plowed to the low side. This operation will leave a windrow of snow in the center of the ramp for a period of time depending upon whether one or two plows are being used. A second plow following close behind to clear the windrow is preferred. A loader or blower and a following truck may be used to remove snow from the high side.

B. Chemical Spreading

Spinner-type spreaders are in common use for distributing chemicals and sand. Mounting the spinner on the left-hand side of the truck or the use of directional casting equipment, allows distribution across two lanes as the truck travels the outside lane of the mainline. On superelevated ramps, however, care must be exercised in order to spread to the high side.

C. Clean-Up Operations

In areas of heavy snowfall, a motor grader with attached cutter bar may be used to cut back drifted, overhanging snow. Following behind the grader, a snow blower is used to transfer the snow further back on the slope.

Wing plows are useful for clearing shoulders of snow and casting over or through the guardrail.

Operations requiring plows to oppose traffic by backing up the ramp, should be prohibited. An extreme safety hazard is created when a queue of vehicles forms behind the plows. Routing of plows which avoids this problem is necessary.

INTERCHANGE DESIGN

A. Geometrics
B. Drains
C. Guardrail
D. Appurtenances
E. Structures
F. Maintenance Storage Yards

Interchange Design — A. Geometrics/Cross Section

Interchange geometrics may contribute to several significant snow and ice control problems. Among the factors to be considered are:

1. Cross Section
2. Crossovers
3. Side Slopes
4. Snow Storage

Problem: Cross-drainage of snow melt across superelevated ramp subject to refreezing.

Design Technique:
1) Reverse slope on shoulder and in gore area
2) Add catch basin in gore to accommodate drainage.

Gore area which allows snow melt runoff across pavement. Gore should be graded slightly toward a flush mounted drain located in the center of the gore.

Drainage may be more easily accomplished on the low side of superelevated ramps by using curb and gutter to control flow. A preferred drain grate design is shown. Note the painted "teardrop" on the pavement to indicate location of drain when it is covered by windrow of snow.

A potential icing hazard from snow melt if freezing temperatures should occur. A reverse shoulder slope is needed.

A. Geometrics/Crossovers

A typical median crossover as found in many states is shown. The advantages of crossovers are increased convenience and reduced deadhead for maintenance and emergency vehicles. The major disadvantage is that a severe safety hazard is created. Public traffic will continue to use the crossover in spite of signs making turnarounds illegal.

Crossovers installed on narrow medians provide limited area for large vehicles to clear the traveled portion of the roadway. Diagonal or modified "S" crossovers are an alternative solution. Existing underpass or overpass structures may also serve as crossover locations.

A. Geometrics/Side Slopes

Severe slopes and grade changes cause drifting onto the ramp pavement. If practical and economical, slopes should be flattened to at least 4 on 1 and preferably 6 on 1 to eliminate drifting. A windbreak of vegetation planted part way down the upwind slope would help control drifting and keep the pavement clear.

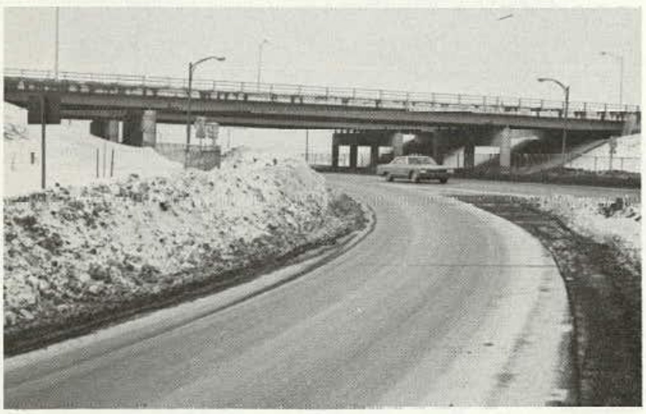
Fencing installed close to the shoulder reduces snow cast and requires shoulders to serve as permanent snow storage areas.

