RECEIVED
JAN 28 1975
MAT. LAB.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 25

RECONDITIONING HIGH-VOLUME FREEWAYS IN URBAN AREAS

REFER TO: ACT. INF.
MATERIALS ENGR. 1
OFFICE MANAGER
QUALITY CONTROL 7
2
PRO.
3
4
5
8-7
6
STRUCTURES
ASPHALT
AGGR.
RECEIVING
MAINTENANCE

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

TRANSPORTATION RESEARCH BOARD 1974

Officers

JAY W. BROWN, *Chairman*
MILTON PIKARSKY, *First Vice Chairman*
W. N. CAREY, JR., *Executive Director*

Executive Committee

HENRIK E. STAFSETH, *Executive Director, American Assn. of State Highway and Transportation Officials* (ex officio)
NORBERT T. TIEMANN, *Federal Highway Administrator, U.S. Department of Transportation* (ex officio)
FRANK C. HERRINGER, *Urban Mass Transportation Administrator, U.S. Department of Transportation* (ex officio)
JOHN W. INGRAM, *Federal Railroad Administrator, U.S. Department of Transportation* (ex officio)
ERNST WEBER, *Chairman, Division of Engineering, National Research Council* (ex officio)
ALAN M. VOORHEES, *President, Alan M. Voorhees and Associates* (ex officio, Past Chairman 1972)
WILLIAM L. GARRISON, *Director, Inst. of Transp. and Traffic Eng., University of California* (ex officio, Past Chairman 1973)
JAY W. BROWN, *Director of Road Operations, Florida Department of Transportation*
L. S. CRANE, *Executive Vice President (Operations), Southern Railway System*
JAMES M. DAVEY, *Managing Director, Wayne County Road Commission*
DOUGLAS B. FUGATE, *Commissioner, Virginia Department of Highways*
ROGER H. GILMAN, *Director of Planning and Development, The Port Authority of New York and New Jersey*
NEIL V. HAKALA, *President, Exxon Research and Engineering Company*
ALFRED HEDEFINE, *Senior Vice President, Parsons, Brinckerhoff, Quade and Douglas*
ROBERT N. HUNTER, *Chief Engineer, Missouri State Highway Commission*
GEORGE KRAMBLES, *General Operations Manager, Chicago Transit Authority*
A. SCHEFFER LANG, *Assistant to the President, Association of American Railroads*
BENJAMIN LAX, *Director, Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology*
HAROLD L. MICHAEL, *School of Civil Engineering, Purdue University*
D. GRANT MICKLE, *President, Highway Users Federation for Safety and Mobility*
JAMES A. MOE, *Executive Engineer, Hydro and Community Facilities Division, Bechtel, Inc.*
ELLIOTT W. MONTROLL, *Professor of Physics, University of Rochester*
MILTON PIKARSKY, *Chairman, Chicago Transit Authority*
J. PHILLIP RICHLEY, *Director of Transportation, Ohio Department of Transportation*
RAYMOND T. SCHULER, *Commissioner, New York State Department of Transportation*
B. R. STOKES, *Executive Director, American Public Transit Association*
ROBERT N. YOUNG, *Executive Director, Regional Planning Council, Baltimore, Maryland*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Advisory Committee

JAY W. BROWN, *Florida Department of Transportation* (Chairman)
MILTON PIKARSKY, *Chicago Transit Authority*
HENRIK E. STAFSETH, *American Association of State Highway and Transportation Officials*
NORBERT T. TIEMANN, *U.S. Department of Transportation*
ERNST WEBER, *National Research Council*
ALAN M. VOORHEES, *Alan M. Voorhees and Associates*
WILLIAM L. GARRISON, *University of California*
W. N. CAREY, JR., *Transportation Research Board*

Advisory Committee on Project 20-5

J. N. CLARY, *Virginia Department of Highways* (Chairman)
JACK F. ANDREWS, *New Jersey Department of Transportation*
W. S. EKERN, *Minnesota Department of Highways*
WILLIAM P. HOFMANN, *New York State Dept. of Transp.*
JOHN W. HOSSACK, *Village of Hoffman Estates, Ill.*
FRANK E. LEGG, JR., *University of Michigan*
ALGER F. MALO, *Consulting Engineer*
GEORGE W. McALPIN, *New York State Dept. of Transp.*
JOHN K. MLADINOV, *New York State Dept. of Transportation*
T. F. MORF, *Consulting Engineer*
HOWARD L. ANDERSON, *Federal Highway Administration*
ROY C. EDGERTON, *Transportation Research Board*

Topic Advisory Panel on Reconditioning High-Volume Freeways in Urban Areas

PAUL E. CUNNINGHAM, *Federal Highway Administration*
STANFORD P. GROSS, *City of Detroit*
THEODORE KOCH, *New York State Dept. of Transportation*
RICHARD A. McCOMB, *Federal Highway Administration*
CHARLES H. McLEAN, *Illinois Department of Transportation*
J. C. OBERMULLER, *California Department of Transportation*
FRANK D. SHEPARD, *Virginia Highway Research Council*
A. G. CLARY, *Transportation Research Board*
W. G. GUNDERMAN, *Transportation Research Board*
K. B. JOHNS, *Transportation Research Board*

Consultant to Topic Advisory Panel

LLOYD G. BYRD, *Byrd, Tallamy, MacDonald and Lewis, Division of Wilbur Smith and Associates*

Program Staff

K. W. HENDERSON, JR., *Program Director*
LOUIS M. MACGREGOR, *Administrative Engineer*
JOHN E. BURKE, *Projects Engineer*
R. IAN KINGHAM, *Projects Engineer*
ROBERT J. REILLY, *Projects Engineer*
HARRY A. SMITH, *Projects Engineer*
DAVID K. WITHEFORD, *Projects Engineer*
HERBERT P. ORLAND, *Editor*
PATRICIA A. PETERS, *Associate Editor*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **25**

RECONDITIONING HIGH-VOLUME FREEWAYS IN URBAN AREAS

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

AREAS OF INTEREST:
- PAVEMENT DESIGN
- PAVEMENT PERFORMANCE
- CONSTRUCTION
- MAINTENANCE, GENERAL
- TRAFFIC CONTROL AND OPERATIONS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1974

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

NCHRP Synthesis 25

Project 20-5 FY '73
ISBN 0-309-02304-1
L. C. Catalog Card No. 74-17241

Price: $4.00

Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.
The members of the advisory committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the advisory committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.
Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.
The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

(See last pages for list of published titles and prices)

Printed in the United States of America.

PREFACE

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

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

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to highway administrators and engineers faced with the many problems involved in planning, designing, constructing, and providing traffic controls when major rehabilitation projects must be undertaken to restore the structural capability of badly worn pavements of heavily traveled freeways in urban areas. Information is presented on a variety of practices that have achieved a degree of success in a number of difficult situations.

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

An important mileage of the pavement of busy urban freeways built in the accelerated construction programs of the 1960's is showing unmistakable signs of structural wear and deterioration indicative of a need for major rehabilitation for continued efficient operation. In fact, a significant amount of rehabilitation already has been required. A continuation of the need at an accelerated rate over the next several years is predictable. The problem of urban freeway rehabilitation is compounded by the interference of construction operations with high-density traffic, and in turn by the interference of traffic with the construction operations. The safety of both the freeway user and the construction worker are items of deep concern. The constraints of accommodating overhead structure clearances, of retention of drainage features, and other problems unique to freeway rehabilitation make this type of construction a difficult and expensive effort.

This report of the Transportation Research Board records current practices in freeway rehabilitation that have been used successfully to overcome some of the problems that have been faced. Planning and programming processes that have produced good results are described step-by-step, design considerations that need to be taken into account are noted, and construction management practices inclusive of traffic control that have resulted in some successes are described. Numerous unfilled needs for improving the urban freeway rehabilitation process are identified. Some of these are being approached currently in the National Cooperative Highway Research Program (NCHRP Project 14-4), and in research programs of the Federal Highway Administration and others. Additional research still to be undertaken offers a potential for high payoff in view of the numbers of people who can be served and the economic benefits that can be realized.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from many highway departments and agencies responsible for highway planning, design, construction, operations, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. Meanwhile, the search for better methods is a continuing process that should go on undiminished.

CONTENTS

1 SUMMARY

PART I

2 CHAPTER ONE Introduction

3 CHAPTER TWO Project Planning
Project Selection
Project Objectives
Environmental Considerations
Task Forces
Public Information

10 CHAPTER THREE Design Considerations
Constraints
Design Procedure
Traffic Controls

21 CHAPTER FOUR Construction Management
Preconstruction Conferences
Traffic Handling During Construction
Removal of Deteriorated Materials
Patching
Resurfacing
Completion Schedules

24 CHAPTER FIVE Conclusions and Recommendations
Desirable Design Features
Current Research
Areas for Research

PART II

26 APPENDIX A Selected Bibliography

27 APPENDIX B Detroit Procedures for Handling Traffic During Freeway Rehabilitation

35 APPENDIX C Specifications for Repair with Precast Slabs

51 APPENDIX D California Procedure for Estimating Lane Closure Delays

54 APPENDIX E Michigan Special Provision for Concrete Pavement Patching

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers.

Special appreciation is expressed to Lloyd G. Byrd, Vice President and Manager, Byrd, Tallamy, MacDonald and Lewis, Division of Wilbur Smith and Associates, who, as special consultant to the Topic Advisory Panel, was responsible for the collection of data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Advisory Panel, consisting of Paul E. Cunningham, Chief, Maintenance Branch, Construction and Maintenance Division, Office of Highway Operations, Federal Highway Administration; Stanford P. Gross, Superintendent, Traffic Engineering Operations, Department of Streets and Traffic, City of Detroit; Theodore Koch, Associate Civil Engineer, Highway Maintenance Subdivision, Department of Maintenance, New York State Department of Transportation; Richard A. McComb, Highway Research Engineer, Pavement Systems Group, Office of Research, Federal Highway Administration; Charles H. McLean, Regional Operations Engineer, Illinois Department of Transportation; J. C. Obermuller, Assistant Construction Engineer, California Department of Transportation; and Frank D. Shepard, Head, Traffic Section, Virginia Highway Research Council.

A. G. Clary, Engineer of Maintenance; W. G. Gunderman, Engineer of Materials and Construction; and K. B. Johns, Engineer of Traffic and Operations, all of the Transportation Research Board, assisted the Special Projects staff and the Topic Advisory Panel.

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

RECONDITIONING HIGH-VOLUME FREEWAYS IN URBAN AREAS

SUMMARY

Urban freeways reaching a maturity in service life and operating at or near peak capacity present a formidable task for rehabilitation. And more than 17,000 miles (27,000 km) of controlled-access freeways in the United States are ten or more years old.

A major problem is the development of plans and procedures for rehabilitation that can be carried out without creating long-term interruptions in traffic flow patterns. Safety is a vital concern to both the highway user and the maintenance employee. In addition, with rehabilitation costs continuing to increase, maintenance budgets face heavy demands. Thus, rehabilitation programs are receiving increasing attention by highway agencies and the same comprehensive planning and preparation given to new highway construction.

Rehabilitation program planning is usually preceded by an inspection using sufficiency rating systems or other quantifiable values for project selection. Project objectives can be defined in terms of the types of repairs and/or improvements to be made and the intended service life. Both program planning and definition of objectives recognize the constraints of environmental considerations in all urban highway projects today. Air and noise pollution, waste disposal, and energy and resource utilization are considered and evaluated in the project planning phase.

Initial efforts in carrying out freeway rehabilitation projects include a comprehensive public information program if the impact of the project on urban traffic patterns is to be controlled. News conferences, news releases, radio and TV announcements, extensive signing programs, and other efforts can contribute to the orderly control of traffic while rehabilitation interrupts normal flow patterns.

The design of a rehabilitation project in an urban area needs to accommodate overhead structure clearances, retention of drainage features, limitations of work area, curing time restrictions, deadload restrictions on structures, and a cost-versus-service-life evaluation.

Typical pavement rehabilitation projects have included leveling courses and additional wearing courses of bituminous concrete, varying in thickness from 2 to 5 in. (50 to 130 mm). Some successful strip-resurfacing in each wheelpath (where rutting had occurred) has been completed by the New York State Thruway Authority. Slip-form paving of thin bonded concrete resurfacing has been performed experimentally in Greene County, Iowa.

In establishing traffic controls for rehabilitation work sites, the available alternatives include roadway closures and off-site detours, detours within the right-of-way, and lane closures or lane constrictions. Lane reversals in conjunction with median crossovers have been employed successfully by a number of agencies, but safety considerations necessitate special design features when this alternative is selected.

Construction management is of major importance in the successful implementation of a rehabilitation program. Pre-construction conferences with the con-

tractor, special assistance in traffic handling, and continuing public information programs are necessary parts of the construction activity.

Experience in reconditioning urban freeways has suggested the need for considering design characteristics for new or rebuilt freeways that will provide maintainability; i.e., accommodate the future need for maintenance and rehabilitation. Such features include parallel service roads; full-width, full-strength paved shoulders; membrane protection of bridge decks; adequate concrete cover over reinforcing steel; additional clearances under structures; drainage features positioned in anticipation of future pavement surface elevation changes; and power outlets installed along the right-of-way in conjunction with electric service to roadway lighting, signs, and signals.

Research of benefit to urban freeway reconditioning programs needs to be directed to in-situ repair techniques, replaceable wearing surfaces and parts for pavements and bridge decks, and prefabricated repair units.

CHAPTER ONE

INTRODUCTION

As the freeways in urban areas mature, many agencies face extensive rehabilitation programs in order to maintain full service on these facilities. Typically, these urban freeways are already operating at or near peak capacity for many hours each day and the prospect of performing rehabilitation work on them is a formidable one.

A few of the urban freeway systems constructed during the earlier part of the Interstate program, or before, have already undergone major rehabilitation programs and provided many lessons in performing this difficult work. Many more urban area freeways constructed during the 1960's are rapidly reaching the limits of their initial service life and the agencies responsible for them currently are facing the need to develop and carry out reconditioning programs. As a result of this aging of urban freeways and the dramatic slackening of new highway construction in urban areas, there is a significant interest and emphasis on reconditioning, maintenance, and operations of the existing highway system.

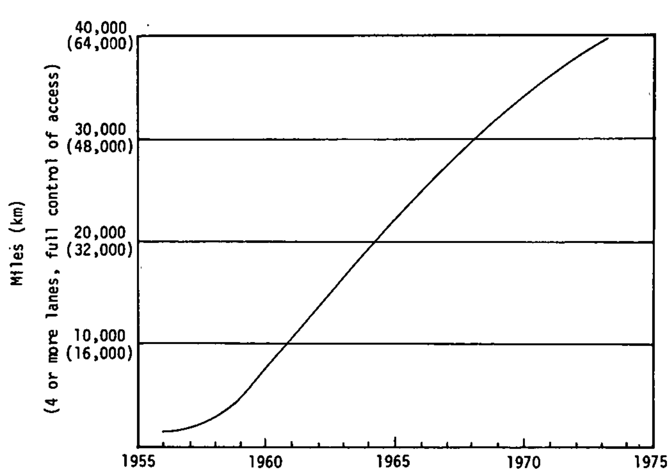


Figure 1. Increase in mileage of controlled-access freeways with four or more lanes. (From "Highway Statistics, 1973," FHWA, U.S. DOT).

In the 17-year period, 1956-1973, the length of controlled-access urban and rural freeways of four or more lanes increased from 704 to more than 38,000 miles (1130 to 61,000 km) (see Fig. 1). In 1974 that total is even greater and more than 17,000 miles (27,000 km) of the freeways are at least ten years old. With the heavy axle loads and high volumes of traffic on these facilities, the service life of pavements in terms of axle loads is being reached in less than ten years in many instances. Thus, there is good reason to predict that maintenance and reconditioning work on both urban and rural freeways will continue to increase over the next few years.

Reconditioning of high-volume freeways presents many problems for the responsible highway agency. A major problem is the development of a plan and procedure for rehabilitation that accomplishes the work without creating intolerable chaos in the traffic flow pattern for the area served. This challenge is further compounded by the need to perform the maximum amount of work possible with the always-limited dollars available for rehabilitation.

Another problem that cannot be subordinated is that of providing safety, both to the highway user and to the maintenance employee or contractor performing the rehabilitation work. Under the best of planning, freeway rehabilitation is an expensive program in terms of direct costs to the agency funding the project and in terms of service loss to users. Further, a major part of the total expense involved in such projects is consumed in occupying the freeway and controlling traffic. As a consequence, the cost of the rehabilitation work alone must be considered from a different vantage point. The longer the service life of the reconditioned system, the lower the cost per unit of time. This cost-time relationship is accentuated by the high cost of occupancy and traffic control so that greater emphasis can be put on high-quality rehabilitation without adversely affecting the ratio.

In recognition of the importance of the work and the significant investment required, many highway agencies are approaching rehabilitation projects with the same comprehensive preparation given to new construction projects. The following chapters synthesize the current practices of highway agencies with experience in the planning, design, and construction of reconditioning projects on high-volume freeways.

CHAPTER TWO

PROJECT PLANNING

PROJECT SELECTION

Inspection

Most agencies have some type of formal annual inspection (Fig. 2) of the highway system that provides the initial input for selecting rehabilitation projects. Many states use a sufficiency rating system that quantifies the conditions found on the roadway and provides a numerical rating for each section of highway. Other agencies perform an annual inspection that confines itself substantially to an evaluation of the facilities and the need for rehabilitation to restore them to as-built condition.

Serviceability Ratings

Other agencies have established evaluation procedures that take into account the axle loadings to which the pavement is being subjected and the resulting rate of deterioration that is occurring on the facility. By use of these data they are able to project future rehabilitation requirements for as much as a ten-year period (see Fig. 3). Agencies using five- to ten-year projections to program work also include an annual inspection, so the final program for each year reflects current rather than projected conditions. The five- to ten-year projections have significant value, however, in that they permit agencies to anticipate major fluctuations in the year-to-year work load and to take action wherever possible to level out these fluctuations. Projections also permit an agency to schedule the sequential performance of individual projects over a period of several years in a pattern creating the least impact on facility users while permitting the orderly completion of the work.

Structural Ratings

Current techniques for structural evaluation of pavements usually include deflection measurements made by means of the Benkelman beam, the Dynaflect, the Road Rater, or the Traveling Deflectometer.

California's pavement evaluation system includes a survey of pavement defects (which are quantified) and a measurement of roughness using a PCA Road Meter. The values of the defects and roughness are combined to give California's engineers a single Pavement Condition Rating, which is then used as one factor in a judgmental decision on the type of work warranted.

PROJECT OBJECTIVES

For the planning and design process to be carried on effectively, the project objectives in a reconditioning program must be clearly defined. Projects in the category of spot repairs performed by maintenance crews as required on a day-to-day basis for continuity of service are not considered to be reconditioning projects even though many of these repairs require to a significant degree some of the same planning and traffic control as would a larger rehabilitation project.

However, for reconditioning projects, the types of project objectives that have been defined include:

1. Repair and overlay of pavements that have deteriorated to an unacceptable level.
2. Blowup repairs and installation of relief joints.
3. Grooving, surface treatment, or other methods of correcting slick pavements.
4. Bridge deck repairs and/or waterproofing.
5. Relocation and redesign of appurtenances to meet current safety standards.
6. Geometric improvements to meet current capacity and safety requirements.
7. Lane additions and/or interchange additions to meet new capacity requirements.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

PROGRAM ANALYSIS BUREAU

FIELD SCORE SHEET

1 2 3 4	5		6	7 8	9			
Touring Route No.	Region	County		County Order No.	Control Segment No.	Scorer ____	Date ____	Sheet ____ of ____

MILE POINT	Start	10 11 12 13
	End	14 15 16 17
ROAD SECTION LENGTH		18 19 20 21
STATE HIGHWAY NUMBER		22 23 24 25 26
Structural Score	P	27
	R	28
Maintenance Index *		29
ROADWAY	Number Roadway	30
	Number Lanes	31
	Pavement Width (ft)	32 33
	Shoulder Width (ft.)	34 35
	Shoulder Type	36
	Trees	37
	Median Width	38
	Median Type	39
	Surface	40
	Base	41
	Sub-Base	42
AREA	Terrain	43
	Area Type	44
	Culture	45
CAPACITY	% Parking	46
	Passing Distance Tenths of Mile	47 48
COSTS	Work	49
	Condition	50
	R.O.W.	51
	Excavation	52
OFFICE USE ONLY	% Trucks	53 54
	Traffic Year	55
	D. H. Volume ÷ 10	56 57 58
	A. A. D. T Volume ÷ 100	59 60 61
	F A Type	62
	H N Class	63
	Hwy. Control	64
	Year Scored	65
Work Year		66 67
Access		60
E D P Control		80

*Recommendation of County Resident Engineer

Figure 2. Field score sheet used by the New York State Department of Transportation for annual field evaluation of highway sections.