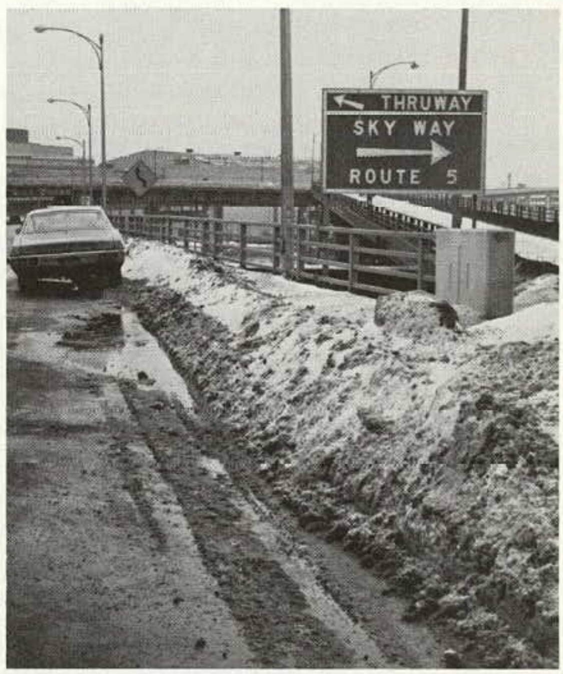
The alternative solutions are to haul thé snow elsewhere or remove by snow blower.

Lack of storage area in regions of heavy snowfall results in a narrow lane width in ramp. Reduced driver sight distance occurs because of the windrow in the gore. A wider gore would have reduced this excessively high windrow.

Careful attention to grading and drainage at ramp separations is required on structures because of their use as snow storage areas and the hazard which frozen melt water would provide.

Heavy reliance upon melting by the use of chemicals is the standard operational procedure.





A. Geometrics/Snow Storage

Wide, depressed gore and wide shoulder next to the retaining wall are good design features of this ramp area.

The narrow shoulders and median of the depressed interchange shown below severely limit snow storage area. In the condition shown, additional heavy snow will result in reduced lane width.

Snow storage and plowing problems are caused by the use of a raised and crowned gore, by the use of curbs and by the use of guardrail close to the ramp.

The raised gore complicates plowing and causes snow melt to flow across the ramp pavement. The curbs on both sides could be eliminated, the gore area slightly depressed and a drain installed in the gore area and connected to the existing ramp drain. The guardrail could be moved further away from the ramp pavement to provide increased snow storage area.

Preferred drainage design is to locate the drain within the traveled portion of the pavement so that it will be cleared as the pavement is plowed.

Drainage for interchanges below grade is more difficult and generally requires an extensive drainage system. Where interchanges are closely spaced, drains may be interconnected to carry flow to a nearby outlet, a river for example, as is done for the median drain shown. Cleaning of this drain is complicated by the installation of curbing on three sides.

C. Guardrail

The problems created by guardrail are reduced snow cast, formation of windrows, and drifting onto the pavement.

Under certain wind conditions, a guardrail may be beneficial in controlling drifting and creating drifts off the pavement. Where the guardrail is omitted in the photograph below, drifting can be seen extending further onto the ramp shoulder.

C. Guardrail

If the guardrail is placed close to the ramp surface, snow storage area is severely restricted. As in the photograph below, snow must be blown over the guardrail or hauled elsewhere between storms in order to eliminate a reduction in pavement width by snow gradually extending out into the driving lane.

C. Guardrail

On median approaches to bridge structures, it is important to provide as much snow storage area as possible. If storage is limited then snow must either be transferred across the roadway, plowed ahead across the structure, blown over the guardrail by use of a snow blower, or loaded on trucks for transfer elsewhere.

Cable guardrail allows increased snow cast and is preferred from the snow removal point of view. This type of guardrail, however, does not completely eliminate the windrow problem in areas of heavy snowfall.

D. Appurtenances

The use of a raised gore area and curbs create obstacles to plowing. By constructing signs and other appurtenances in the gore, its use for snow storage is restricted. Whenever possible, signing should be on existing overhead structures or on sign supports set back of the usable shoulder.

Note the extensions on pavement delineators to make them visible to plow operators in heavy snow.

Rumble strips, although a successful means of delineation to the vehicle driver, may become damaged by plow blades or cause damage to plow blades. The area cannot be plowed clear and melt from the remaining snow will continue to flow across the ramp until exhausted.

D. Appurtenances

During clean-up operations when the snow is winged back to make room for future storms, delineators and signs will reduce the effective distance of winging. Damage to appurtenances is not unusual and maintenance time and expenditures are required for repair.

Delineators located within or close to the shoulders provide obstacles to plowing during clean-up operations. The plow must turn out into traffic in order to go around each delineator or sign.

Fences can seriously reduce the available snow storage area. Damage to the fence may result from the heavy snow and ice placed against it. Light standards and signs placed near the shoulder create obstacles to plowing. These appurtenances should be moved closer to the fence to allow increased storage and reduce the conflict with traffic and plowing operations.

A curb is shown which severely hinders plowing operations and creates a potential for plow blade damage. As can be seen by the tire tracks, the plow has driven over the curb in order to clear the storage area.

During conditions of wet, blowing snow, traffic control signs may become totally obscured. This produces a safety hazard as well as an inconvenience to the motorist unfamiliar with the area.

E. Structures

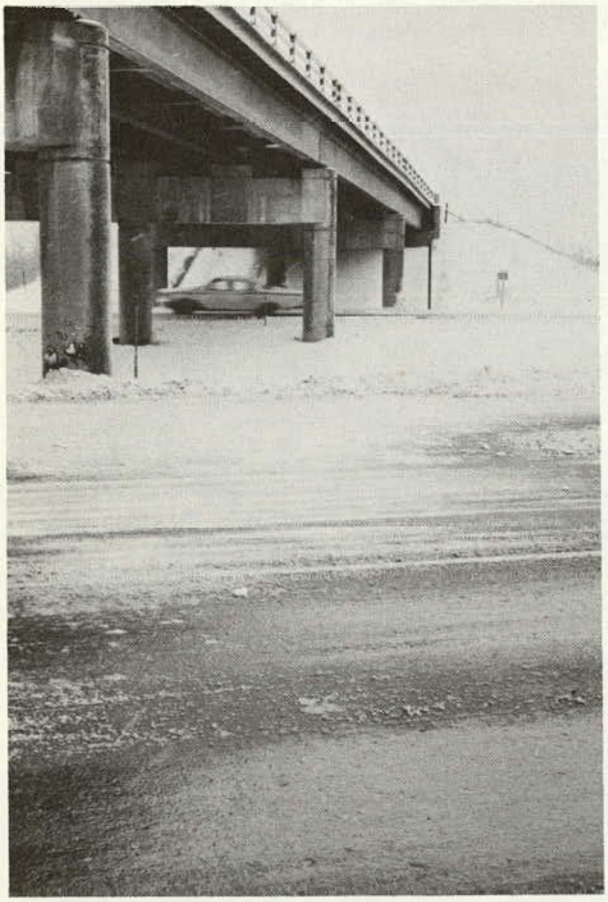
Bridge guardrails and parapets reduce snow cast which in turn creates windrows on either side of the bridge deck. These windrows produce cross-pavement drainage and the potential for drifting. Grading and drains are required to accommodate this snow melt.

Bridge drains are a necessity in order to accommodate snow melt. They should be flush with the pavement so that the plow blade will plow it clean.

Complex, elevated interchanges as shown on the inside cover present a particularly difficult snow and ice control problem. Ramps are superelevated, underlying roadways prevent casting through the guardrail and limited right-of-way reduces snow storage area to a minimum. A combination of all problems requires that attention be given to the design requirements for snow removal.

E. Structures

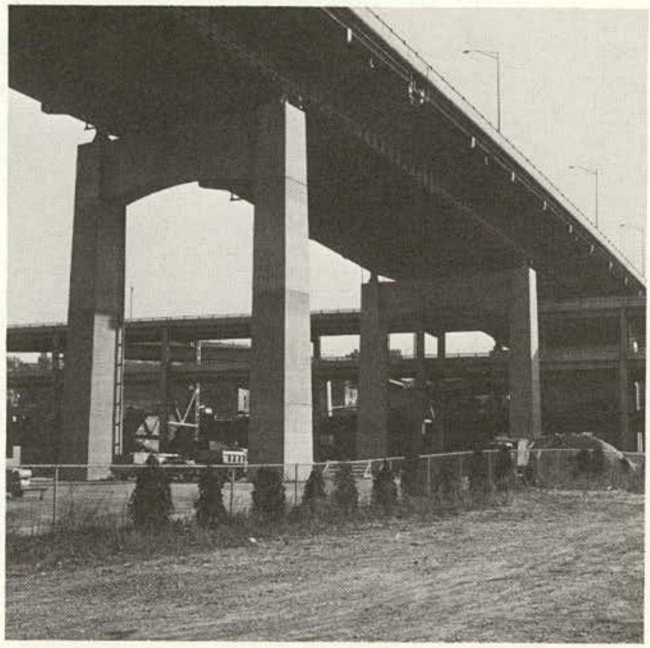
As a result of limited storage area on bridges, snow may be cast over the bridge railing onto the underlying pavement. Where this is a problem and where excessive drifting will not result, a solution technique is to use solid barriers or baffles to confine the cast snow to the bridge deck or sidewalk.



F. Maintenance Storage Yards

Areas under existing overhead structures may be used for auxiliary storage of material and equipment providing access to the highway network is available.

Storage yards for maintenance materials and equipment should be located for accessibility to the highways and interchanges being maintained. In the yard shown, sand is stored under plastic "tarpaulins" and salt stored in the shed.



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