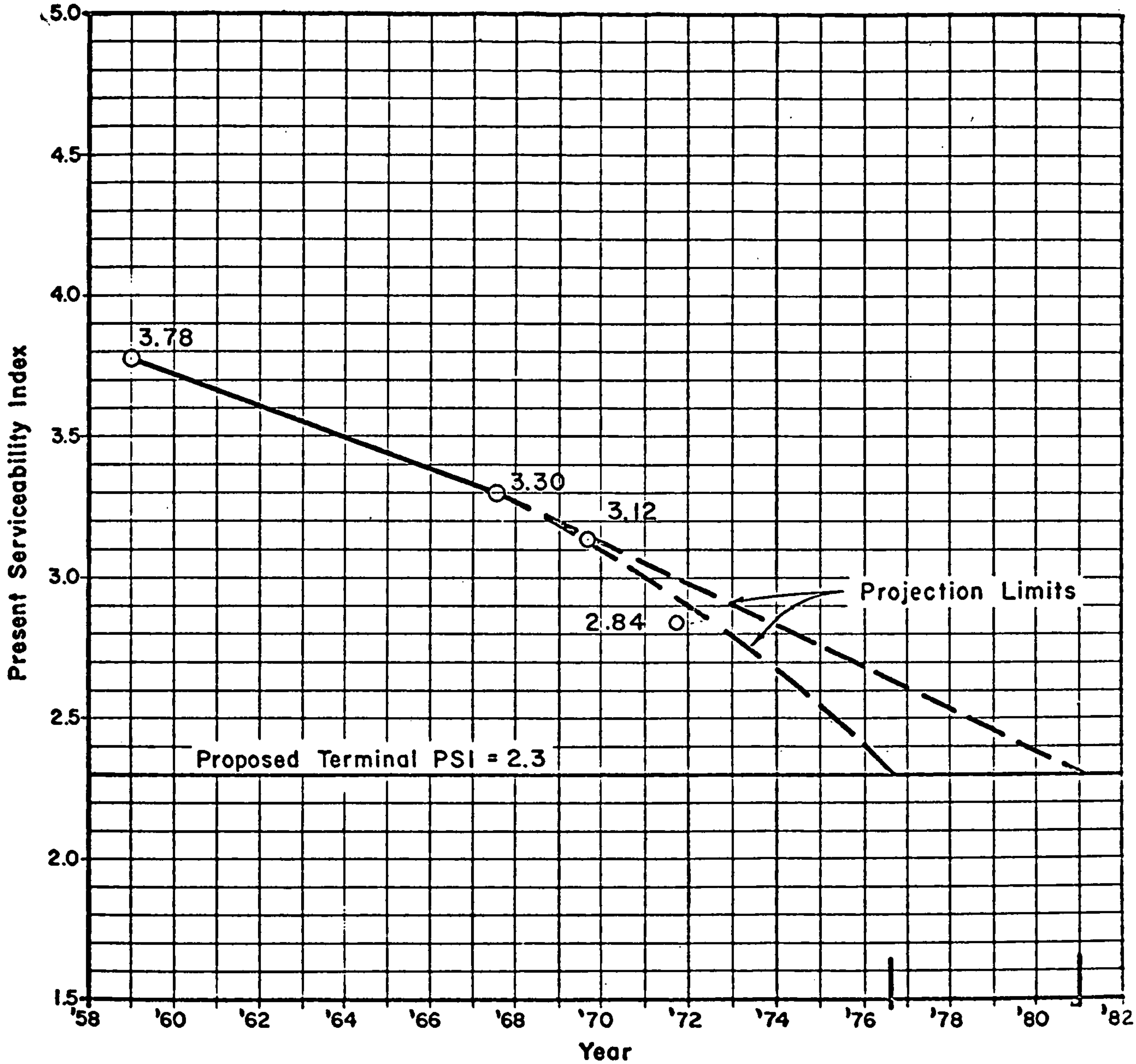


Figure 3. A pavement service life curve. The original curve was based on P.S.I. values obtained by field observations in 1959 and 1967, and high and low projections of the pavement behavior beyond 1967 were plotted as broken lines. Subsequent observations in 1969 and 1971 were plotted as points to show their relationship to the projection curves on which a long-range pavement rehabilitation program was based. (From "Long-Range Pavement Maintenance Program, Illinois State Toll Highway System, Supplemental Report No. 2, 1971," by Byrd, Tallamy, MacDonald and Lewis)

8. Major rehabilitation programs that include several or all of the foregoing.

Another element in the definition of project objectives relates to service life. Obviously, one alternative is to make quick, relatively inexpensive repairs that yield a short service life. The opposite alternative would provide for carefully designed comprehensive repair procedures requiring a significant investment and providing a long-term service life.

One method that has been developed to assist management in pavement system study and evaluation is shown in Figure 4. Recently completed research (NCHRP Project 1-10A) has refined a computer program that will give highway designers total costs over an analysis period for various design strategies.

Generally, most agencies indicate that resurfacing projects have been planned with a defined service life objective of eight to ten years. However, several agencies have reported that the achieved service life on resurfaced pavements under heavy traffic has been as low as four to five years.

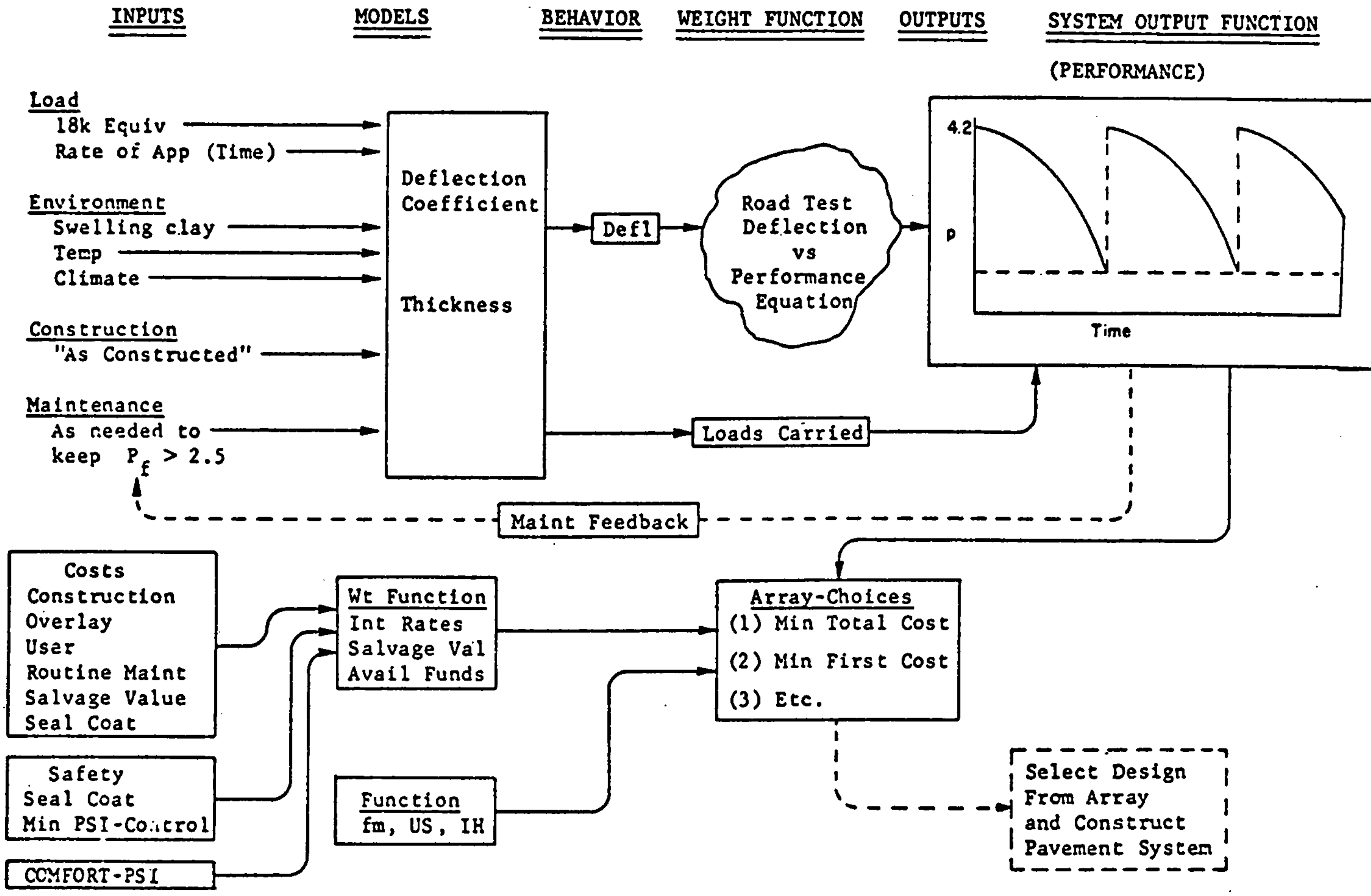


Figure 4. A conceptual diagram of a working pavement system, showing the data and processes leading to maintenance and rehabilitation decisions. (From "A General Framework for Pavement Rehabilitation," by W. R. Hudson and F. N. Finn, Workshop on Pavement Rehabilitation, San Francisco, Calif., Sept. 19, 1973)

Most agencies, when considering project objectives, recognize that a large portion of the cost is represented by the occupancy of the roadway. Research conducted under NCHRP Project 14-2, "Techniques for Reducing Roadway Occupancy Time During Routine Maintenance Activities," showed that less than 50 percent of the time that a work zone was occupied was assigned to productive work. The majority of the time was used in setting up or removing traffic controls, in curing of materials in place, and by delays (Fig. 5).

Some agencies take full advantage of the availability of a roadway to perform all currently needed maintenance activities during the occupancy period. An example of this concept was a bridge deck repair program carried out on the urban expressway system in the Chicago metropolitan area by the Illinois Department of Transportation. While the bridge deck was under repair, with a resulting lane closure on the structure, the approach pavement was also closed for a distance of approximately two miles and all required maintenance work (including pavement patching, joint sealing, shoulder repairs, and pavement striping) was carried on while the bridge deck work was under way so that these supplemental activities would not require additional traffic interference at a later date.

The Districts of the California Department of Transportation attempt to combine rehabilitation with scheduled lane additions. By including the lane addition work as a part of the rehabilitation program, the agency is able to perform the work without reducing the number of lanes of pavement available to traffic. When the lane addition is constructed, rehabilitation of the existing pavement, structures and appurtenances is performed as part of the contract.

ENVIRONMENTAL CONSIDERATIONS

As is the case with all other highway planning and construction programs today, environmental considerations become a significant factor in the planning and design of freeway reconditioning projects. Typical of the environmental considerations that must be included are growing concern over dust and sulfur dioxide emissions in asphalt plants and air pollution resulting from the dissipation of volatiles in asphalt cutbacks. A number of agencies, including the State of Wisconsin, have implemented restrictions on sandblasting as a result of air and water pollution from the dispersal of waste sand and paint and metal oxides removed by the sand. Dust dispersion from shoulder and pavement sweeping represents a violation of air pollution regulations in many areas and may necessitate use of water or other dust inhibitors as a part of such programs. Michigan has a statewide regulation requiring that tarpaulins or hard covers be fixed on all open-body maintenance trucks to prevent hauled materials from falling or being blown onto the pavement or into the air. A similar ordinance is in effect in the City of Detroit.

The problem of waste disposal is becoming acute in some areas. Removal of deteriorated concrete, steel, and other waste materials from a rehabilitation project aggravates this problem.

Burning restrictions based on air pollution concerns have prevented the use of heater planers and other burning techniques for pavement cutting and pavement repairs in some urban areas (Los Angeles, for example).

Noise restrictions have limited the use of pile drivers, air hammers, and other major construction equipment units. This problem is further compounded by a growing interest in nighttime maintenance operations, which take place during hours when noise levels are most closely regulated.

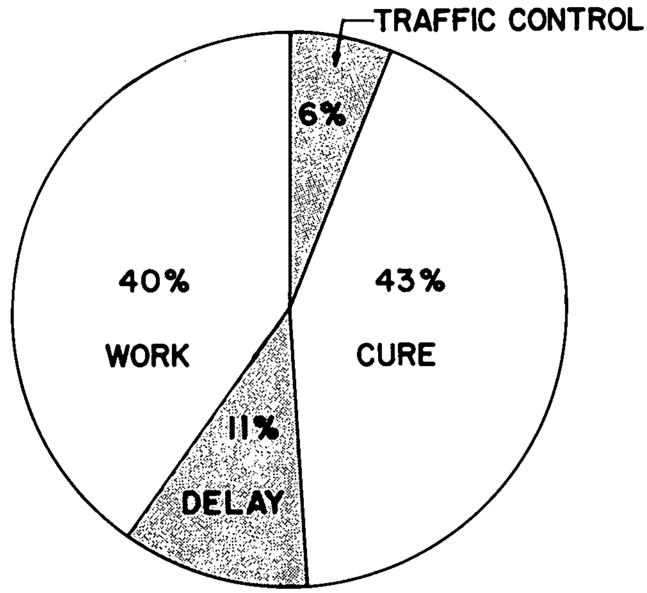


Figure 5. Average distribution of observed roadway occupancy time for concrete, cast-in-place, full-depth repairs.

TASK FORCES

Because of the complex interrelationship of the various departments or bureaus within the highway organization concerned with freeway reconditioning projects, several agencies have adopted the task force concept for successful development of such projects. The task force consists of representatives from planning and programming, design, traffic engineering, construction, maintenance, and the public information offices of the agency plus local law enforcement agencies. This task force defines the objectives of the project, reviews the design concepts, the construction plans, the method for handling traffic, and the proposed public information program. The task force monitors the project from its inception through the contract letting.

In some instances, the responsibilities of the task force have continued through the construction of the rehabilitation project so that the lessons learned during the performance of the contract can be quantified, evaluated, and recorded for the benefit of future planning.

In addition to the internal task force or project team, the need exists for careful coordination and cooperation with a large number of external agencies. Most urban freeway systems serve an area under the responsibility of many different jurisdictions. Because the activities carried on on the freeway have repercussions on all other transportation facilities within the system, coordination is essential.

At a minimum, a specific plan should be developed for coordinating the project through regular meetings, review, and information exchange, with other local governments, with police and fire departments, with the public transit companies serving the system, and with the automobile clubs and trucking organizations in the area. This planning and coordination effort should be initiated as far in advance as possible, preferably a minimum of one year.

Planning data needed for development of a rehabilitation project include traffic counts. Hourly volumes and lane distribution information may be valuable in planning the work program. Also needed are scheduling and traffic data from other agencies and organizations whose plans may generate significant variations in traffic flow. This would include organizations planning major sports events, parades, demonstrations, or other activities that will generate considerable public interest.

The planning and coordination effort is equally as important for a series of small projects on a freeway system as it is for a single major project.

PUBLIC INFORMATION

For those agencies with a record of successful experience in carrying out major freeway rehabilitation projects, one of the dominant factors contributing to that success has been the use of an effective public information program. Typical of the successful public information procedures followed is the program carried on by Region One (Chicago Metropolitan Area) of the Illinois Department of Transportation. The project involved was a $16 million resurfacing of a 15-mile (24 km) major expressway system, as well as pavement replacement on a 6-mile (10 km) section of local lanes on a contiguous expressway. The public information program included the following steps:

1. A task force composed of design, construction, maintenance, and traffic personnel prepared project contracts and traffic phasing and controls.
2. A meeting was held with other highway agencies and interested public and private transportation organizations to discuss the proposed work and identify possible conflicting work areas affecting alternate routes.
3. A pre-bidding meeting was held with contractors to discuss the project work and phasing as well as the importance of the traffic controls required.
4. Formal briefings were held with the communications center dispatchers, the expressway emergency patrol supervisory staff, expressway surveillance personnel, and maintenance yard supervisors. In addition, individual briefings

RESEARCH AND MAINTENANCE OPERATIONS TO CLOSE SEGMENT OF LODGE FREEWAY FOR 8 HOURS ON JUNE 9

On June 9 (late Saturday night and early Sunday morning) a combined research-maintenance traffic engineering project will close a segment of the northbound John C. Lodge Freeway.

This northbound section of the Lodge from the Milwaukee ramp to the Chicago ramp will be closed to all traffic from 2:30 a.m. to 10:00 a.m. The eastbound Edsel Ford interchange ramp to northbound Lodge will also be closed – the only interchange ramp to be closed. The first phase of closing the freeway will begin about midnight. In case of inclement weather the project will be postponed until June 16.

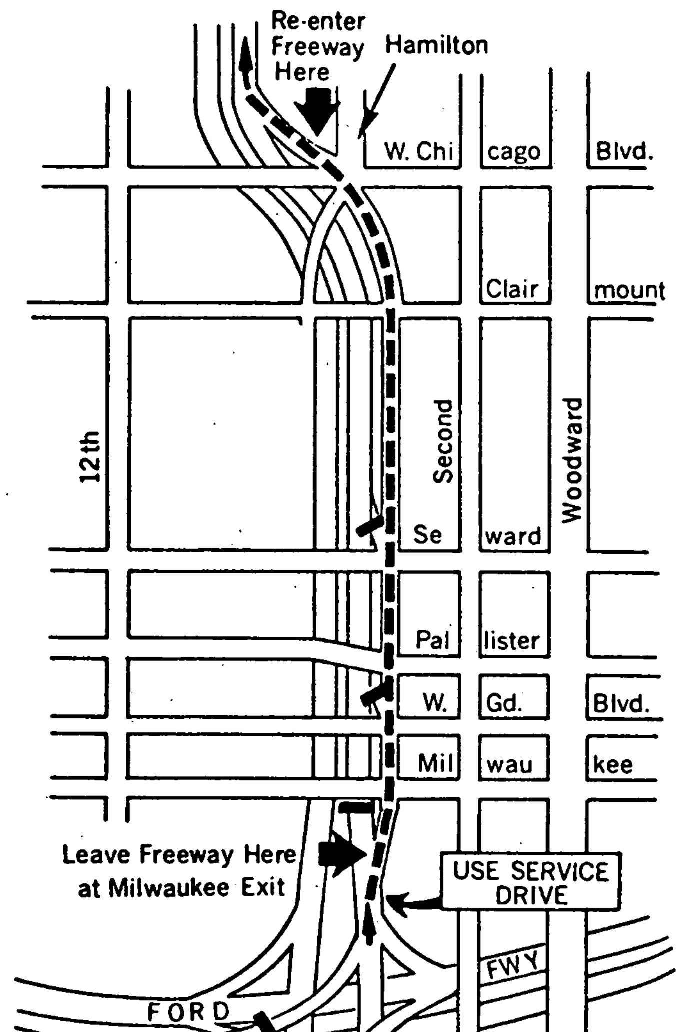
The Michigan Department of State Highways, the Detroit Department of Streets and Traffic and the Wayne County Road Commission are conducting the program to study the feasibility of total closure of freeway sections in order to make much needed repairs on the 20-year old roadways.

Part of the study is to determine how to handle the traffic diverted from the freeway – what increased traffic volumes will be using the altemate routes and what additional accident and congestion factors may be created.

It is expected that total closure will result in greater safety and greater convenience for the motorist as the hazards and conflicts between moving traffic and maintenance work are eliminated – as well as the long slow-downs caused by closing one or two lanes at a time in work areas.

Motorists are urged to pay attention to advance signings and wamings. An extensive system of signs, signals and barricades has been devised to wam and protect drivers in the area. Note areas in red on the map on the right which show where closure barricades will be posted.

According to officials of the Highway Department and County Road Commission a backlog of essential maintenance work on the freeways makes it necessary to devise a new system. The increase in traffic volumes since the freeways were opened precludes the mass closing of entire freeways and the current system of working one or two lanes at a time during restricted hours is slow, costly, hazardous and often temporary. What is sought is a new system that will close, where possible, large enough sections for efficient and safe repair operations and still permit sufficient altemate routes to handle traffic volumes safely during the time required for the maintenance work.



Northbound routes only are shown on map.

Detroit Police Traffic Central will send out advance bulletins to keep motorists informed. Drivers in the area are urged to stay tuned to one of the following radio stations for up-to-the-minute advisories and bulletins on the ramp closings: WCAR, WCHB, WJBK, WJR, WKNR, WWJ, WXYZ, and CKLW.

Produced by the Department Report and Information Committee, City of Detroit, and the Traffic Safety Association of Detroit.

Figure 6. Flyer prepared by the City of Detroit for public distribution prior to freeway closing.

were given to radio traffic reporters from the major municipal radio stations to review the details of traffic phasing, the recommended alternate routes, and other modes of travel available.

5. A formal press conference was held by the Secretary of Transportation to discuss justification for the pavement repairs because of expected public interest. Film clips were distributed showing the specific problem areas of roadway to be replaced.

6. Private companies responsible for large changeable-message advertising signs adjacent to the expressways were requested to publicize starting date of the project.

7. A formal press conference was held by the Secretary of Transportation to announce the project approximately one week in advance of the work start. A public information officer of the department provided liaison between news media and project personnel. Field trips were arranged after the conference to permit the media representatives to photograph the project site.

8. Cross-street bridge-mounted signs were displayed on the day of the press conference indicating "expressway repairs begin on [date]—only two lanes open." Advisory signs also were erected on approaching Interstate Highways indicating the work planned and alternate routes available.

9. On the day the work started, traffic engineers accompanied the helicopter traffic reporters to assure avail-

KENNEDY - RYAN DAILY PROGRESS REPORT

DATE 7-22-71

STAGE I - PHASE 1 16th Day

DAYS REMAINING 5

WORK COMPLETED AS OF Noon (Time) 7-22-71 (Date)

AREA A John F. Kennedy Expressway - Southeast Bound
Old Mannheim Road to East River Road
Crossover Provided at East River Road to Express Lanes

2 TRAFFIC LANES

	Circle One	
Left Lane:	Open	(Closed)
Right Lane:	(Open)	Closed

WORK TO BE DONE: 80% COMPLETE (Estimated)

Patching and joint repair	80%
Bridge Repairs	60%
Painting	100%
Resurfacing	70%

COMMENTS UNUSUAL SITUATIONS PROBLEMS

NONE

ENTRANCE / EXIT RAMPS

	Circle One	
Mannheim Road Entrance	(Open)	Closed
Mannheim Road Exit	(Open)	Closed
DesPlaines River Road Entrance	Open	(Closed)
DesPlaines River Road Exit	(Open)	Closed

Figure 7. Rehabilitation project progress report used by Illinois Division of Highways to advise press and public of work status.

ability of traffic control explanations. Up-to-date traffic condition reports were provided through the state regional communications center. The office staff was augmented to handle citizen telephone inquiries with specific questions about alternate routes, closed ramps, and access to high-traffic generators.

10. Weekly work status reports were issued throughout the project. Special project features were highlighted and field trips were arranged for the news media throughout the project to discuss activities with the traffic engineers, construction engineers, and contractors involved.

11. Signs thanking the motorists for their cooperation were erected at the conclusion of the project. Press releases were issued announcing completion of the project ahead of schedule, as well as the bonuses earned by the contractor for early completion.

12. The Secretary of Transportation arranged a luncheon for project engineers and news media personnel where they were individually recognized for their contributions to the project's success.

Obviously, such a public information program can contribute to the orderly control of traffic in the work area (Fig. 6; see also Appendix B). There are other supplemental considerations which experience has suggested to several agencies. One is the advantage of beginning a project on a midweek day rather than on a Monday morning. Detroit found in its research on the June 1968 closing of the John C. Lodge Freeway that the commuter tends to forget about the traffic control information disseminated during the prior week and thus the effectiveness of the message to the motorist is reduced. It was found that the motorist is more likely to remember radio messages and sign messages along the route if he hears and sees them the day before the project begins. Further, midweek days produce a somewhat lighter traffic volume than Monday morning and thus the reaction to barricades and traffic constrictions is less severe on a midweek morning.

The Illinois State Toll Highway Authority has set up a communications center where the public is invited to make telephone inquiries about project status, traffic delays, and other factors influencing travel. These communications centers have been publicized through press releases and in some instances agencies have used full-page paid advertisements in local papers to announce projects, the availability of communications centers, and alternative transportation modes and routes.

The daily progress report shown in Figure 7 has been used by the Illinois Department of Transportation to (a) alert other maintenance crews working within the closure of the relative status of all activities with which they must coordinate their plans; (b) warn traffic and signing crews of impending changes that they must accommodate; and (c) inform all internal offices and departments of the work status so that they can respond accurately to public inquiries and management requests.

CHAPTER THREE

DESIGN CONSIDERATIONS

When the objectives of the project have been clearly defined, a number of alternative design concepts are available. The design effort required in a rehabilitation project consists of two parts, one dealing with the design of the physical structures to be rehabilitated, the other with the design of the procedures whereby this rehabilitation is to be carried out. This involves the procedures for removal and replacement of deteriorated material as well as the procedures for the accommodation of traffic on the system or adjacent systems while the construction work is being performed. These two parts of the design are closely interrelated and interdependent.

CONSTRAINTS

Where traffic operations dictate that work periods must be limited to off-peak hours with traffic restored to all lanes during peak hours, design concepts for the structure must reckon with limited installation and curing requirements. Where detours around the construction site can be maintained for extended periods of time, structural design concepts can be predicated on the limitations of total construction time rather than the short-term installation and curing requirements at each repair site.

Lateral and vertical clearances may further compromise the design of the structural elements and procedures by placing limitations on the types of construction equipment employed and the elevation of pavement sections under overpasses. Dead load restrictions in bridge decks may place a further constraint on rehabilitation plans.

DESIGN PROCEDURE

Pavement rehabilitation programs can encompass one or more of the following design procedures:

- Spot patching of existing pavements.
- Mudjack leveling and undersealing of existing pavements to restore base support and riding qualities.

• Breaking and seating of existing rigid pavement and overlaying with bituminous concrete.
• Patching and repairing of existing rigid pavement and overlaying with bituminous concrete.
• Patching and repairing of existing flexible pavement and overlaying.
• Patching and repairing of existing composite pavement and overlaying.
• Overlaying of rigid pavements with portland cement concrete, bonded, partially bonded, or unbonded.
• Overlaying of flexible pavements with portland cement concrete.

Variations on these procedures can be added by use of bonding agents and synthetic binders and by use of surface treatments in lieu of or in addition to the procedures listed.

Most agencies undertaking a pavement rehabilitation program as part of a freeway reconditioning project elect to use a bituminous concrete overlay. Where the overlay is placed on a portland cement concrete pavement or a composite pavement, the design standards have ranged from a 1-in. (25 mm) minimum to 2¾ in. (70 mm) of resurfacing plus a leveling course as required for a total thickness of up to about 5 in. (130 mm). Where overlays are placed on existing flexible pavements, most design standards have called for a minimum lift of 2 in. (50 mm) plus leveling as required. Overlay design procedures are discussed in detail in *NCHRP Synthesis of Highway Practice 9,* "Pavement Rehabilitation—Materials and Techniques."

Several agencies have standard plan sheets that provide construction details for pavements. The Illinois standards for bituminous and PCC pavements are shown in Figures 8 and 9.

The Engineering Department of the New Jersey Turnpike Authority has developed a comprehensive procedure for the design of resurfacing projects as an alternative to simply setting the screed on a paving machine for a minimum overlay thickness. This technique is particularly applicable on flexible pavements where profile corrections are required in addition to structural rehabilitation. The agency's resurfacing design procedure includes the following steps:

1. A field survey is performed to cross-section the existing roadway in the area to be resurfaced. This work is done during the winter by the engineering department personnel who will supervise and inspect the resulting construction during the following spring and summer. Cross sections are taken every 25 ft (7.6 m); 12 control points are used for each section. All drain inlets are also located, both vertically and horizontally, and provision is made for them to be raised as required. The sectioning is accomplished by first closing the left (fast) lane. Stations are then measured in and painted on the pavement. Bench marks are established on median guardrail posts at 200-ft (60 m) intervals (see Fig. 10). All bridge clearances are checked and noted as the sectioning progresses.
2. After existing profiles have been plotted, design profiles are plotted and adjusted using a control of 1½-in. (38 mm) minimum overlay. After a good economical profile is designed, it is only necessary to check cross slopes and critical areas to assure minimum cover.

Excerpts from contract plans for roadway and structure repairs are shown in Figures 11 and 12.

Special Designs and Techniques

The New York State Thruway Authority, which has experienced rapid wearing of wheelpaths from the use of studded tires, has successfully employed a resurfacing program in which a 2-ft (0.6 m)-wide strip resurfacing has been placed in each wheel track of each lane of a composite pavement. The resurfacing strips, placed with a special screed box, permitted restoration of the pavement cross section at low cost and without loss of clearance at underpasses. The 2-ft-wide resurfacing strips are dark in color and conspicuous to the roadway user for a brief period after placement, but soon assume the same color as the remaining pavement surface when the aggregates are exposed under traffic and oxidation of the surface takes place.

Other types of pavement rehabilitation design that have been used include the removal and replacement of broken portland cement concrete slabs with precast slab sections (Figs. 13, 14, 15). This program has been carried on successfully by the Michigan Department of State Highways and Transportation as a standard part of their repair procedure (see Appendix C). Latex-modified mortar overlays have been used for bridge deck repairs by several agencies. The New York State Thruway Authority is currently using precast concrete deck planks as a rapid repair method for bridge decks (Appendix C).

A high-cement-content (9 sacks; 500 kg cement/m^3 concrete) concrete with a 4- to 6-hr curing time has been successfully employed in the City of Detroit for freeway repairs. A technique used in some experimental work on U.S. freeways, but successfully employed as a production technique on motorways in England, makes use of a small, precast, partial-depth concrete patch bonded in a repair area with epoxy mortar.

Thin bonded overlays using fibrous concrete have been employed by some agencies. Greene County, Iowa, in 1973 placed a thin concrete overlay on 16,000 ft (4,900 m) of old portland cement concrete pavement using a slip-form paver. The project included 41 test sections with various overlay thicknesses ranging from 3 in. to 5 in. (75 to 130 mm). Unreinforced concrete, wire reinforcement, and steel fibrous reinforcement were used in selected test sections that will be observed and evaluated annually.

The Pennsylvania Turnpike Commission has done some repaving using gussasphalt. Others have expressed interest in the use of this material for overlays of bridge decks and for flexible pavement repairs and resurfacing.

TRAFFIC CONTROLS

Three basic alternatives are available when the requirements for handling traffic during rehabilitation projects are considered:

1. Roadway closure and off-site detours.
2. Detours within the right-of-way.
3. Lane closures and constrictions.

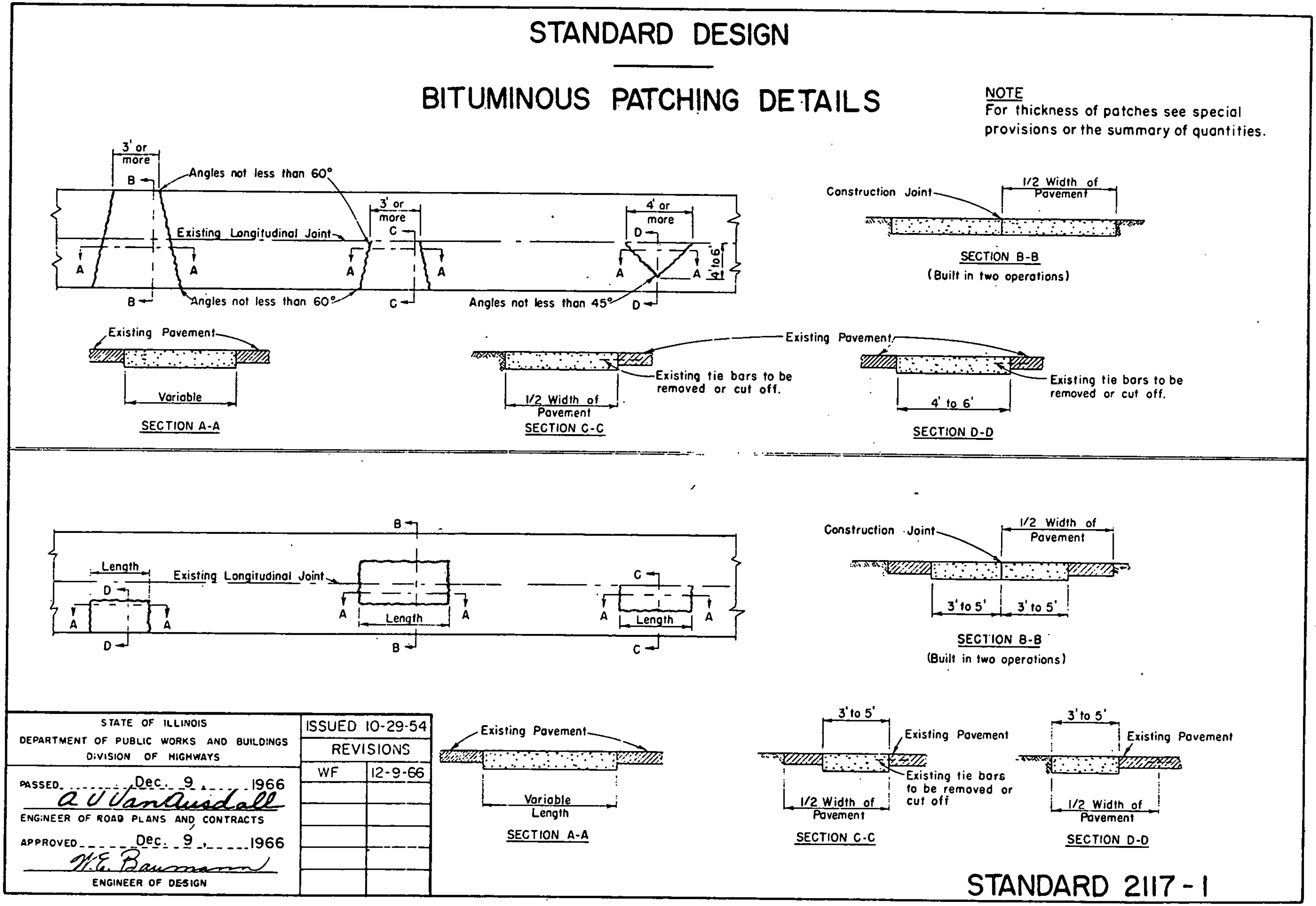


Figure 8. Standard design details for patching pavements with bituminous concrete (Illinois Dept. of Transportation).

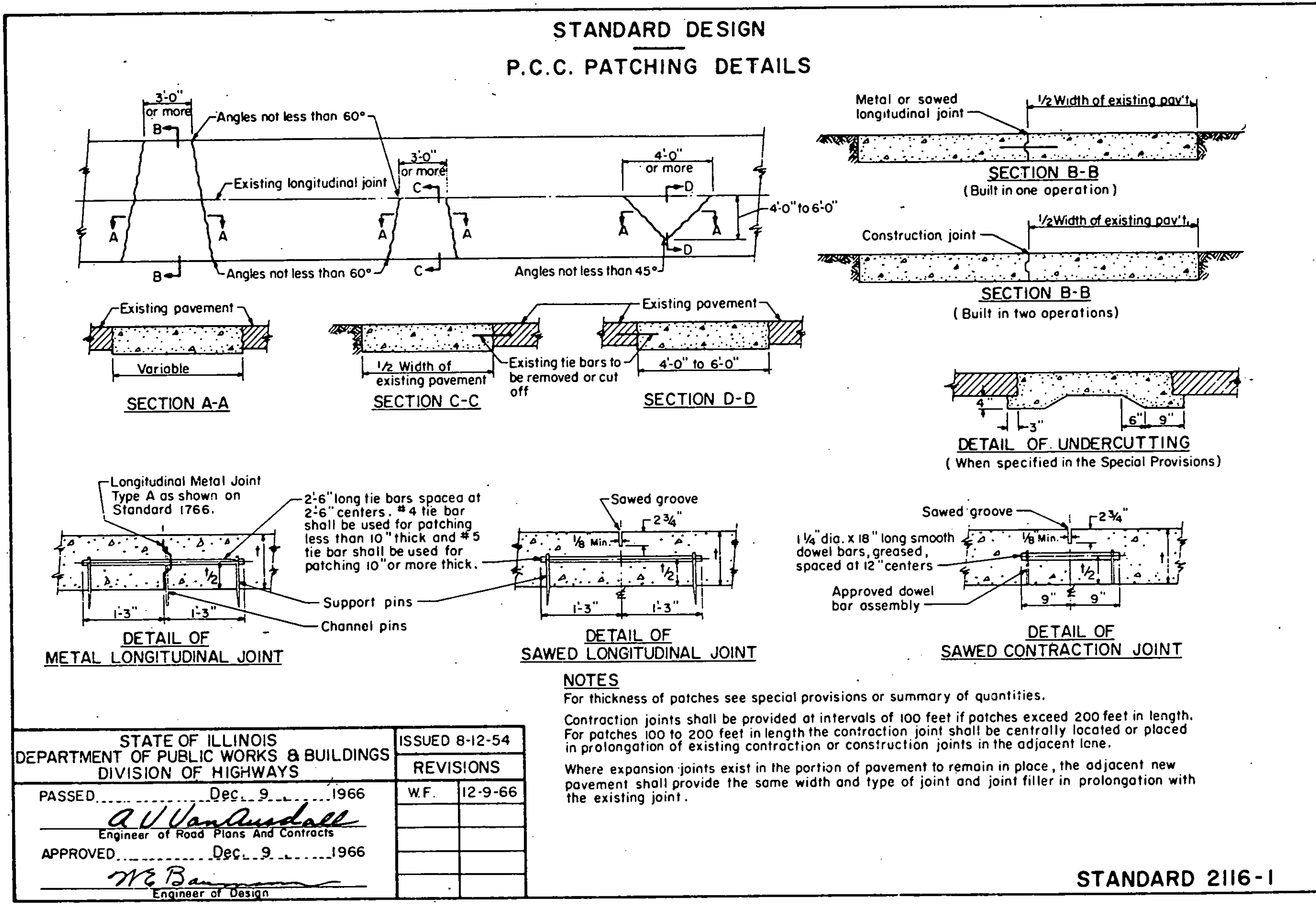


Figure 9. Standard design details for patching pavements with portland cement concrete (Illinois Dept. of Transportation).

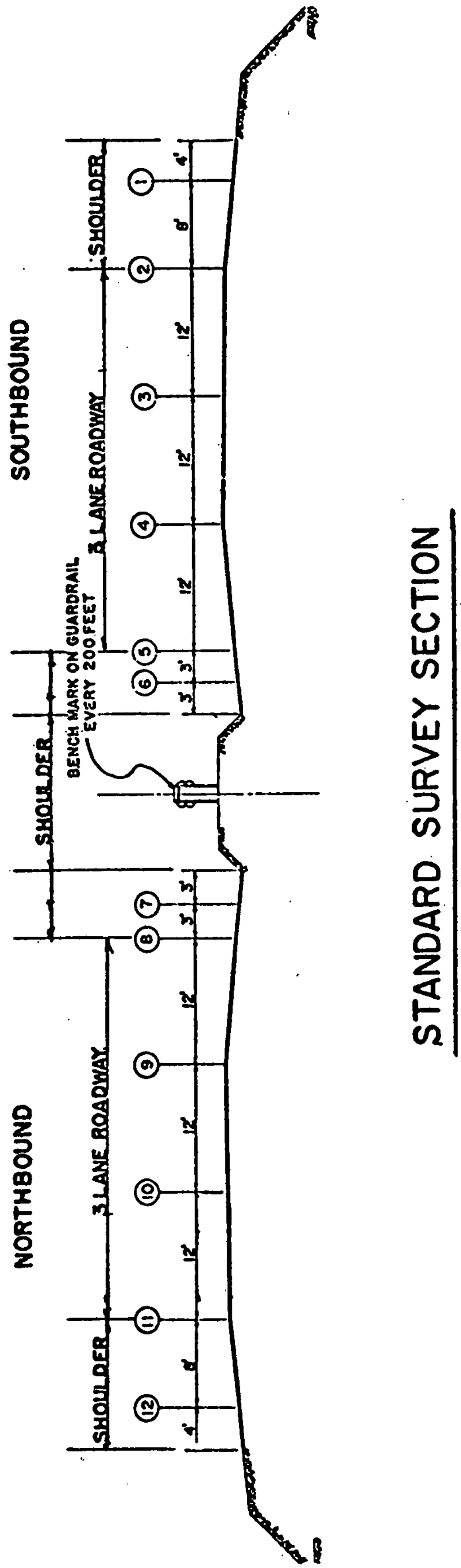


Figure 10. Survey section and bench mark location details for New Jersey Turnpike field survey to prepare plans for pavement resurfacing and correction of irregularities.

Off-Site Detours

Planning of off-site detours to permit closing of segments of a freeway system can serve as a valuable tool for emergency closures on the freeway system as well as for prescheduled closures to accommodate reconditioning projects. Several agencies have developed detailed detour plans, with maps and other procedural information filed and available for police and other emergency agencies in the event that an unexpected closure due to accident or natural disaster should occur.

In Detroit, comprehensive studies have indicated that closing of segments of the freeway system during night hours permitted reconditioning work to be carried on at the optimum rate and cost (Fig. 16). The detour route on parallel local streets was carefully signed and traffic signal coordination was established to permit optimum flow of traffic (Figs. 17 and 18). The conclusions reached from evaluation of the freeway closures in Detroit included the following:

- Time of closure. From mid-June through July and August is the best season. Mid-week closures from 10 PM to 5 AM appeared to be best. The best weekend closures appeared to be from 2 AM until 10 AM.
- Width of ramp. Ramps serving as the exit and entrance points around a freeway closure should be able to handle at least two lanes of traffic. Two-lane capability may be provided by use of shoulders and temporary laning materials to mark lane lines.
- Adjacent ramps. Entrances to the freeway system within a mile of the closure area should be closed so that traffic will not unknowingly enter the freeway system only to be diverted back onto the local street system.

Detours Within the Right-of-Way

On-site detours have been provided by construction of temporary new pavements and structures, use of paved shoulders as detour lanes, reversal of lanes in the opposing traffic roadway, and restriping or remarking pavements to maintain the number of lanes while reducing lane widths (Fig. 19).

When temporary new roadways and structures are constructed as detours, it is highly desirable that the facilities be constructed to the same geometric design standards as the permanent roadway so that traffic movements around the detour can be accomplished safely at normal operating speeds. Where short-radius turns are injected into the temporary runaround, operating difficulties and accidents frequently result.

Paved shoulders have been successfully employed as supplemental pavement lanes by a number of agencies. Carefully planned advance signing is necessary to inform all approaching drivers of the shoulder lane and to redirect drivers back onto the pavement beyond the construction site (Fig. 20). Where the shoulder pavement design sections have not been comparable to pavement design sections, some agencies have attempted to confine use of the shoulder lane to passenger traffic by advanced signing requesting that "passenger vehicles only use shoulder lane." Under heavy urban mixed-traffic volumes, this sorting out of vehicles is sometimes difficult.

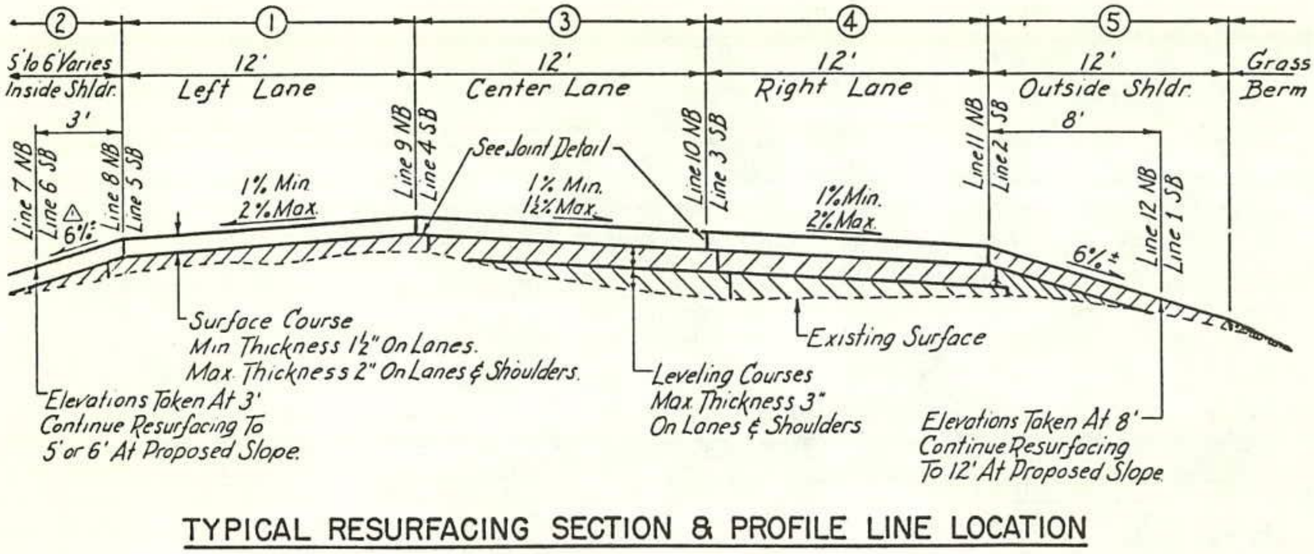


Figure 11. Details of resurfacing section from contract plans for pavement resurfacing on the New Jersey Turnpike.

Obviously, the practice suggests strong warrants for the construction of freeway shoulder pavements capable of carrying heavy traffic loads. The original construction cost of a pavement and shoulder section built to uniform full-width standards may be no greater than the cost of constructing a separate and different shoulder pavement section. Even if the full-width shoulder does cost more originally, it may still be more economical if future maintenance or rehabilitation is considered.

Although lane reversals in conjunction with median crossovers have been successfully employed by a number of agencies, some freeway operations groups have experienced problems with this procedure. The acceptability of lane

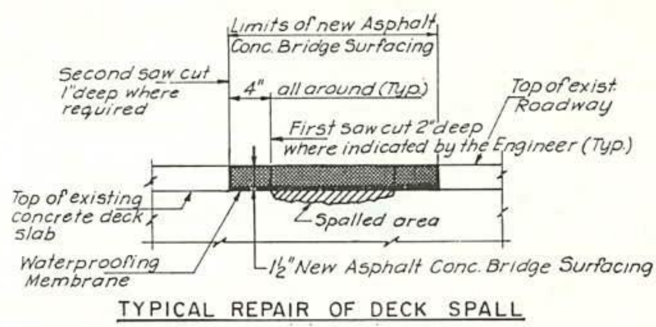


Figure 12. Detail of repair procedure from contract plans for bridge deck repairs on the New Jersey Turnpike.

Figure 13. Precast concrete slab being placed at full-depth repair site.

Figure 14. Precast partial-depth concrete patches eliminate curing before traffic use. (NCHRP 14-2)

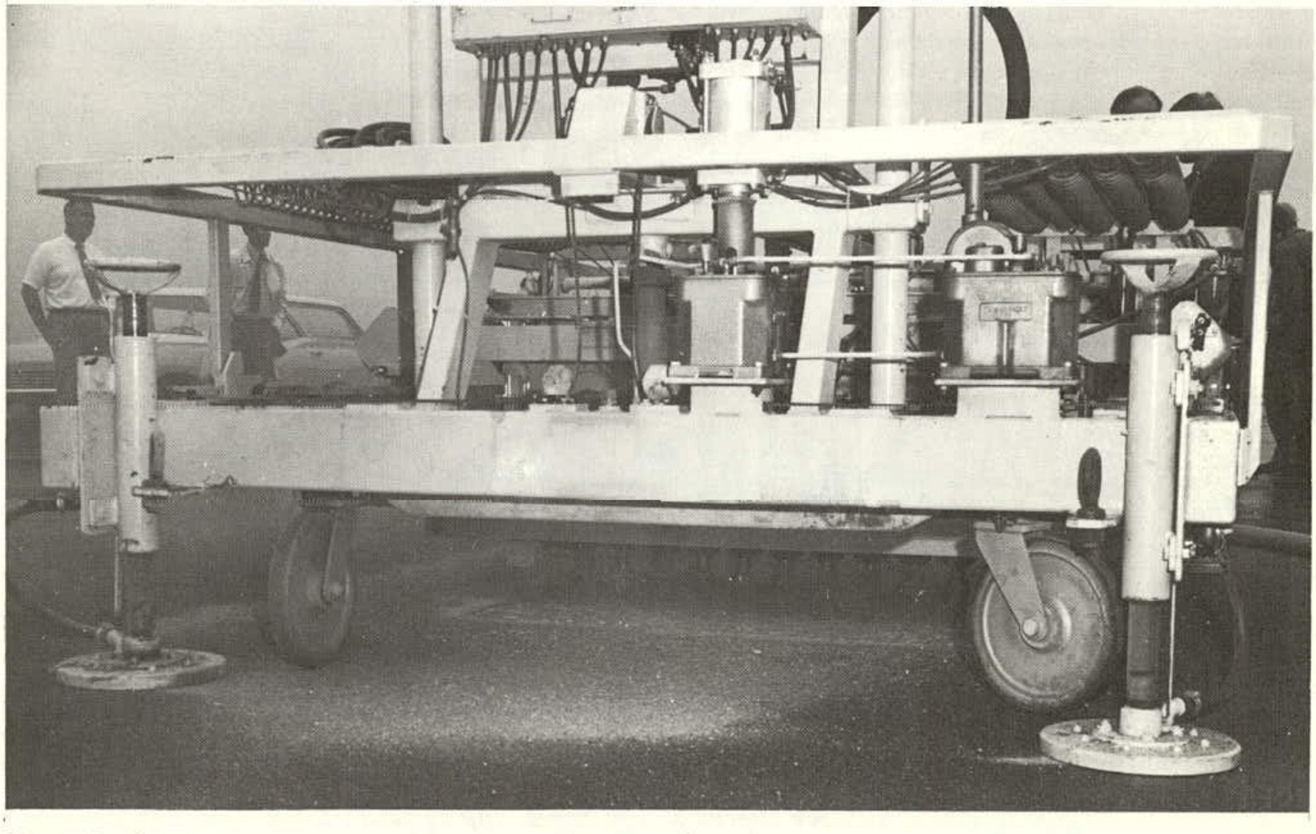


Figure 15. Klarcrete machine automatically cuts rectangular holes for pavement patching. (NCHRP 14-2)

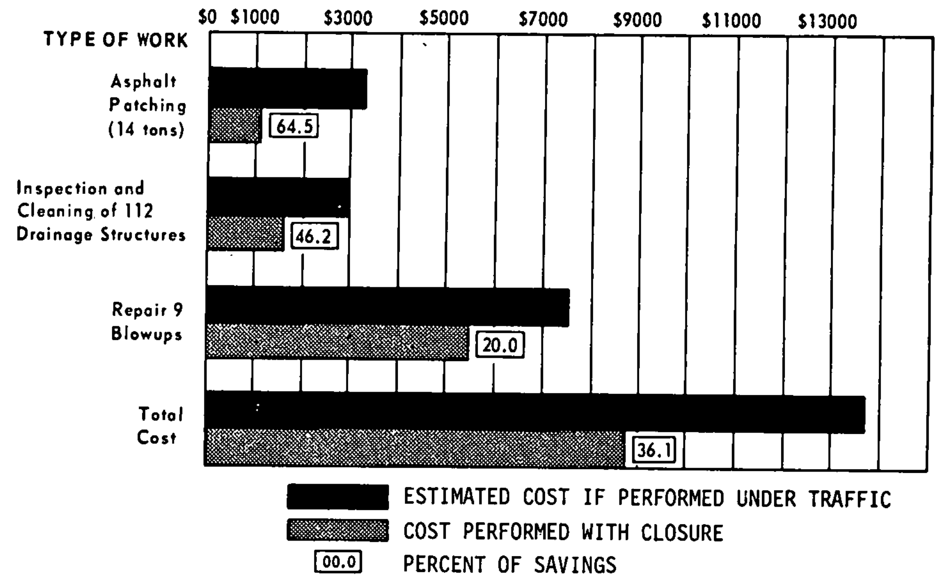


Figure 16. Cost analysis for indicated quantities for work performed on the John C. Lodge Expressway in June 1968 between West Grand Boulevard and Chicago Boulevard in Detroit, Mich., while the northbound lanes were closed to traffic. (From "Report of the Freeway Traffic Control Study Committee for the Year 1968," Michigan Dept. of State Highways)

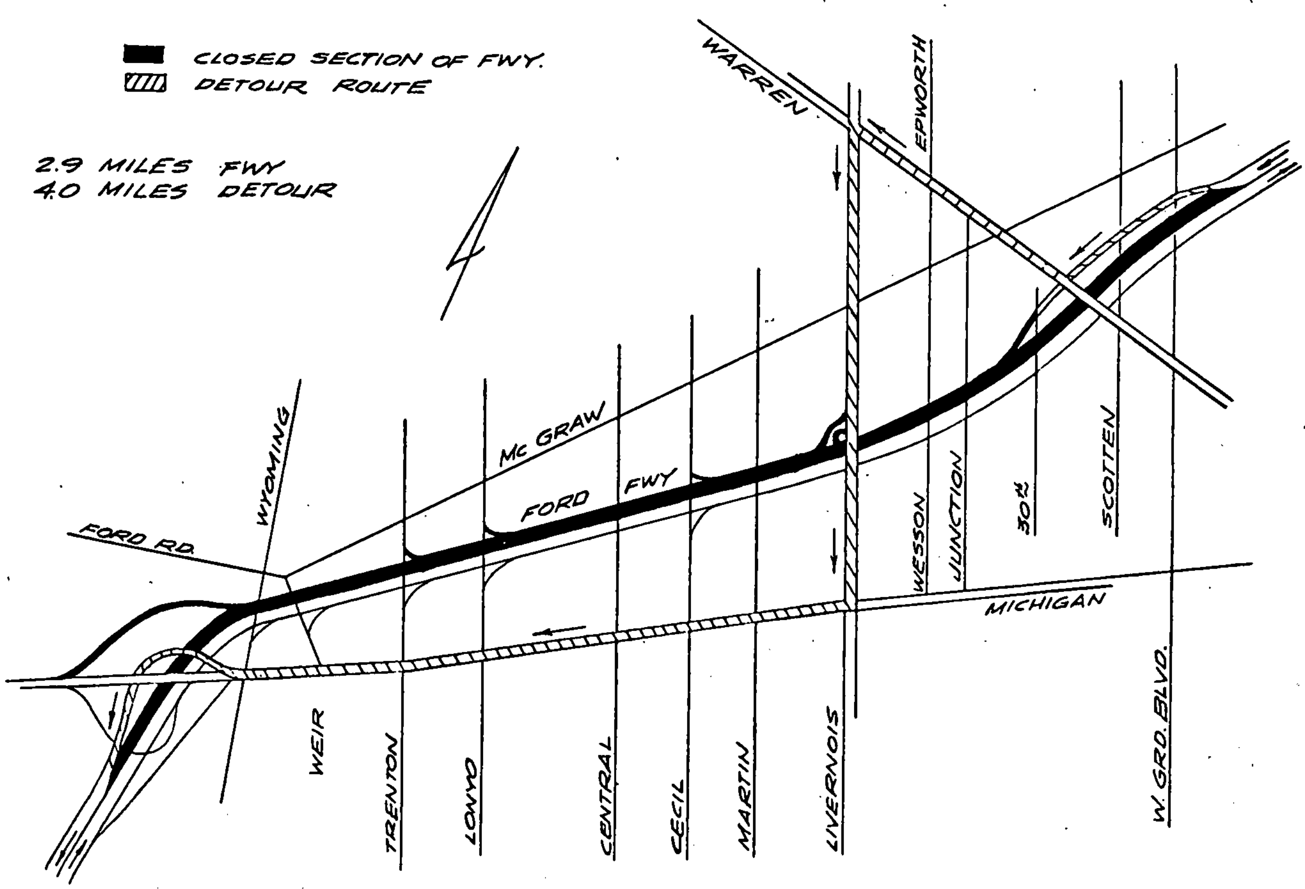


Figure 17. Alternate route plan for closure of a section of the Edsel Ford Freeway developed by the Department of Streets and Traffic, City of Detroit.

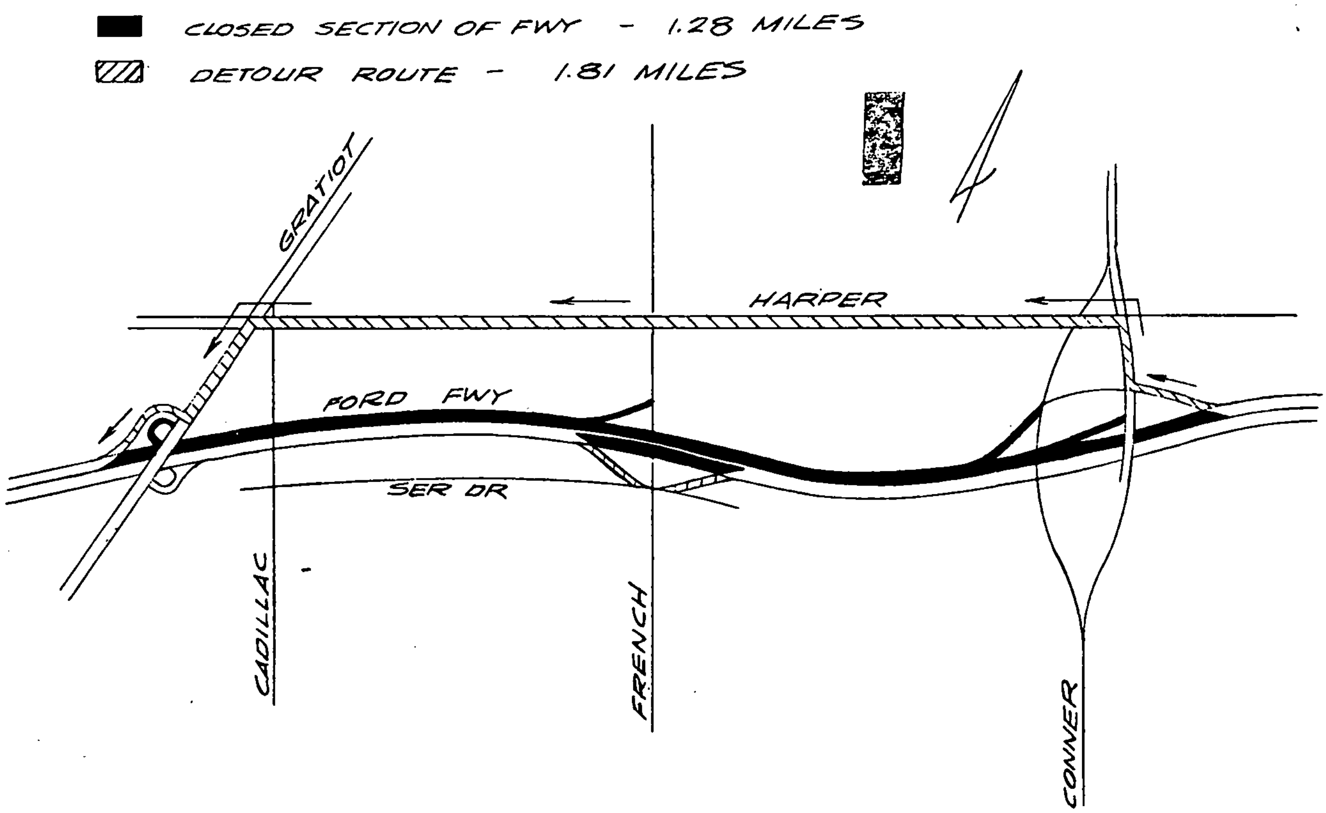


Figure 18. Alternate route plan for closure of a section of the Edsel Ford Freeway developed by the Department of Streets and Traffic, City of Detroit.

reversals depends in part on prevailing speed and density of traffic, and on the design features of the highway, including horizontal and vertical alignment, availability of overhead warning signs, lighting, and other factors. Where lane reversals are employed, it is necessary to provide a significant physical delineation of opposing traffic flows. One barrier being used effectively for this purpose is constructed of precast sections of New Jersey Safety Type concrete median barrier. Other agencies are using 12 x 12-in. timber sections fastened lengthwise and pinned to the pavement.

In all instances, temporary restriping or remarking of pavement lanes is considered a necessary and essential part of the traffic handling program. Plastic adhesive-backed pavement markings have been used successfully for this purpose and simplify removal when traffic is returned to its standard pattern.

On-site detours often involve requirements for construction of temporary drainage facilities, adjustment of appurtenances, and installation of special signing and lighting to properly delineate the detour.

Even with good geometrics on the detour or on adjacent lanes of traffic, construction sites create major interferences with traffic flow due to curious drivers slowing down to observe the construction activity (or lack of activity). To minimize this problem, a number of agencies have required that the construction site be screened from the view of approaching drivers so that there is no incentive to slow down and "gawk." The most commonly used screens are plywood panel sections.

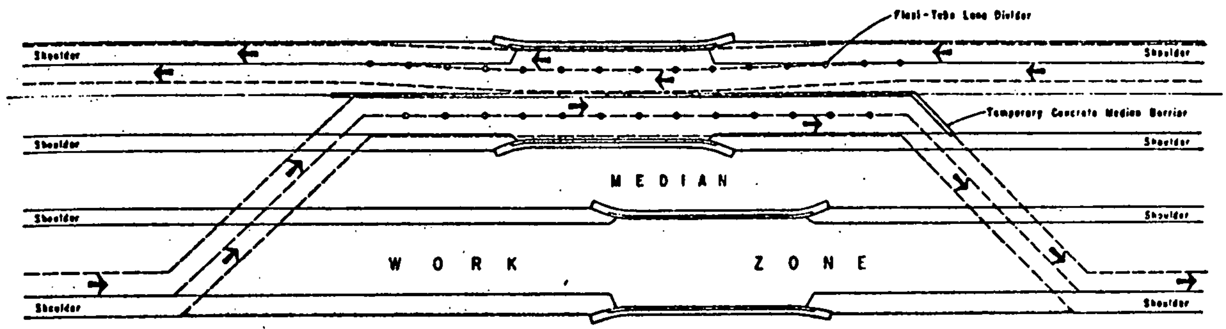
Data collected by the Illinois Department of Transportation during major reconstruction on Chicago freeways in 1966 and 1971 show the effect on system traffic volumes (Tables 1 and 2). These data also indicate that the construction activity has little effect on passenger occupancy (Table 3).

TABLE 1

ANALYSIS OF TRAFFIC DEMAND DURING RECONSTRUCTION WORK ON EDENS EXPRESSWAY, JULY 1966, COOK COUNTY, ILLINOIS [a]

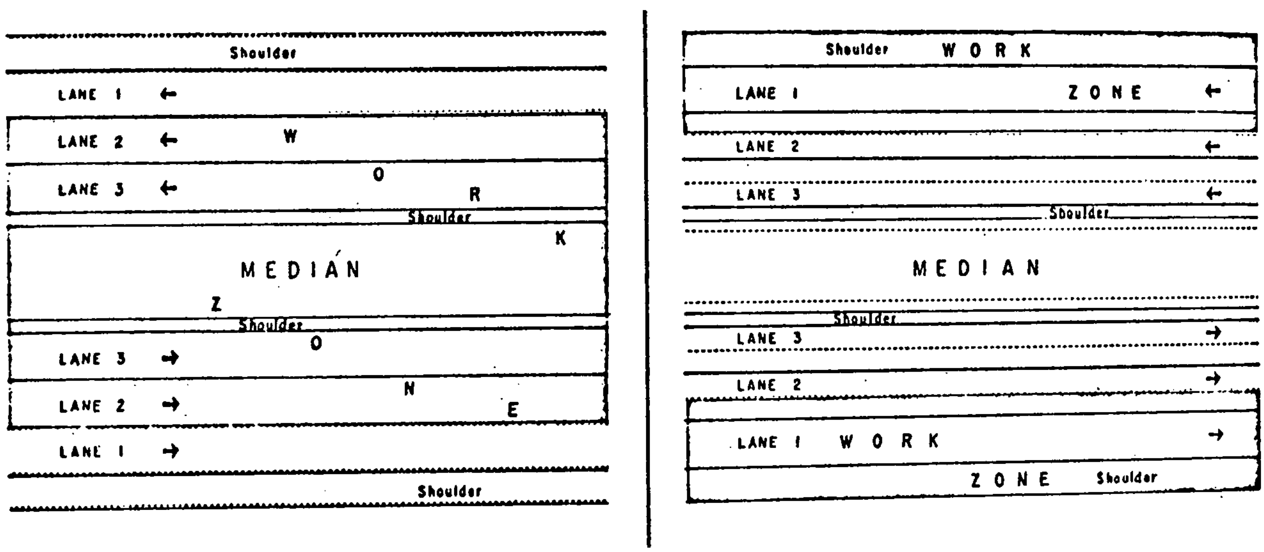
		TRAFFIC DEMAND [b] (VEH)			
EXPRESS-WAY	AT	BEFORE	DURING	DIFF.	RED. (%)
Edens	Foster Ave.	110,100	87,800	22,300	20
Kennedy	Pulaski	199,700	167,900	31,800	16
	Chicago Ave.	195,500	182,400	13,100	7

[a] Resurfacing on Edens with two lanes closed and four open at all times; one open lane reversed.
[b] 24-hr demand, 2-way.



DETAIL OF FLAG CREEK BRIDGE RUN-AROUND

MAINTENANCE OF TRAFFIC
DURING RESURFACING
I-55 to Ogden Ave.



MAINTENANCE OF TRAFFIC
DURING WIDENING
95th to I-55
(7 a.m. to 7 p.m.)

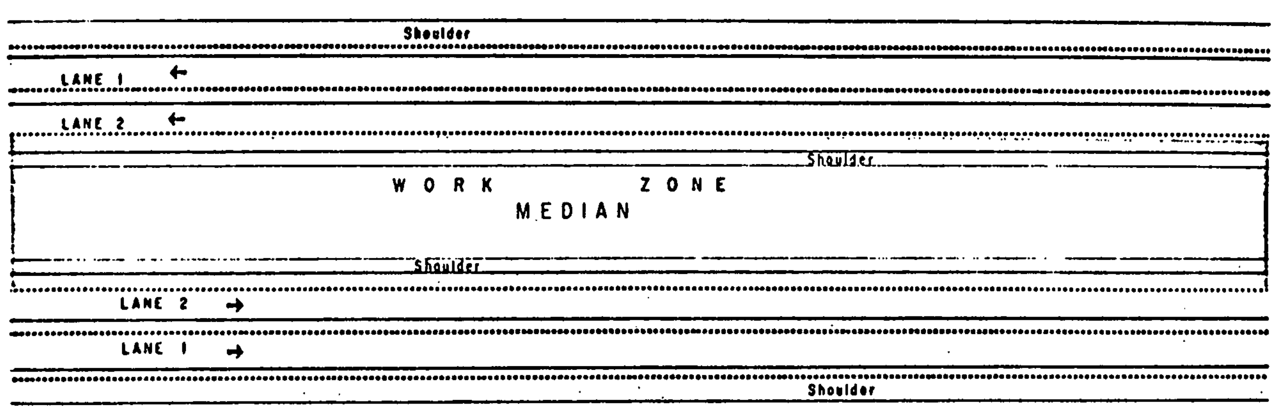
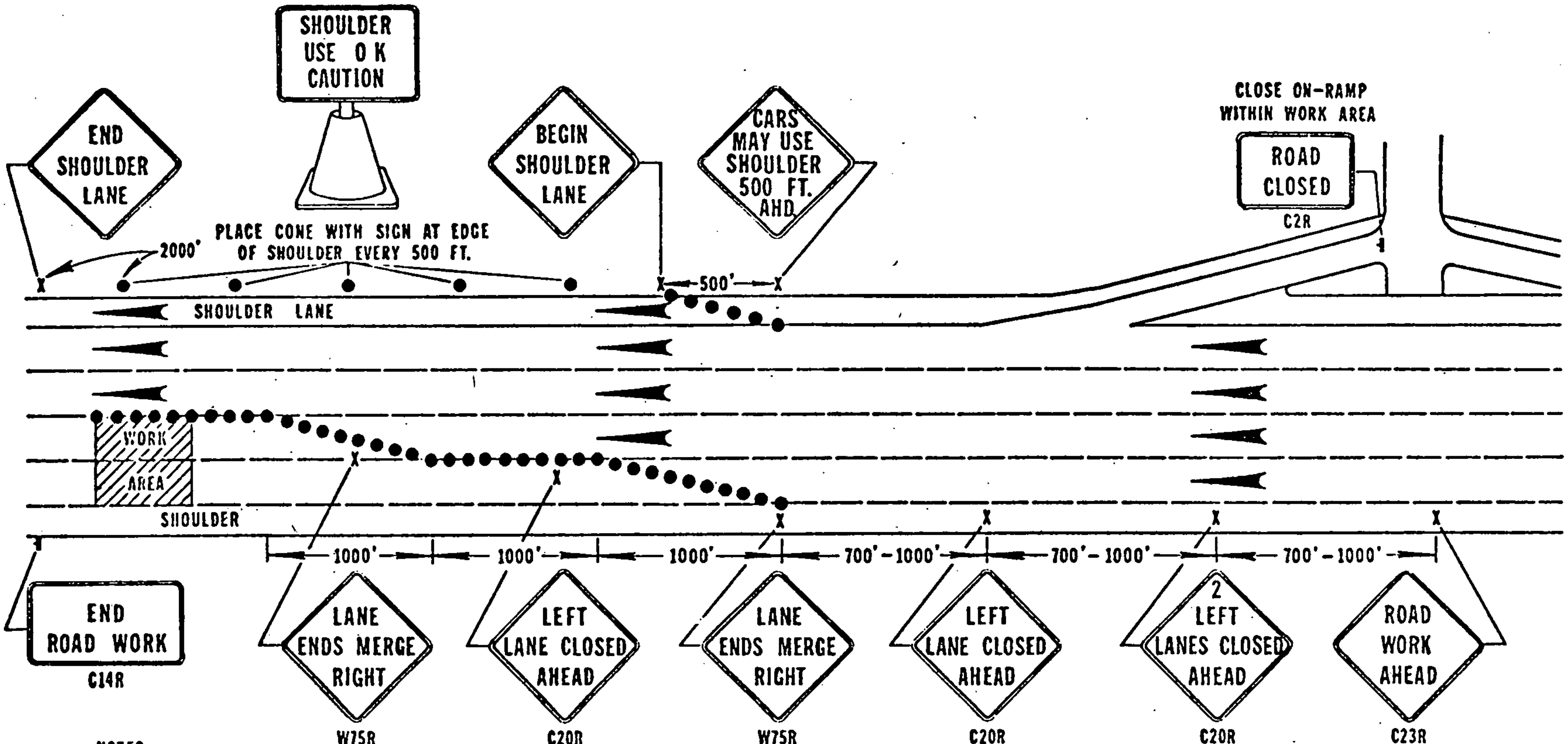


Figure 19. Traffic handling schemes for freeway rehabilitation (Illinois State Toll Highway Authority).



NOTES:

1. Signing for median shoulder lane is same as above but on opposite side.
2. Provide at least 1000' – 2000' between work area and END SHOULDER LANE sign to allow traffic to merge. Do not use shoulder if traffic must merge within the work area.
3. Shoulder lane signs should be covered when shoulder lane is blocked by a stalled vehicle.
4. Do not use shoulder lane when paved width is less than 8' or where there are obstructions such as rolled gutter, drainage structures, restrictions on lateral clearance, or where there are on-ramps within the work area.

Figure 20. Signing for shoulder lane during lane closures on metropolitan freeways. (From "Reducing Motorist Inconvenience Due to Maintenance Operations on High-Volume Freeways," by Forbes, Smith, Schaefer, California Div. of Highways)

TABLE 2

TRAFFIC VOLUME REDUCTIONS DURING RECONSTRUCTION WORK ON KENNEDY EXPRESSWAY, OCTOBER 1971, COOK COUNTY, ILLINOIS [a]

			VOLUME REDUCTION (%)					
			STAGE I			STAGE II		
EXPRESSWAY	AT	NORMAL COUNT, 24-HR (VEH)	OVER-ALL	AM PEAK	PM PEAK	OVER-ALL	AM PEAK	PM PEAK
Kennedy	Cumberland	130,000	40	50	50	25	40	40
	Cicero	125,000	35	35	45	25	25	45
	Ohio	210,000	40	40	30	45	35	50
Ryan	55th	230,000	35	—	—	45	—	—
Edens	Wilson	115,000	50	—	—	35	—	—
	Church	105,000	5	—	—	5	—	—
Eisenhower	Sacramento	190,000	0	—	—	+5 [b]	—	—
	East	125,000	0	—	—	+5 [b]	—	—

[a] Local lane closures on Ryan Expressway; Edens and Eisenhower Expressways open, in full service.
[b] Increase.

Lane Closures and Constrictions

Often the rehabilitation work cannot be performed without lane closures or constrictions. Where the work requires removal from service of more than one lane, on-site shoulder detours may be used in conjunction with reduced lane widths to retain the original number of lanes for through traffic. In other instances, constrictions cannot be used and a reduction in the number of available through lanes must be made.

In either event—constriction or reduction of lanes—maximum attention is given to traffic control measures at the work site. Use of reflective cones, high-intensity lights, and other devices with high visibility is common to most work sites. *NCHRP Synthesis of Highway Practice 1,* "Traffic Control for Freeway Maintenance," delineates practice in some detail.

TABLE 3

VEHICLE OCCUPANCY DURING RECONSTRUCTION WORK, JULY 1966, KENNEDY EXPRESSWAY, COOK COUNTY, ILLINOIS [a]

OCCUPANTS	NO. OF VEHICLES	% OF TOTAL	NO. OF PASSENGERS
1	1417	77.6	1417
2	306	16.6	612
3	69	3.7	207
4	30	1.6	120
5	6	0.2	30
6	7	0.2	42
7	2	0.1	14
Total [b]	1837	100	2442

[a] Vehicles on Randolph St. exit ramp, Kennedy Expressway, southbound, July 13, 1966 between 7:30 and 9:10 AM.
[b] Average occupancy, 1.33 persons per vehicle (normal = 1.5); car pools apparently not increased by public relations effort.

CHAPTER FOUR

CONSTRUCTION MANAGEMENT

Before construction begins, there are a number of detailed arrangements that must be completed in close cooperation with the contractor. Typically, most agencies hold a comprehensive pre-bid meeting at which all potential bidders are advised of the general operating conditions under which they can be expected to perform the work. This is done so that their bids are responsive to these conditions and they are fully aware of the operating requirements.

PRE-CONSTRUCTION CONFERENCES

The successful bidder then is invited to a pre-construction conference where discussions are held regarding his proposed haul routes and schedules, the location of storage yards and plant sites, the public relations efforts that the agency is planning and the contractor's participation in these efforts, and the details of traffic handling.

Frequently, the rehabilitation project involves two or more independent contracts, either for contiguous work sites or for unique activities within a common site. In either event, each contractor is included in the pre-construction conference and coordination between contractors is an important item on the agenda. Some agencies also include known subcontractors in the conferences.

TRAFFIC HANDLING DURING CONSTRUCTION

Arrangements for on-site or off-site detours for lane closures, signing, signals, and lighting are developed in detail as part of the design phase of rehabilitation projects. During the construction phase, the implementation of these design concepts usually requires on-site assistance from experienced traffic engineering, maintenance, and police personnel. The California procedure for estimating lane closure delays is given in Appendix D. The lane capacity rates for typical maintenance construction operations are given in Tables 4 and 5.

Several agencies, including the California Department of Transportation, the City of Detroit, and the New Jersey Turnpike Authority, have developed special teams of police patrol officers with experience and expertise in handling traffic at freeway construction sites. These teams are assigned to the construction site during rehabilitation projects. Some teams provide observation and evaluation of the design concepts to make sure that they are functioning properly. The traffic control team also functions in an important capacity in handling traffic as transitions are made from one lane closure to another or from standard operations to lane reversals.

On the New Jersey Turnpike, the State Highway Patrol team assigned to construction operations has developed special techniques whereby a platoon of patrol cars can merge with the traffic flow upstream of a construction site and gradually form a moving barrier to slow traffic. This maneuver is used several miles in advance of a construction site to create a time gap in the traffic flow sufficient for moving heavy equipment across the roadway or erecting beams or other actions which would otherwise require traffic to be stopped. By creating the gap in the traffic flow the patrol squad provides the time for these crossroad activities to be completed without actually stopping traffic.

This same technique has been used by the police patrol to create a traffic gap when traffic is being diverted from one lane closure to another lane closure. The redirection controls are shifted during the gap and traffic flows in the newly assigned lanes behind the police patrol vehicles.

Police patrol vehicles or other specially marked official vehicles have been employed as "pilot" vehicles to lead traffic when a detour route is being opened up so that the traffic stream follows the pilot vehicle and establishes a new traffic flow pattern.

TABLE 4

OBSERVED CAPACITY RATES FOR SOME TYPICAL OPERATIONS ON LOS ANGELES FREEWAYS[a]

No. of lanes, one direction (normal operation)	2	3 or 4	4
No. of lanes open, one direction	1	2	3
TYPE OF OPERATION	CAPACITY, ONE DIRECTION (VPH)		
Median barrier or guardrail repair	1500	3200	4800
Pavement repair, mudjacking, pavement grooving	1400	3000	4500
Striping, resurfacing, slide removal	1200	2600	4000
Pavement markers	1100	2400	3600
Middle lanes, any reason	—	2200	3400

[a] From: Forbes, C. E., et al., "Reducing Motorist Inconvenience Due to Maintenance Operations on High-Volume Freeways." *HRB Spec. Rep. 116* (1917) pp. 181-188.

TABLE 5

SUMMARY OF TRAFFIC CAPACITIES DURING CONSTRUCTION OF RAMPS AND WIDENING, SOUTHBOUND HOLLYWOOD FREEWAY AT LANKERSHIM

DAY OF WEEK	DATE	TIME OF DAY	WEATHER	4-LANE CAPACITY[a] (VPH)	REMARKS
M	10/27/69	0830	Overcast	6400	Open trench; equipment working both sides.
Th	10/30/69	0700	Sunny	6800	Open trench; loader and trucks working on right.
M	11/2/69	0830	Sunny	6200	Pavement breaker working on right.
Tu	11/4/69	0715	Sunny	6700	Motor grader working on right.
W	11/12/69	0730	Cloudy	6200	Roller and motor grader working on right.
F	11/14/69	0700	Clear	6200	Bottom-dump trucks and motor grader working on right.
Tu	12/16/69	0800	Overcast	6400	Paving ramp.

[a] Maximum observed capacity both before and after construction, 7,600 vph.

REMOVAL OF DETERIORATED MATERIALS

In the removal of deteriorated concrete and other materials preparatory to the resurfacing and rehabilitation, the use of concrete saws for full depth cuts and lifting pins to remove blocks of concrete intact, has proven to be effective and provides a time savings over the breaking up of the material and its removal as loose debris. Removing broken pavement sections in sawed blocks also results in less damage to the subgrade and subbase material in most instances. Where the base material is not the cause of failure, this expedites the preparation of the area for replacement of the failed concrete.

Vacuum units have been used for the collection and removal of deteriorated pavement materials. They eliminate some dust problems where small particles and loose debris are prevalent.

Ecological considerations and resource conservation may warrant reuse or recycling of deteriorated materials in some instances. Old concrete pavements have been broken down in place by impact hammers and rollers to form a broken stone base for new pavements. This technique was used successfully in rehabilitating a deteriorated pavement section in western New York State by the New York State Thruway Authority. Aggregate shortages or unavailability of waste areas may lead to the recycling of broken pavements through crushers and washers to provide aggregate for base of pavement mixtures.

PATCHING

Where rigid pavements are patched in preparation for overlays, two techniques are employed. Most common is filling of the prepared void with portland cement concrete. In anticipation of the overlay, these patches usually are consolidated and struck-off roughly without expending time on developing a smooth-textured final surface.

Another technique, as used by the New York State Thruway Authority, is patching of rigid pavement with full-depth bituminous concrete before placing overlays. Although the curing time is reduced below what would have been required for portland cement concrete, the bituminous full-depth patches may require up to 24 hours for the heat to escape from the material so that it will support wheel loads without deformation.

Where patching operations are limited to short off-peak periods with traffic restored during rush hours, several alternatives have been used. The District of Columbia and others have used steel plates to bridge patch excavations when traffic must be restored before patches are filled or cured. The City of Detroit uses a fast-setting patching concrete (Appendix E). Epoxy resin and aggregate mixes also are used by some agencies as patching mortars. Although fast-setting, the epoxies are expensive, sensitive to the presence of moisture, and have higher coefficients of expansion than concrete. As a consequence, their use is usually confined to small patches warranting special treatment, or to bonding coats.

Precast slabs and partial-depth planks have not been used for pavement repairs where pavements were to be overlaid.

RESURFACING

Where resurfacing is done using asphaltic concrete, quite often the traffic is directed onto the old and new pavement sections throughout the resurfacing operation. Some agencies do not permit traffic to use pavement sections where there is a differential in the elevation between one lane and the other. Other agencies limit the elevation differential between adjacent lanes under traffic to a maximum of 2 in. (50 mm).

The New Jersey Turnpike does not permit traffic to change lanes where adjacent lane elevations differ. To maintain traffic within lanes, the Turnpike uses plastic pylons glued to the lane lines with an epoxy cement. The pylons are easily dislodged with a shovel when resurfacing operations are renewed at the lane line. Where an elevation differential exists, some agencies have used a temporary wedge of bituminous material to minimize the difficulty in changing lanes. The temporary material wedge must be removed before the resurfacing operation continues.

In placing overlays, to avoid adversely affecting pavement surface drainage the sequence of placement is important. Where two or more lanes of pavement are all sloped in the same direction, the resurfacing sequence must progress from the highest lanes to the lowest lanes with each resurfacing lift in order to avoid ponding rainwater on the pavement.

Overlays using portland cement concrete are not commonly used on urban freeways due to the time requirements for preparation of the old pavement and curing of the new concrete.

COMPLETION SCHEDULES

Most agencies consider completion schedules on reconditioning projects to be of critical importance. Bonus or incentive payment programs have been used by some agencies to encourage early completion of projects under contract. In almost all instances a completion date is specified in the contract.

In the opinion of some agencies, however, early completion incentives are a mixed blessing because they may encourage a contractor to short-cut or neglect traffic control and coordination in favor of faster work schedules.

From the viewpoint of public service, most agencies consider it essential that the maximum amount of work is performed on the facility during the time that the facility or portions of the facility are closed to use by the traveling public. Where closures are on a continuous around-the-clock basis, the agency usually specifies that the contractor shall work a minimum of 20 hours each day on a 7-day-a-week basis. Where closures are intermittent, the contractor may be restricted in the number of hours to be worked, but required to be productively engaged on the site during all hours that the site is closed to traffic.

Most agencies are concerned about lane closures occurring at times when no work is under way in the closed lane. The outcry of highway users, delayed by a closing in which they see no activity, has made public officials sensitive to this problem. The City of Detroit requires that the contractor be mobilized and ready to work before a lane is closed. The Illinois Department of Transportation takes advantage of a closure to perform needed cleaning, painting, sealing, and other housekeeping activities in the closure area; thus obvious activity is under way at all times even though the closure may be required only for curing of completed repairs.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Reconditioning of high-volume urban freeways is a major task requiring the maximum effort in planning, design, and construction supervision. With a thorough and comprehensive plan carefully developed, and with an extensive public relations effort initiated and continued throughout the project, freeway reconditioning programs can be carried on while minimizing traffic jams and adverse public reaction.

With the requirements for freeway reconditioning promising a nationwide program, it is important that all agencies facing such work take full advantage of the lessons learned by programs already completed and that an ongoing information exchange and evaluation be maintained to yield further improvements in the techniques employed to perform this challenging work.

Reconditioning projects are high in cost and in impact on the highway user and the community served by the freeway system. These projects need to be planned with even greater attention to traffic handling, design details, and construction supervision than would be given to many new construction projects.

The development of traffic handling plans must be given as much comprehensive professional attention as is required for the physical repairs themselves. Agencies must be prepared in some instances to spend as many dollars on the traffic handling requirements of the project as on its basic construction features.

Project planning and coordination can best be handled by a task force encompassing all the necessary disciplines involved in the project. This task force should define the objectives of the project, review the design concepts, the construction plans, the method for handling traffic, and the proposed public information program. The task force should monitor the project from its inception through the contract letting.

A special team including police officers should be developed for job site traffic control. This team should be responsible for the evaluation of the traffic handling plan.

DESIRABLE DESIGN FEATURES

When new or rebuilt freeways are developed, certain features to accommodate the inevitable need for maintenance should be considered as a part of the basic design. In other words, every effort should be made to design maintainability into the freeway. These features include the following items.

Service Roads

Parallel service road lanes provide valuable access to accident blockage, pavement blowups, or other emergency problems on the main roadways. Parallel service roads serve as collector-distributor lanes minimizing weaving movements and capacity reductions in the through lanes and serve as diversion lanes when repairs and reconditioning of the through lanes are required.

Shoulders

Full-width, full-strength paved shoulders can provide an emergency stopping site during routine freeway operations and can serve as an available supplementary lane. Full shoulder sections carried across all structures make the use of shoulder lanes a feasible alternative during maintenance or emergency closures. Full-width, full-strength shoulders may prove to be financially feasible and no more costly than alternative designs incorporating lesser sections.

Bridge Decks

The design of concrete bridge decks should provide for sufficient cover over reinforcing steel to prevent or reduce the incidence of concrete cracking and spalling over the bars. Recent trends have seen some specifications calling for 3 in. (75 mm) of concrete over the top steel, seemingly a desirable requirement.

One method for protection of new or existing sound concrete bridge decks is use of a waterproof membrane covered by a separate wearing surface. Research under NCHRP Project 12-11, "Waterproof Membranes for Protection of Concrete Bridge Decks," evaluated membrane materials and application procedures. Promising membrane systems include those using elastomeric or plastic sheets properly treated and impregnated.

Where possible, the design should require the stringers to be located within the lane lines so that if bridge deck concrete must be removed and replaced the operation can be carried on within the confines of a single lane.

Clearances

Overpass clearances should be designed with the anticipation that the roadway beneath the overpass will ultimately require resurfacing and thus raise the pavement surface elevation. Where initial clearances were not adequate, some agencies have incorporated design features to permit superstructures to be jacked up and repositioned.

Drainage

Inlets and other surface features of highway drainage systems can be designed in anticipation of pavement resurfacing. The design can incorporate adjustable surface fixtures that can meet new pavement elevations without reconstruction. Gutters, curbs, and barriers may be designed or located to accommodate some change in pavement surface elevations without significant change or loss of the original design functions.

Pavement design should include provisions for subgrade drainage. Pipes and drainage blankets can be used to transport subsurface water away from the pavement.

Electric Power

Wherever practical (in conjunction with electric service to lights, signs, signals, etc.) along the right-of-way on freeways, electric power outlets can be installed so that emergency lighting, pumps, and other special power needs can be accommodated quickly and economically for repair and rehabilitation work.

Pavement Design

Freeway reconstruction in less than ten years has been the pattern on many facilities designed with inadequate or unrealistic criteria. Realistic determinations should be made of the traffic volumes and the magnitude of axle loads to which freeway pavements will be subjected. With reliable design criteria in hand, pavement designs can be developed to yield service lives of no less than 20 years in order to eliminate earlier costly reconstruction.

The Federal Highway Administration's Federally Coordinated Program of Research and Development in Highway Transportation, as delineated June 30, 1972, includes project area 5E, "Premium Pavements for Zero Maintenance," which specifically addresses the need for investment strategy and design technology for "zero maintenance" pavements.

Another consideration in pavement design should be use in the pavement surface of special aggregates with hardness and friction characteristics resistant to the abrasion of heavy traffic volumes.

CURRENT RESEARCH

Active research is being conducted under NCHRP Project 14-4, "Reconditioning Heavy-Duty Freeways in Urban Areas." This project has as its objective the development of new technology for reconstituting or replacing all or part of the pavement structure with a minimum of interruption to traffic.

AREAS FOR RESEARCH

Almost all design and materials research offers potential payoffs in the area of pavement rehabilitation. Several construction and design needs, however, have specific importance to this topic and were frequently cited by agencies responsible for rehabilitation programs.

One problem area needing attack is the variability of existing pavement conditions at the time of rehabilitation. In any given mile of pavement scheduled for rehabilitation, existing conditions will vary from complete structural failure to sound, serviceable sections. Preliminary or preparatory work typically includes removal and replacement of failed sections before overlaying. If in-situ repair techniques were available, much time could be saved and the resurfacing thickness might be reduced to that only necessary for restoration of riding qualities.

The concept of replaceable parts as a maintenance feature on mechanical equipment and electronic equipment is an established principle. In present highway and bridge design, however, the obvious wearing items are an integral part of the structural system and quite difficult to replace. A structural design system with replaceable wearing surfaces could achieve significant savings in time and costs over present pavement and bridge deck rehabilitation programs.

In keeping with the replacement parts concept, several agencies are now using precast pavement slabs for full-depth repair of rigid pavements. This technique was originally used in Germany and developed in Michigan. The New York State Thruway Authority has work under way to perfect a system of bridge deck replacement using precast deck panels. In England, and experimentally in the United States, small precast concrete planks have also been used successfully for partial-depth rigid pavement repairs. Much additional research and development is warranted in this area to produce quick, reliable, and economical techniques for utilization of prefabricated repair units for pavements and structures.

Research is also needed on preventive maintenance techniques that could defer or reduce major rehabilitation.

APPENDIX A

SELECTED BIBLIOGRAPHY

"A Final Report on a Cooperative Appraisal of Devices to Guide Traffic Through Construction." California Div. of Highways (Apr. 1967) 36 pp.

"Asphalt Overlays and Pavement Rehabilitation." *Manual Series 17,* The Asphalt Inst. (Nov. 1969) 134 pp.

BILLINGSLEY, N. A., JR., "Salvaging Old Pavements by Resurfacing." *Hwy. Res. Circ. 34* (1966) pp. 1-12.

"Bonded Concrete Resurfacing." HB-23, Second Ed., Portland Cement Assn. (1960) 6 pp.

BYRD, L. G., "Criteria for Maintenance of Multilane Highways." *Jour. Hwy. Div. ASCE,* Vol. 94, No. HW 1 (June 1968) pp. 43-60.

DEETZ, R. S., "Safety Precautions Needed in Maintenance of Expressways." *Proc. 20th Hwy. Eng. Conf.,* Ohio State Univ. (Apr. 6, 1966) pp. 295-303.

"Design of Overlays and Pavement Rehabilitation: 12 Reports." *Hwy. Res. Record No. 300* (1969) 65 pp.

DIEHL, J. E., "Through a Construction Project While Grout Jacking Concrete Pavement." *Proc. 16th Hwy. Eng. Conf.,* Ohio State Univ. (1962) pp. 295-301.

FORBES, C. E., ET AL., "Reducing Motorist Inconvenience Due to Maintenance Operations on High-Volume Freeways." *HRB Spec. Rep. 116* (1971) pp. 181-188.

GILL, E. D., "Salvaging of Old Pavements to Meet Interstate Standards by Resurfacing with Asphaltic Concrete." *Hwy. Res. News,* No. 21 (Nov. 1965) pp. 45-47.

GILLETTE, R. W., "A 10-Year Report on Performance of Bonded Concrete Resurfacings." *Hwy. Res. Record No. 94* (1965) pp. 61-76.

GOULD, V. G., "Summarized Committee Report 1948-1960: Salvaging Old Pavements by Resurfacing." *HRB Bull. 290* (1961) pp. 1-14.

HATTON, R. L., "Traffic Controls for Maintenance Operations." *Pub. Works,* Vol. 101, No. 11 (Nov. 1970) pp. 54-55.

KELLER, C. R., "Working Plan—Highway Signing for Safety." Virginia Highway Research Council (Dec. 1967) 11 pp.

KERMODE, R. H., and MYYRA, W. A., "Freeway Lane Closures." *Traffic Eng.,* Vol. 40, No. 5 (Feb. 1970) pp. 14-18.

KLUCHER, R. H., "Maintenance Experience on the Pennsylvania Turnpike." *Proc. Purdue Univ. Road School* (1965) pp. 28-41.

LANG, C. H., "Expressway Maintenance—Costs and Problems in Urban Areas." *Civil Eng.,* Vol. 34, No. 9 (Sept. 1964) pp. 42-44.

"Manual on Uniform Traffic Control Devices for Streets and Highways." Federal Highway Admin., U.S. Dept. of Transportation (1971) 377 pp.

MARCH, G. T., "Traffic Controls During Maintenance Operations on the Chicago Expressway System." Illinois Div. of Highways (1968).

MCDONALD, C. H., "A New Patching Material for Pavement Failures." *Hwy. Res. Record No. 146* (1966) pp. 1-16.

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

MERTEN, F. K., "Detouring Traffic on Urban Construction." *Proc. Western Assn. of State Highway Officials* (1958) pp. 233-239.

MORIMOTO, T. T., "Rehabilitating Chicago's Expressways." *Civil Eng.* Vol. 42, No. 12 (Dec. 1972) pp. 59-62.

"Mudjack Contractors' Handbook." Koehring Company (1970) 58 pp.

"Mudjacking — Slabjacking — Limejacking — Subsealing." *Maintenance Aid Digest 2,* Federal Highway Admin. (Apr. 1971) 6 pp.

"New Techniques Speed Turnpike Resurfacing." *Constructioneer* (June 13, 1966) pp. 34-93.

"Pavement Rehabilitation and Design of Overlays: 8 Reports." *Hwy. Res. Record No. 327* (1970) 82 pp.

"Pavement Rehabilitation—Materials and Techniques." *NCHRP Synthesis of Highway Practice 9* (1972) 41 pp.

PERRY, B. F., "Subsealing of Concrete Pavements." *HRB Bull. 322* (1962) pp. 30-33.

"Planned Detours." *Proc. Assn. of Highway Officials of North Atlantic States* (1965) pp. 60-106.

"Procedure for Handling Traffic on Freeways for Construction." Detroit Dept. of Streets and Traffic (Mar. 1, 1966) 4 pp.

"Quick Repair System Tried." *Michigan Roads and Constr.,* Vol. 68, No. 14 (May 1971) p. 4.

"Rapid Patching of Concrete Roads." *Indian Conc. Jour.,* Vol. 39, No. 3 (Mar. 1965) pp. 100-115.

RAY, G. K., ET AL., "Design of Concrete Overlays for Pavements." *Proc. ACI,* Vol. 64 (1967) pp. 470-474.

RIZZUTO, I. F., and HAVILAND, J. E., "An Investigation of Asphalt-Cement Subsealing and Lime-Cement Jacking." *Hwy. Res. Circ.,* No. 58 (Nov. 1966) 31 pp. + App.

"Shallow Patches Keep Concrete Ship-Shape for Heavy Traffic." *Rural and Urban Roads,* Vol. 9, No. 1 (Jan. 1971) pp. 24-25.

SIMONSEN, J .E., "Progress Report—Concrete Pavement Joint Repair with Pre-Cast Slabs." *Res. Rep. No. R-762,* Research Laboratory Section, Testing and Research Div., Michigan State Highway Comm. (Apr. 1971) 13 pp.

SIMONSEN, J. E., "Construction Report on Concrete Pavement Joint Repair with Pre-Cast Slabs." *Res. Rep. No. R-804,* Research Laboratory Section, Testing and Research Div., Michigan State Highway Comm. (Feb. 1972) 13 pp.

"Specifications for Undersealing Portland Cement Concrete Pavements with Asphalt." *Spec. Series No. 6,* The Asphalt Institute (Dec. 1966) 17 pp.

STAIB, F. C., "Full-Depth Concrete Pavement Repairs on the Ohio Turnpike." *Hwy. Res. Record No. 146* (1966) pp. 17-27.

"Traffic Control for Freeway Maintenance." *NCHRP Synthesis of Highway Practice 1* (1969) 47 pp.

APPENDIX B

DETROIT PROCEDURES FOR HANDLING TRAFFIC DURING FREEWAY REHABILITATION

MICHIGAN STATE HIGHWAY COMMISSION
6 - 2S

MACKINAC BRIDGE AUTHORITY INTERNATIONAL BRIDGE AUTHORITY

CHARLES H. HEWITT, Detroit, *Chairman*
ARDALE W. FERGUSON, Benton Harbor
WALLACE D. NUNN, East Tawas, *Vice Chairman*
RICHARD F. VANDER VEEN, Grand Rapids

HENRIK E. STAFSETH, *State Highway Director*

GEORGE ROMNEY
Governor

LANSING 48926

517 - 373 - 2160

FOR IMMEDIATE RELEASE June 4, 1968

DETROIT -- A two-mile section of the John C. Lodge Freeway will be closed to traffic for eight hours Sunday (June 9) in a project designed to establish a regular system of freeway maintenance in the Detroit area.

It will be a combined research, maintenance and traffic engineering project that will help determine the feasibility of closing freeway sections for repairs that ordinarily would be spread over several weeks. The Department of State Highways, the Detroit Department of Streets and Traffic and the Wayne County Road Commission all are taking part.

Traffic will be barred from the northbound section of the freeway from the Milwaukee Ave. ramp to the Chicago Ave. ramp between 2 a.m. and 10 a.m. Sunday. Detroit police will begin the first phase of the closing about midnight.

Traffic, which falls to its lowest ebb of the week during those hours, will be rerouted over the freeway service drive and other roughly parallel routes.

State and county road officials say a backlog of essential maintenance work on the freeways makes it necessary to devise a new fast-repair system. Traffic volumes make closing of whole freeways impractical and the current system of working one or two lanes at a time during restricted hours is slow, costly and hazardous.

The alternative is to close sections large enough for efficient and safe repair operations and to offer alternate routes sufficient to handle traffic safely during the time required for the repairs.

The project will give traffic engineers valuable information on how to handle traffic diverted from the freeway. They will check on motorists' choices of alternate routes during the closing and learn about any accident factors that may develop.

An extensive system of temporary signs, signals and barricades has been devised to warn and protect drivers in the area.

Nine major "blow-ups" in the surface of the closed freeway section will be repaired on the 20-year-old freeway. The relatively long shut-down will enable repairmen to apply long-lasting hot-mix patches of asphalt rather than the cold patch used when one or two lanes are closed for shorter maintenance periods.

The plan also calls for cleaning of 114 manholes and catch basins; repair, replacement and cleaning of signs; marking of pavement lanes and ramps; inspection of bridges and removal of loose or scaling concrete and repair of minor joint failures.

Officials estimate the closure will save 80 percent in maintenance costs. Offsetting those savings will be additional costs of temporary signing, lighting and temporary police personnel. Total closure, however, will mean greater safety for repair crews and motorists than with the usual maintenance system and more convenience for the traveling public.

In the event of bad weather, the project will be postponed until the following Sunday, June 16.

More than 200 men, including supervisors from the three agencies involved, will be working at the project site Sunday. These do not include many others involved in five months of planning and preparation.

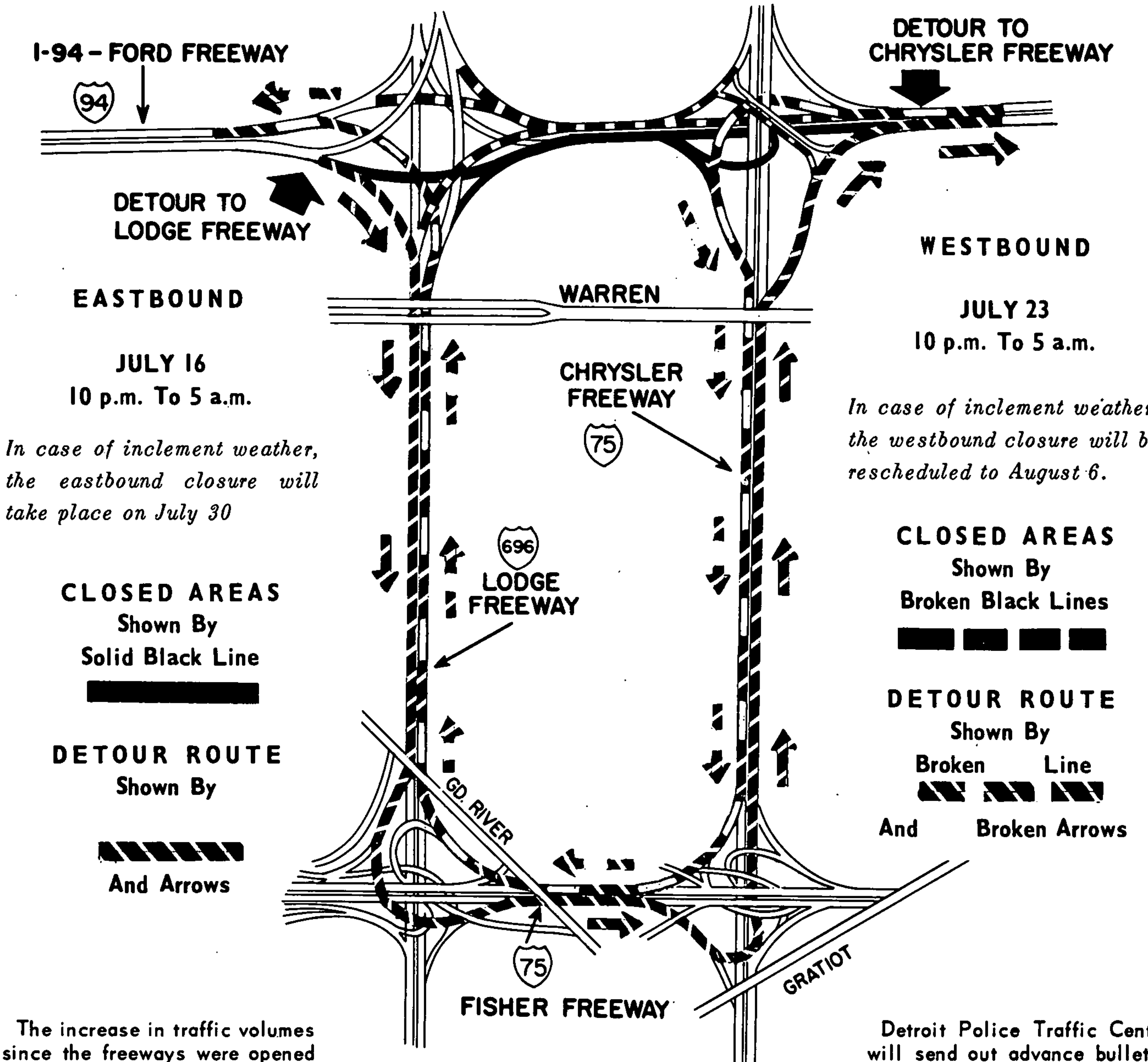
Alger F. Malo, director of the Detroit Department of Streets and Traffic, and Frank Skebensky, Detroit Metropolitan district engineer for the Department of State Highways, are directing the project.

Stanford Gross, DST traffic operations engineer and Joseph Marlow, District Traffic and Safety Engineer for the Highway Department are in charge of the closure phases. Robert G. Perry, district maintenance engineer for the Highway Department, will have charge of maintenance operations. William Mascaro, Wayne County highway maintenance engineer, will direct field operations.

- 0 -

"IT COSTS MORE TO USE BAD ROADS THAN TO BUILD GOOD ROADS."

I-94-FORD FREEWAY CLOSINGS - JULY 16, JULY 23



The increase in traffic volumes since the freeways were opened precludes the mass closing of entire freeways and the current system of working one or two lanes at a time during restricted hours is slow, costly, hazardous and often temporary.

These closures are designed to permit efficient and safe repair operations with sufficient alternate routes to handle traffic volumes safely during the time required for the maintenance work.

The eastbound Edsel Ford Freeway (I-94) will be closed to traffic between the Lodge-Ford Interchange and the Ford-Walter P. Chrysler Freeway (I-75) Interchange from 10:00 p.m. to 5:00 a.m. Thursday, July 16.

The following week the westbound Ford Freeway will be closed from 10:00 p.m. to 5:00 a.m. Thursday, July 23.

Traffic for both closures will be detoured via Lodge, Fisher and Chrysler freeways (see map above). Motorists are urged to pay attention to advanced signs and warnings.

Detroit Police Traffic Central will send out advance bulletins to keep motorists informed. Drivers in the area are urged to stay tuned to one of the following radio stations for up-to-the-minute advisories and bulletins on the ramp closings:

WCAR • WCHB • WDEE
WIID • WJR • WKNR
WWJ • WXYZ • CKLW

Produced by the Department Report and Information Committee, City of Detroit, and the Traffic Safety Association of Detroit.

Figure B-1. Urban freeway detour information sheet (Detroit). Two-color printing provided emphasis on the original.

FREEWAY CLOSURE

EASTBOUND I-94 FROM I-696BS TO I-75

METHOD OF CLOSURE

1. THREE (3) POLICE VEHICLES (WITH A. R. BRIERE AND STAN GROSS) AT THE EASTBOUND ENTRANCE RAMP AND WEST GRAND BOULEVARD INFORM ROBERT PERRY IN COMMAND CAR TO START THE CLOSURE OF RAMPS.

2. STATE VEHICLE (RADIO EQUIPPED) AT SOUTHBOUND I-696BS RAMP TO EASTBOUND I-94 (HAROLD ABBOTT, 04) RECEIVES ORDER FROM COMMAND CAR (ROBERT PERRY, 1906) TO CLOSE THE RAMP.

3. STATE VEHICLE (RADIO EQUIPPED) AT SOUTHBOUND I-696BS RAMP TO EASTBOUND I-94 (AL WILLIAMS, 3150)RECEIVES ORDER FROM COMMAND CAR TO CLOSE THE RAMP.

4. STATE VEHICLE (RADIO EQUIPPED) AT BEAUBIEN STREET ENTRANCE RAMP TO EASTBOUND I-94 (JOE BASSIL, 2389) RECEIVES ORDER FROM COMMAND CAR TO CLOSE THE RAMP.

5. COUNTY VEHICLES (WITH ILLUMINATED TARGET ARROWS) ON 14TH STREET RAMP CLOSED BY POLICE. (AL RADZIBON WILL BE IN CHARGE AND NEAR POLICE CAR.)

6. THE THREE POLICE VEHICLES AT WEST GRAND BOULEVARD RECEIVE WORD FROM ROBERT PERRY THAT THE ABOVE RAMPS ARE CLOSED AND MAY ENTER THE FREEWAY.

7. POLICE VEHICLE AT LINWOOD AVENUE ENTRANCE RAMP TO EASTBOUND I-94 RECEIVES ORDER FROM STAN GROSS AND A. R. BRIERE TO CLOSE THE RAMP TEMPORARILY. AT THE SAME TIME AL RADZIBON WILL BE ALERTED AT THE 14TH STREET RAMP.

8. THE POLICE VEHICLES PROCEED TO SLOW DOWN TRAFFIC TO TEN MILES PER HOUR. A STATE VEHICLE WITH FLASHER (LARRY BROWN, 3097) WILL FOLLOW LAST MOTORIST. WHEN HE PASSES THE 14TH STREET RAMP THE COUNTY VEHICLES, WITH ILLUMINATED TARGET ARROWS, MAY ENTER THE ROADWAY.

9. WHEN LARRY BROWN ARRIVES AT THE CLOSURE AREA THE WORK CREWS SET THE TAPER AND NECESSARY SIGNS.

10. THE POLICE VEHICLES LEAD THE TRAFFIC THROUGH THE DETOUR ROUTE.

11. THE COMMAND CAR (ROBERT PERRY, 1906) THEN PROCEEDS THE LENGTH OF THE CLOSURE AND INFORMS THE CREWS THEY MAY START WORK AND TO PLACE BARRICADES AT THE DEQUINDRE YARD BRIDGE.

12. AT THIS TIME THE POLICE MAY ORDER THE LINWOOD AVENUE AND 14TH STREET RAMPS REOPENED.

CITY OF DETROIT
Department of Streets and Traffic
Water Board Building
Detroit, Michigan 48226

December 1, 1971

PROCEDURE FOR HANDLING TRAFFIC ON FREEWAYS FOR CONSTRUCTION

The following working restrictions supersede all previous restrictions set forth on Procedure for Handling Traffic on Freeways for Construction purposes or maintenance. These restrictions are necessary to minimize the amount of traffic interference on the freeway system. These revisions made in the procedure for handling traffic on our freeway system apply to Monday through Friday traffic conditions. There are numerous sections of the system that require working restrictions on Saturdays and Sundays, depending on activities at Tiger Stadium and downtown shopping conditions. However, the weekend restrictions would be based on the particular type of construction or maintenance depending on the number of lanes that would be affected.

WORKING RESTRICTIONS

Edsel Ford Freeway

1. No work shall be performed:
   - A. On the eastbound Edsel Ford Freeway between Wyoming and Third 6 am to 10 am and 2:00 pm to 10 pm.
   - B. On the eastbound Edsel Ford Freeway between Third and Conner 7 am to 9 am and 2:00 pm to 10 pm.
   - C. On the eastbound Edsel Ford Freeway between Conner and Detroit City Limits at Kingsville from 2:30 pm to 10 pm.
   - D. On the westbound Edsel Ford Freeway between Detroit City Limits and Kingsville and Conner from 7 am to 9:30 am.
   - E. On the westbound Edsel Ford Freeway between Conner and Chene from 7 am to 9:30 am and 2:00 pm to 10 pm.
   - F. On the westbound Edsel Ford Freeway between Chene and Grand River from 6 am to 9:30 am, and 2:00 pm to 10 pm.
   - G. On the westbound Edwel Ford Freeway between Grand River and Wyoming from 6 am to 10 am and 2:00 pm to 10 pm.
   - H. Gratiot-Edsel Ford Interchange
     On the westbound Gratiot on-ramp from 7am to 9:30 am and 2:00 pm to 10 pm.
   - I. On the eastbound Gratiot off-ramp from 7 am to 9 am and 2:30 pm to 10 pm.
     On the eastbound Gratiot on-ramp from 2:30 pm to 10 pm.
   - J. Livernois-Edsel Ford Interchange
     On the westbound Livernois on and off ramps from 7 am to 10 am and 2:00 pm to 10 pm.
     On the eastbound Livernois on and off ramps from 7 am to 10 am and 2:00 pm to 10 pm.
   - K. Conner-Edsel Ford Interchange
     On the eastbound Conner off ramp from 2:30 pm to 10 pm.
     On the westbound Conner on ramp from 7 am to 9:30 am.

John C. Lodge Freeway

1. No work shall be performed:
   A. On the southbound John C. Lodge Freeway between Wyoming and W. Davison from 7 am to 10 am and 2:00 pm to 10 pm.
   B. On the southbound John C. Lodge Freeway between W. Davison and Canfield from 7 am to 10 am and 2:00 pm to 10 pm.
   C. On the southbound John C. Lodge Freeway between Canfield and Howard from 7 am to 10 am and 2:30 pm to 10 pm.
   D. On the southbound John C. Lodge Freeway between Howard and Jefferson (including Jefferson to Griswold) from 7 am to 9 am.
   E. On the northbound John C. Lodge Freeway between Jefferson and Grand River from 7 am to 8:30 am and 2:00 pm to 10 pm (including Jefferson to Griswold).
   F. On the northbound John C. Lodge Freeway between Grand River and W. Davison to 7 am to 10 am and 2:00 pm to 10 pm.
   G. On the northbound John C. Lodge Freeway between W. Davison and Wyoming from 2:00 pm to 10 pm.
   H. Davison W. - John C. Lodge Interchange
      On all ramps in the Davison interchange from 6 am to 10 am and 2:00 pm to 10 pm.
   I. John C. Lodge-Livernois Interchange
      On the southbound Livernois off ramp from 6 am to 10 am.
   J. On the southbound Livernois on ramp from 6 am to 10 am.
      On the northbound Livernois off ramp from 2:00 pm to 10 pm.
   K. John C. Lodge Freeway Extension (Walled Section)
      On the southbound John C. Lodge Freeway between W. Eight Mile and Wyoming from 6 am to 10 am and 2:00 pm to 10 pm.
      On the northbound John C. Lodge Freeway between Wyoming and W. Eight Mile from 6 am to 10 am and 2:00 pm to 10 pm.

Southfield Freeway

1. No work shall be performed:
   A. On the southbound Southfield Freeway between W. Eight Mile Road and south city limits at Dearborn from 6 am to 9 am and 3 pm to 10 pm.
   B. On the northbound Southfield Freeway between Paul and W. Eight Mile Road between 6 am and 9 am and 3 pm to 10 pm

These provisions are subject to change if traffic conditions indicate such a necessity.

Chrysler Freeway

1. No work shall be performed:
   A. On the southbound Chrysler Freeway between E. Eight Mile Road and Jefferson Avenue from 6 am to 9 am and 3 pm to 10 pm.
   B. On the northbound Chrysler Freeway between Jefferson and E. Eight Mile Road from 6 am to 9 am and 3 pm to 10 pm.

These provisions are subject to change if traffic conditions indicate such a necessity.

PROCEDURE REGARDING CONSTRUCTION, REPAIR AND MAINTENANCE ON ALL FREEWAYS

Freeway Personnel

Currently, there are a number of agencies providing maintenance and construction services on the freeways. These are the Michigan State Highway Department, Wayne County Road Commission, Public Lighting Commission, and selected private contractors. They will attempt all repairs, construction, painting and installation that is required.

Relative to these projects, an authority, the Department of Streets and Traffic, has set forth a set of rules and/or binding regulations. A copy of this information is retained at Traffic Central (Belle Isle) for reference and information. Within this directive is indicated the contractor and/or agency, and the allocated permissible times when such work may be performed. Most often this will necessitate the blocking or shutting off of one traffic lane. Under existing regulations, any work that requires 30 minutes or less will only require flashing yellow caution lights and/or flagmen, properly distanced. In all cases where such work will exceed 30 minutes, it is mandatory that "traffic cones" be placed at a minimum distance of 500 feet to the rear of such project. In the event that median or shoulder distance indicators are used to demote the distance to the project or blockage, they are required to be reasonably accurate.

In any event, should anything of an emergency nature arise which would sharply decrease the flow of traffic and the contributing cause is found to be the work project, freeway patrol officers possess the legal authority to order said project from the freeway. Should there be any violent objection on the part of the project foreman, the officer is to apprise him of the rules and regulations instituted by the Department of Streets and Traffic. However, before any other action is taken, he shall contact the OFFICER IN CHARGE OF THE M.T.B. DESK for proper instructions.

These instructions and regulations are prescribed for use by Edward Aniol and Thomas York, Department of Streets and Traffic, the delegated authority for all freeways within the corporate limits of the City of Detroit.

APPENDIX C

SPECIFICATIONS FOR REPAIR WITH PRECAST SLABS

MICHIGAN

SPECIFICATION
FOR

CONCRETE PAVEMENT REPAIR WITH PRE-CAST SLABS

DESCRIPTION:

This specification covers the removal of failed concrete pavement areas, fabrication of pre-cast concrete slabs, and installation of pre-cast slabs. This repair method shall be limited to repairs 12 feet or less in length.

MATERIALS:

The materials shall meet the requirements of the Standard Specifications as follows:

Concrete Grade P or P-HE.	7.01
Cement Type 1 (for mortar).	8.01
Fine Aggregate 2NS (for mortar)	8.02
Steel Reinforcement	8.05
Joint Materials	8.16
Curing Materials.	8.24

The cement-mortar slurry shall consist of one part cement to two parts sand. Water may be added in sufficient quantity to obtain a mortar that is workable under existing weather conditions.

EQUIPMENT

The procedures specified may in some cases call for special devices not available commercially. If a bidder desires to obtain information on any device specified, these items are available for inspection at the Department's Research Laboratory. Also, personnel experienced with this repair method will be available for discussing with a bidder any details concerning the method and procedures specified.

CONSTRUCTION METHODS

Slab Fabrication

Slabs shall be fabricated in accordance with the plans. Length and thickness of the slabs will be specified in the proposal. Forms may be wood or metal and must be built mortar tight. The forms shall be braced sufficiently to prevent distortion during placing and curing of the concrete. The casting site and equipment required to place and finish the concrete shall be approved by the Engineer.

The reinforcement shall be placed as shown on the plans. Four coil-type inserts placed as shown on the plans shall be placed in each slab. The inserts shall be, or equivalent to, the 1-inch Type S Single Pick-Up Insert manufactured by Superior Concrete Accessories, Inc., 9301 King Street, Franklin Park, Illinois. Swivel plates, bolted to the inserts by use of 1-inch diameter by 5-inch long coil bolts shall be used for attaching to the slabs.

The concrete shall be poured over and through the reinforcement and consolidated by vibration. The surface shall be finished by screeding, hand floating, and brooming. Curing protection shall be applied as soon as the concrete surface has set sufficiently to apply the curing agent without damage.

The slabs shall not be lifted or handled for storing before the concrete has attained a compressive strength of 2,000 psi or 50% of the compressive strength as determined from Table 7.01-5. No slab may be installed before the compressive strength of the concrete is 3500 psi or 100% of the compressive strength as determined from Table 7.01-5.

Pavement Removal

The length of the area to be removed shall be the specified length of the pre-cast slab plus 3 inches. Full-depth saw cuts shall be made as shown on the sawing diagram. The existing base shall not be disturbed during removal of the pavement area designated for removal. The procedure for removing the pavement area shall be as follows:

1. Remove the concrete between narrowly spaced saw cuts with air hammers and hand tools.
2. Install lift pins (see sketch) or other attachment devices and lift out the concrete.
3. Clean out the area with hand tools.

Pre-Cast Slab Installation

The procedure for installing the pre-cast slab shall be as follows:

1. Set the final surface elevation of the pre-cast slab by use of a frame or forms (see sketch). The final slab elevation shall be determined by the Engineer.
2. Place the cement-mortar slurry on the subbase and strike-off to the bottom elevation of the pre-cast slab.
3. Lower the pre-cast slab gradually in a plane parallel to the surface of the mortar. Position the slab so that the joints are of nearly equal width before making uniform contact with the mortar. To insure proper orientation of the slab during installation it may be necessary to adjust the length of each of the chains or cables supporting the slab. A ratchet type chain binder will be satisfactory for this purpose.
4. Insert bituminous filler strips in the transverse joints. Openings less than 1/4-inch wide may be left unfilled.
5. Fill longitudinal joints with cement mortar to within 2 inches of the surface.
6. Resote shoulders in kind to the final elevation except that hard surfaced shoulders will be restored by backfilling full depth with CP-3 or equal.
7. The slabs may be opened to traffic as soon as the installation, except for sealing, is completed and the shoulders restored.
8. The joint sealing operation will be delayed until the slabs have been installed and inspected under traffic to determine that no tilting or misalignment of the slab has occured. If in the opinion of the Engineer any slab is not uniformly bedded or not in the proper alignment or to the grade determined by the Engineer the slab shall be reinstalled using the previously outlined procedures.
9. Clean all dirt from the joints and lifting inserts with compressed air, raking if necessary, and seal with hot-poured rubber-asphalt sealant. The contact surfaces shall be dry at the time of sealing.

Maintaining Traffic

Traffic shall be maintained as specified in the proposal which will include special provisions for working hour restrictions and any additional traffic control devices or signs required. Pre-cast slab installation except for sealing at any location must be performed in the same shift as the pavement removal except for sawing at that location.

MEASUREMENT AND PAYMENT

Method of Measurement

Removing Old Pavement will be measured in place by area in square yards.

Pre-cast Slabs will be measured by area in square yards in accordance with the dimensions on the plans.

Placing Pre-cast Slabs will be measured by the area in square yards in accordance with the dimensions on the plans.

Maintaing Traffic will be measured as a complete unit.

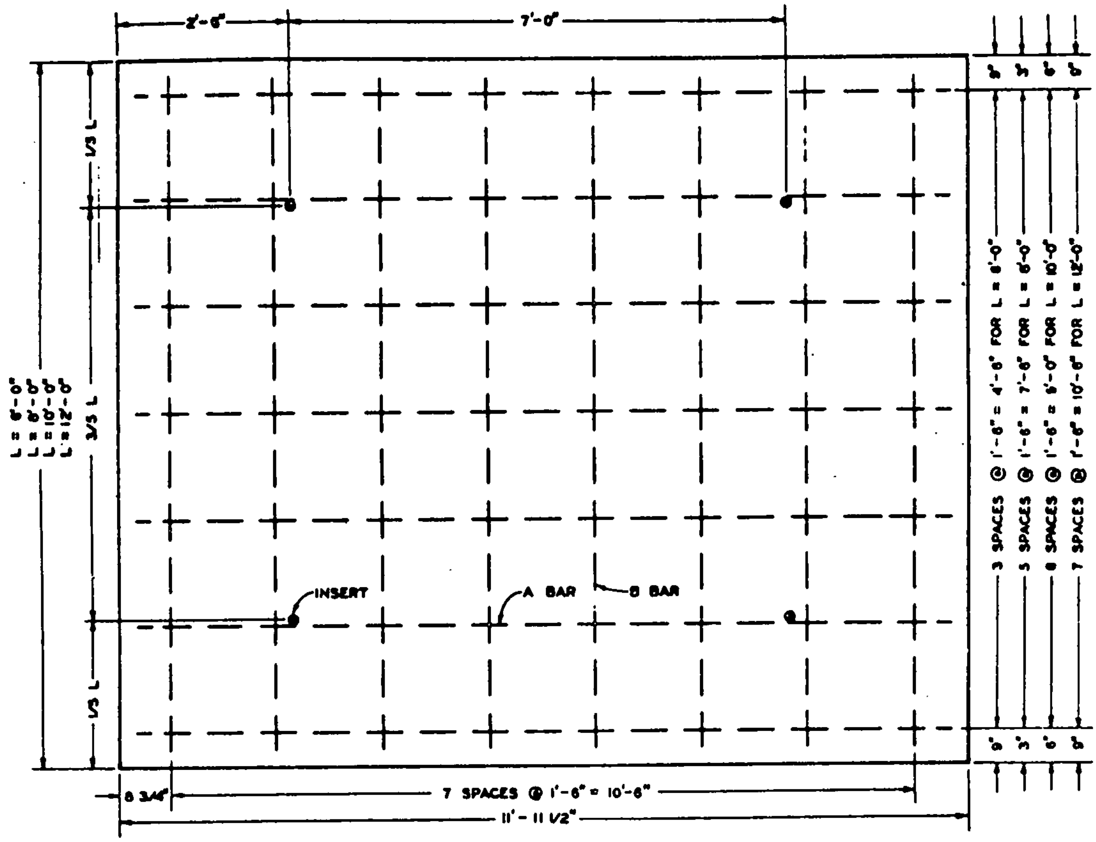
Basis of Payment

"Removing Old Pavement" will be paid for at the contract unit price per square yard which price shall be payment in full for sawing and removing, and disposal or materials.

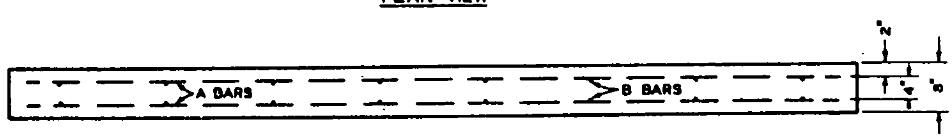
"Pre-Cast Slabs" will be paid for at the contract unit price per square yard which price shall be payment in full for furnishing the pre-cast slabs including reinforcing steel, inserts, attachments, and other material or work required to construct the pre-cast slabs complete. Material or work not otherwise provided for in a separate bid item shall be incidental and not paid for separately.

"Placing Pre-Cast Slabs" will be paid for at the contract unit price per square yard which price shall be payment in full for installing pre-cast slabs complete including mortar bed joint and sealing materials, reinstallation, and any work of Final Trim and Clean-up. All materials, and work not otherwise provided for in a separate bid item, shall be incidental and will not be paid for separately.

"Maintaining Traffic" will be paid for at the contract lump sum price which shall be payment in full for all the materials, equipment and labor required to maintain traffic except illuminated Target Arrow Signs which will be paid for separately.



PLAN VIEW



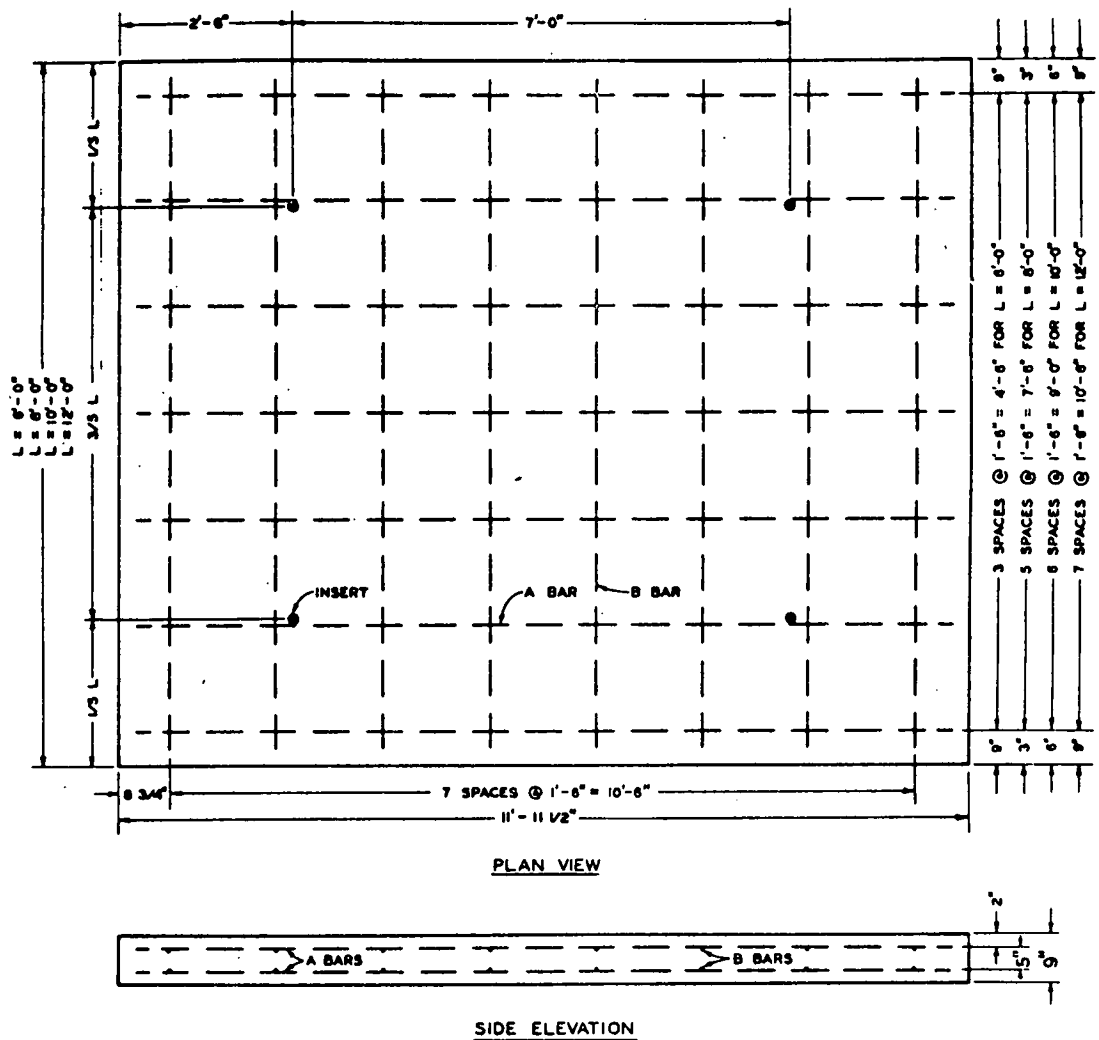
SIDE ELEVATION

Nominal Slab Size	Bar Designation	Bar Size	Bar Dimension	Number Required Per Slab	Concrete Required	Approximate Weight
12' x 12'	A	#3	11' - 6"	16	3.6 yd³	14,400#
	B	#3	11' - 6"	16		
10' x 12'	A	#3	11' - 6"	14	3.0 yd³	12,200#
	B	#3	9' - 6"	16		
8' x 12'	A	#3	11' - 6"	12	2.4 yd³	9,800#
	B	#3	7' - 6"	16		
6' x 12'	A	#3	11' - 6"	8	1.8 yd³	7,400#
	B	#3	5' - 6"	16		

Tolerances:

The variation in length and width shall be not more than ± 1/4".
The variation in thickness shall be not more than ± 1/8".
The squareness of the slab shall not vary more than 1/2" in the length of a side.
The squareness of the sides with respect to the bottom or top surface shall not vary more than 1/8" in the thickness of the slab.
The top and bottom surfaces shall be flat within 1/8" in 10 feet.

Figure C-1. Plan for 8-in. precast slab (for 9-in. pavement).

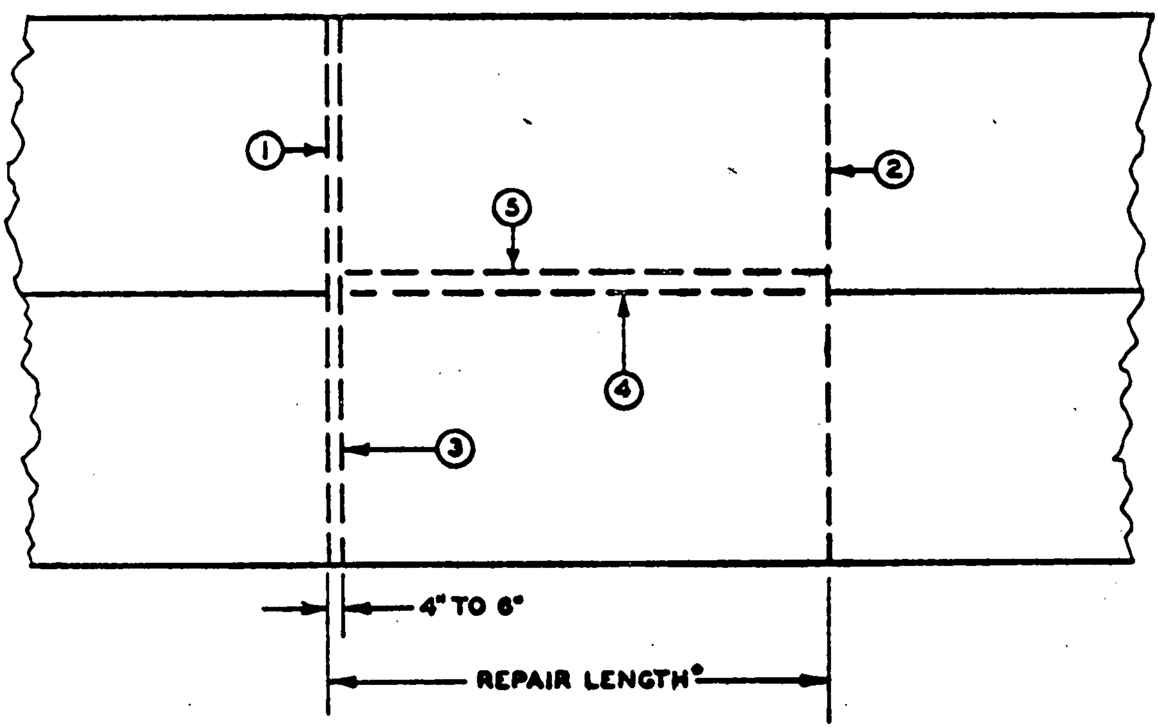


Nominal Slab Size	Bar Designation	Bar Size	Bar Dimension	Number Required Per Slab	Concrete Required	Approximate Weight
12' x 12'	A	#3	11' - 6"	16	4.0 yd^3	16,200#
	B	#3	11' - 6"	16		
10' x 12'	A	#3	11' - 6"	14	3.3 yd^3	13,500#
	B	#3	9' - 6"	16		
8' x 12'	A	#3	11' - 6"	12	2.7 yd^3	10,800#
	B	#3	7' - 6"	16		
6' x 12'	A	#3	11' - 6"	8	2.0 yd^3	8,100#
	B	#3	5' - 6"	16		

Tolerances:

The variation in length and width shall be not more than ± 1/4".
The variation in thickness shall be not more than ± 1/8".
The squareness of the slab shall not vary more than 1/2" in the length of a side.
The squareness of the sides with respect to the bottom or top surface shall not vary more than 1/8" in the thickness of the slab.
The top and bottom surfaces shall be flat within 1/8" in 10 feet.

Figure C-2. Plan for 9-in. precast slab (for 10-in. pavement).



* Repair length to be length of precast slab plus 3 inches.

(1) (2) These sawcuts shall be perpendicular to the edge of the roadway. If the repair is on a curve the cuts shall be perpendicular to a straight line extended between the limits of the repair at the edge of the roadway.

(3) This cut is made to facilitate opening a trench across the slab to relieve compression in the pavement prior to lifting out the failed areas.

(4) This cut is made between lanes, between a lane and a curb, and between a lane and a ramp.

(5) This cut is made for the reasons given in 3 except for facilitating pressure relief in the transverse direction. This cut can be omitted if there are no adjacent lanes, curbs or ramps.

Additional sawcuts may be made inside the repair limits at the contractor's option.

The specified distance between sawcuts (1) and (2) shall be held within a tolerance of -0 + 1/2 inch in 24 feet.

Figure C-3. Sawing diagram; all sawcuts to be full depth.

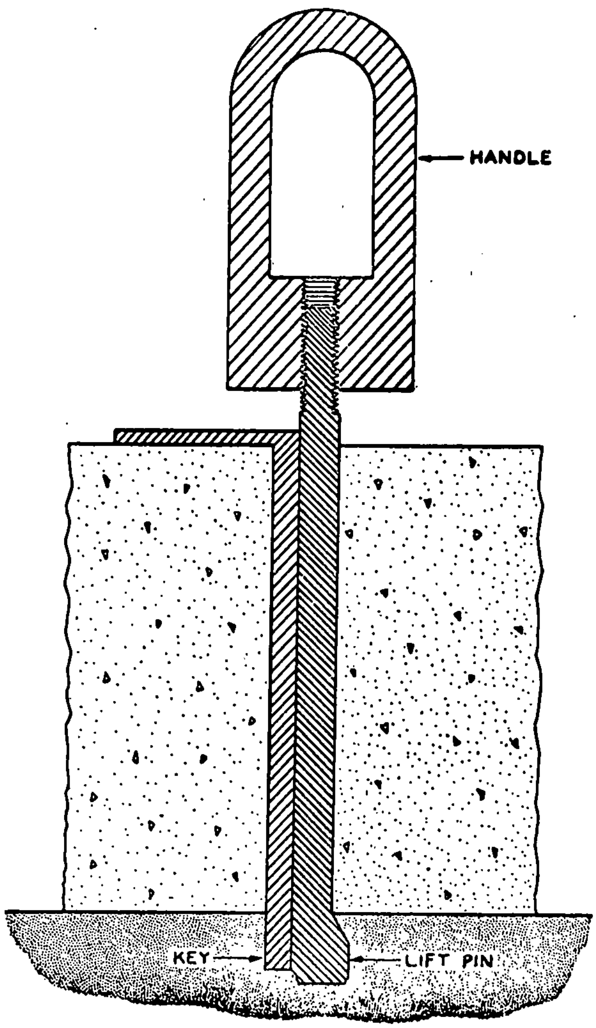


Figure C-4. Lift pin assembly cross-section.

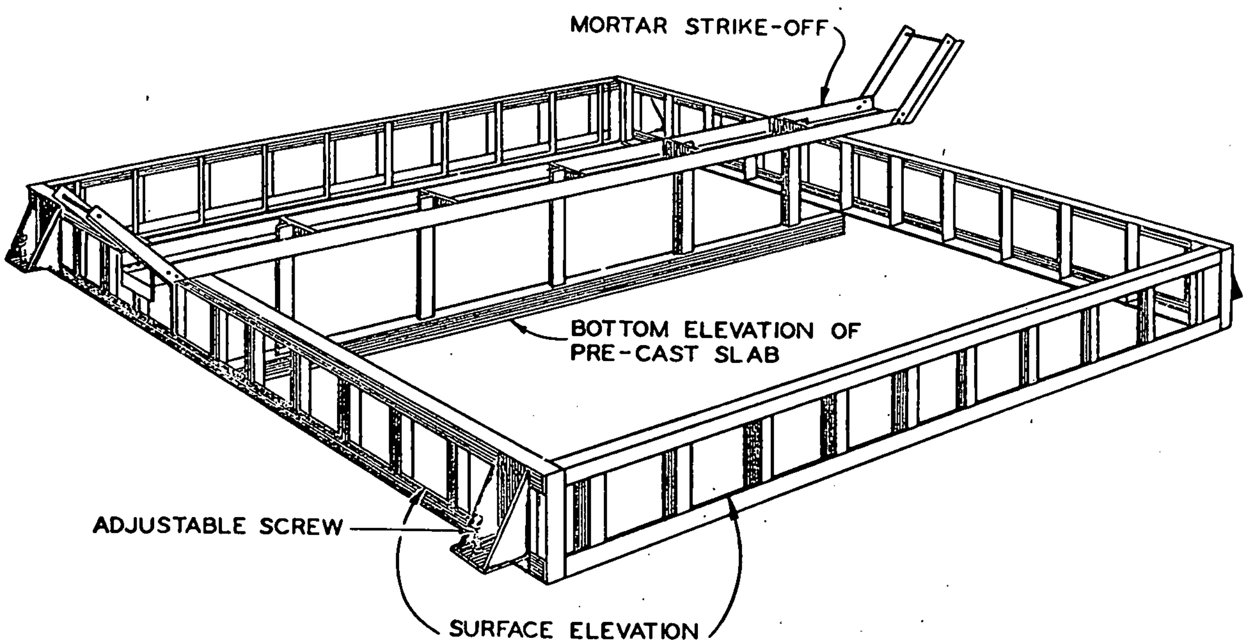


Figure C-5. Frame for setting precast slab elevation.

SPECIFICATION

CONCRETE PAVEMENT PRESSURE RELIEF JOINT

Description:

This specification covers the full depth sawing and removal of the concrete pavement and the installation of a pre-formed expanded polyethelene foam joint filler.

Materials:

The Dow Chemical Company's "Pressure Relief Joint Filler (Polyethelene)", or equal. Sealer to be equal to that recommended by manufacturer.

Equipment:

The concrete pavement saw shall have the capacity to saw the pavement full depth.

Construction Method

A four-inch slot shall be sawed transversly across the pavement at a location designated by the Engineer. After the concrete is removed and the joint cleaned of all rubble, install joint filler into slot with approved sealer material along the walls of the joint.

Method of Measurement:

Concrete pavement pressure relief joint shall be measured by lineal feet.

Basis of Payment

Concrete pavement pressure relief joint will be paid at the contract unit price per lineal foot, which price shall be payment in full for furnishing all materials, labor and equipment to saw the joint slots, clean and prepare the joint slots for the joint filler installation, including the patching of spalls with mortar where required and installing the pressure relief joint complete.

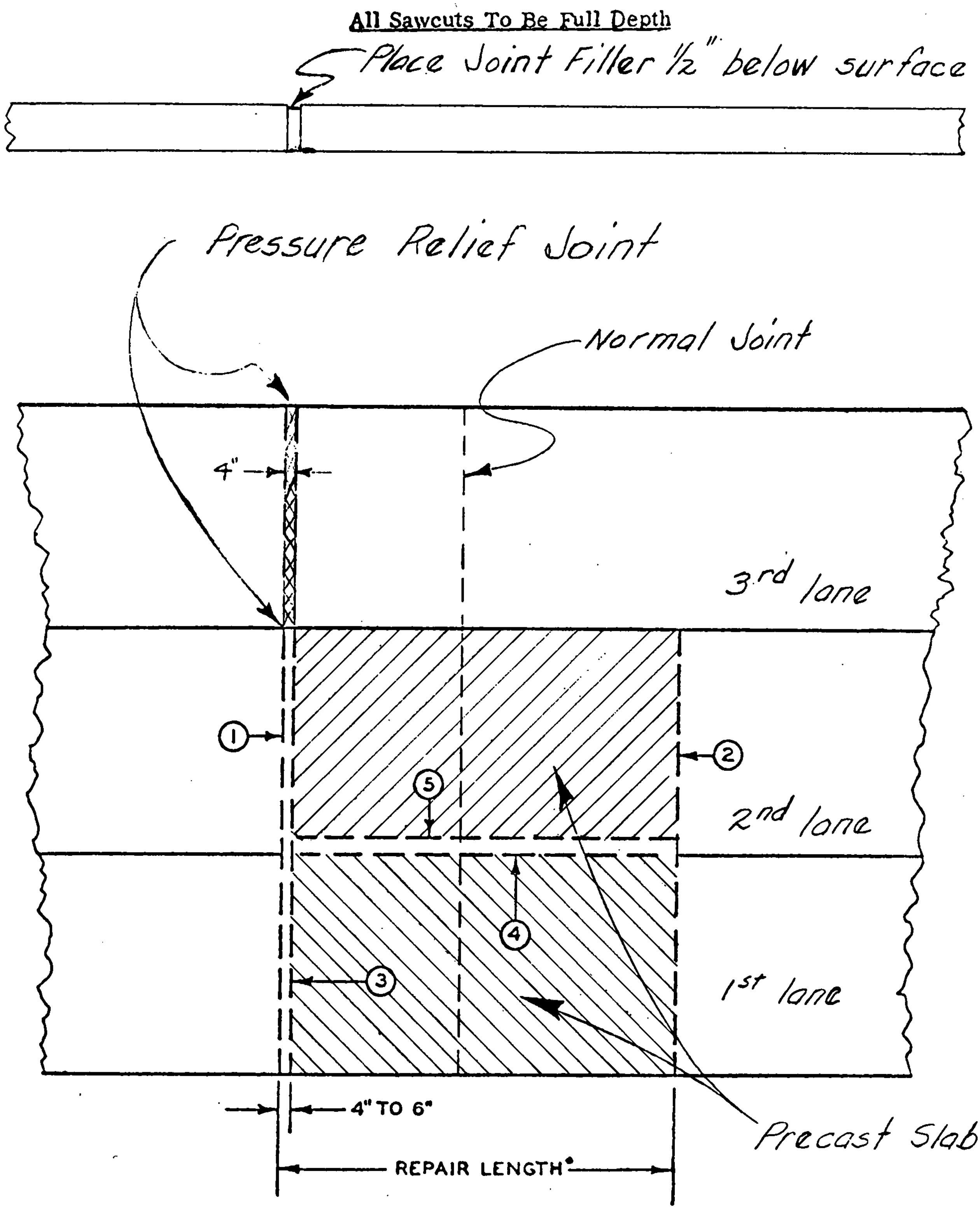


Figure C-6. Typical sawing diagram.

NEW YORK THRUWAY

Deck Slab-Stringer Connection

The New York Thruway Authority has developed a system of connections for fastening new precast bridge deck slab sections to the stringers. Figure C-7 shows the connections used for different designs. Details for some of these are shown in Figures C-8 through C-13.

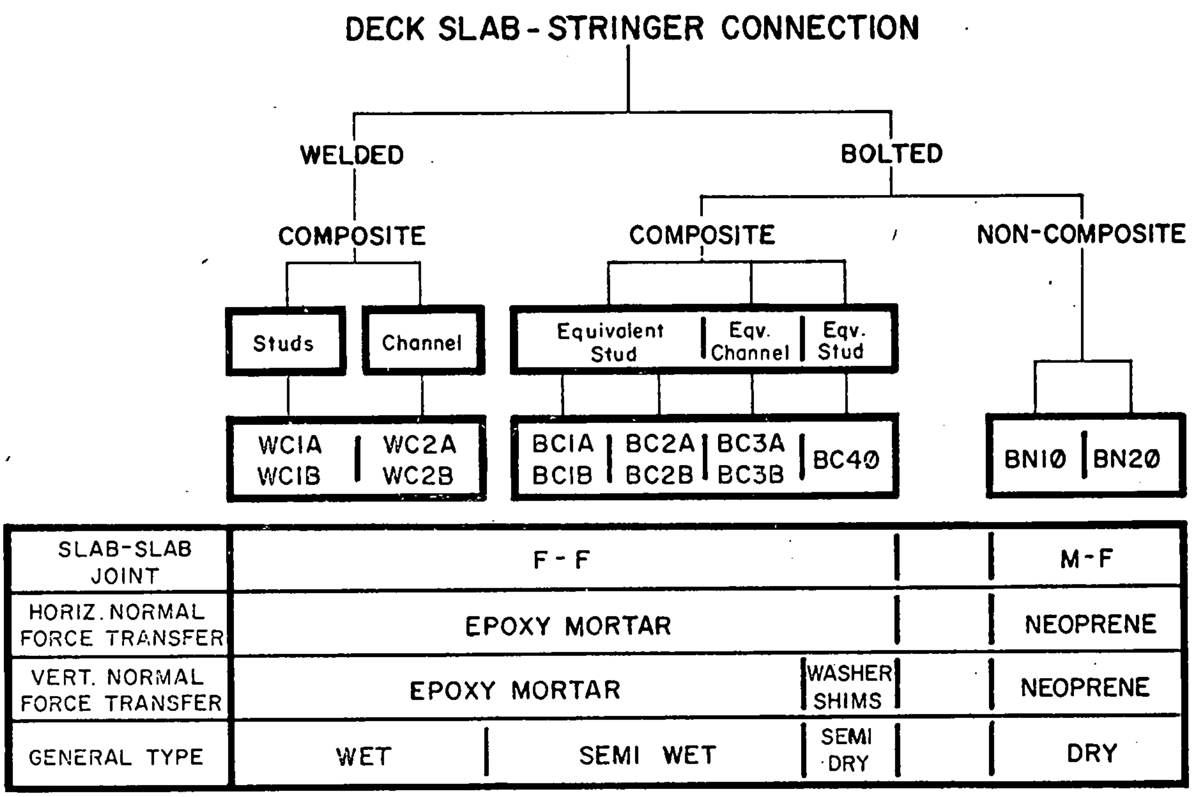
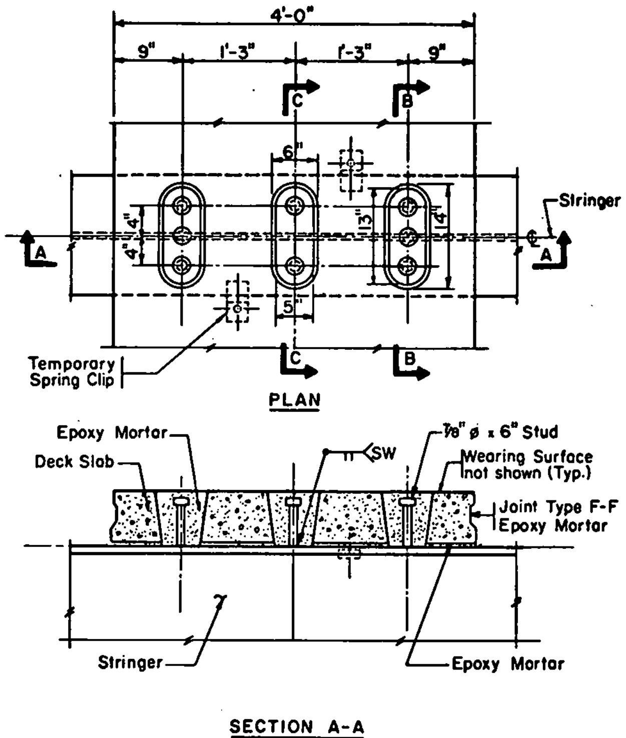


Figure C-7. Deck slab-stringer connection.



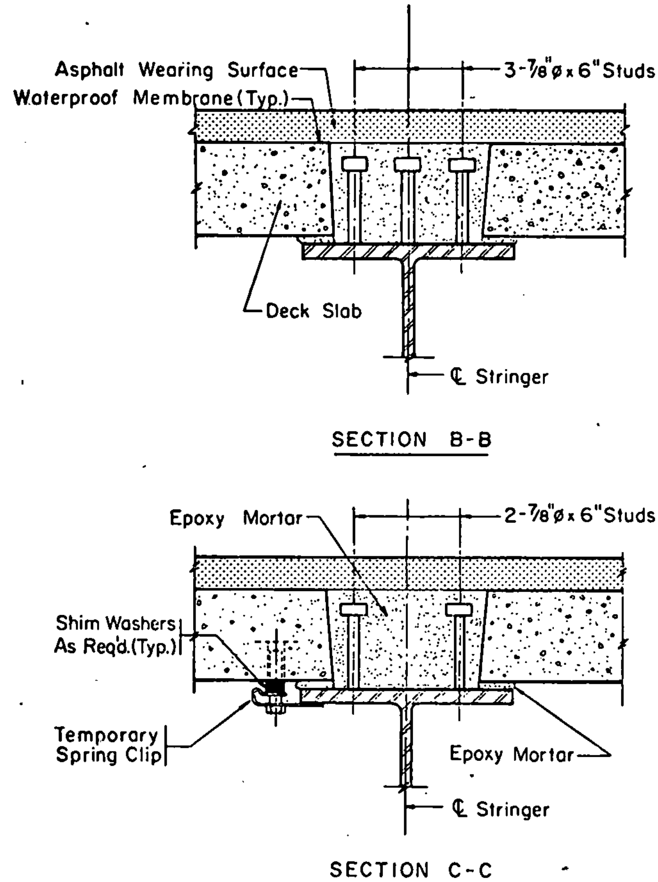
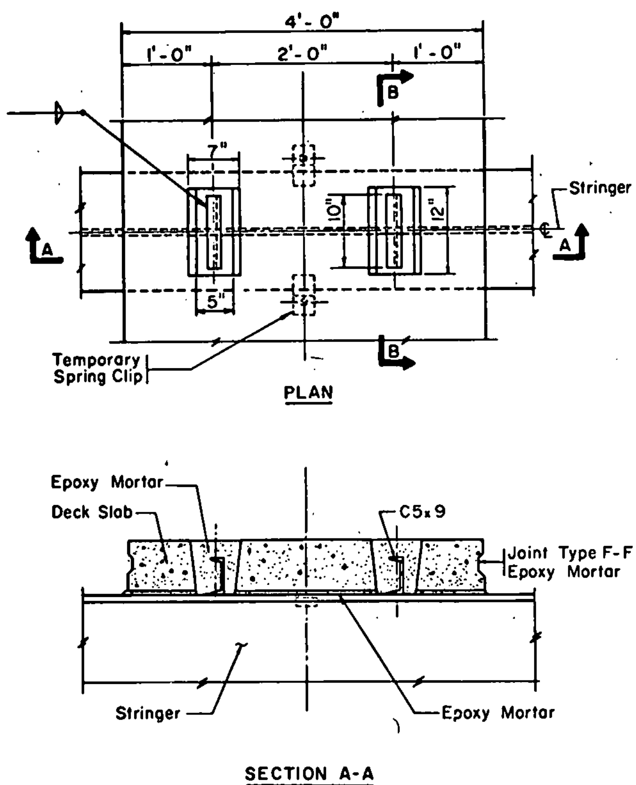


Figure C-8. Connection, type WC1A.



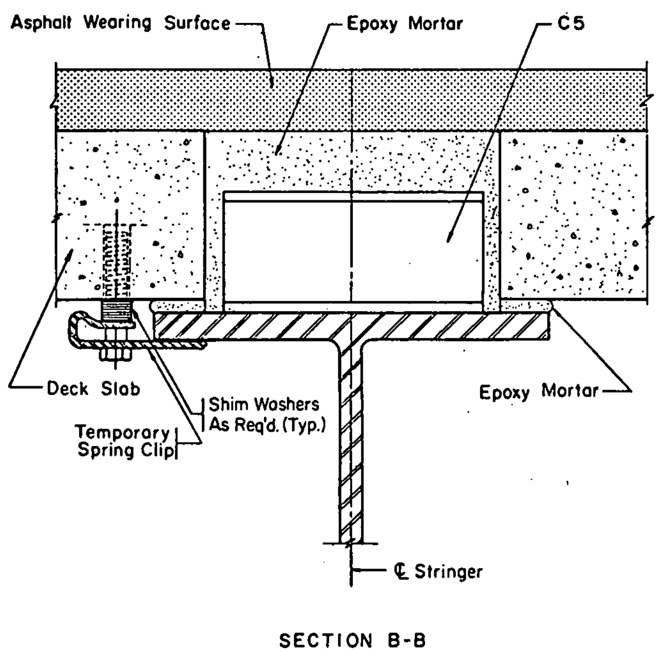


Figure C-9. Connection, type WC2A.

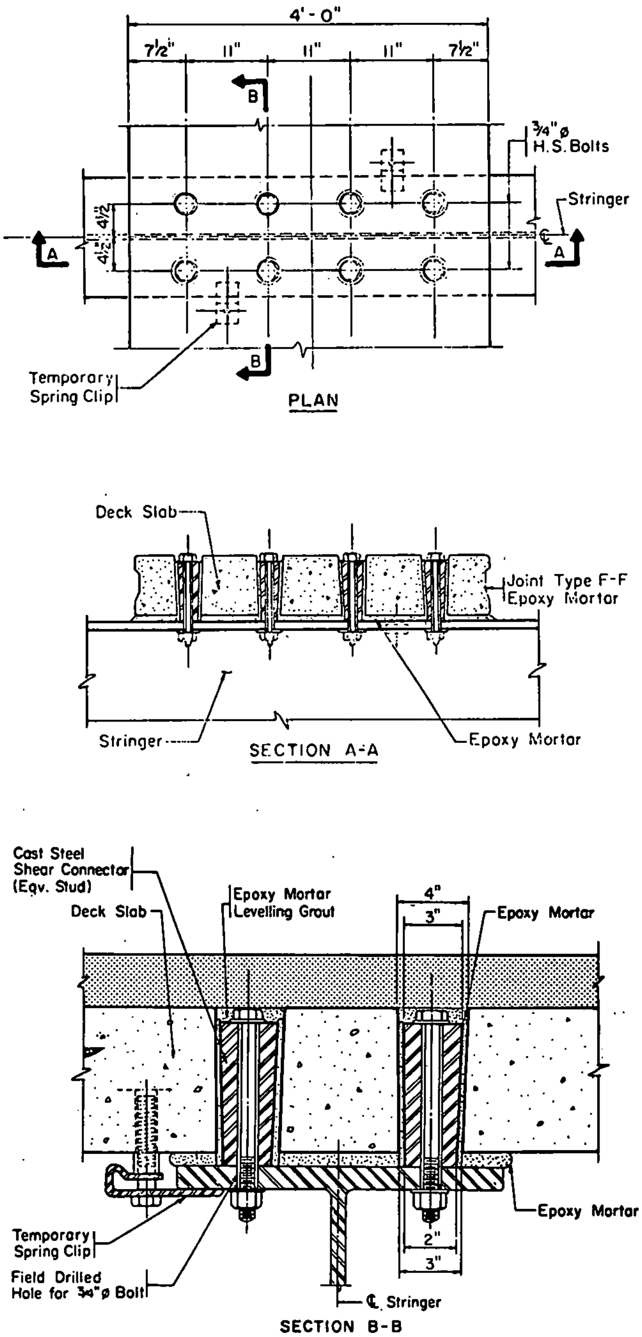


Figure C-10. Connection, type BC1A.

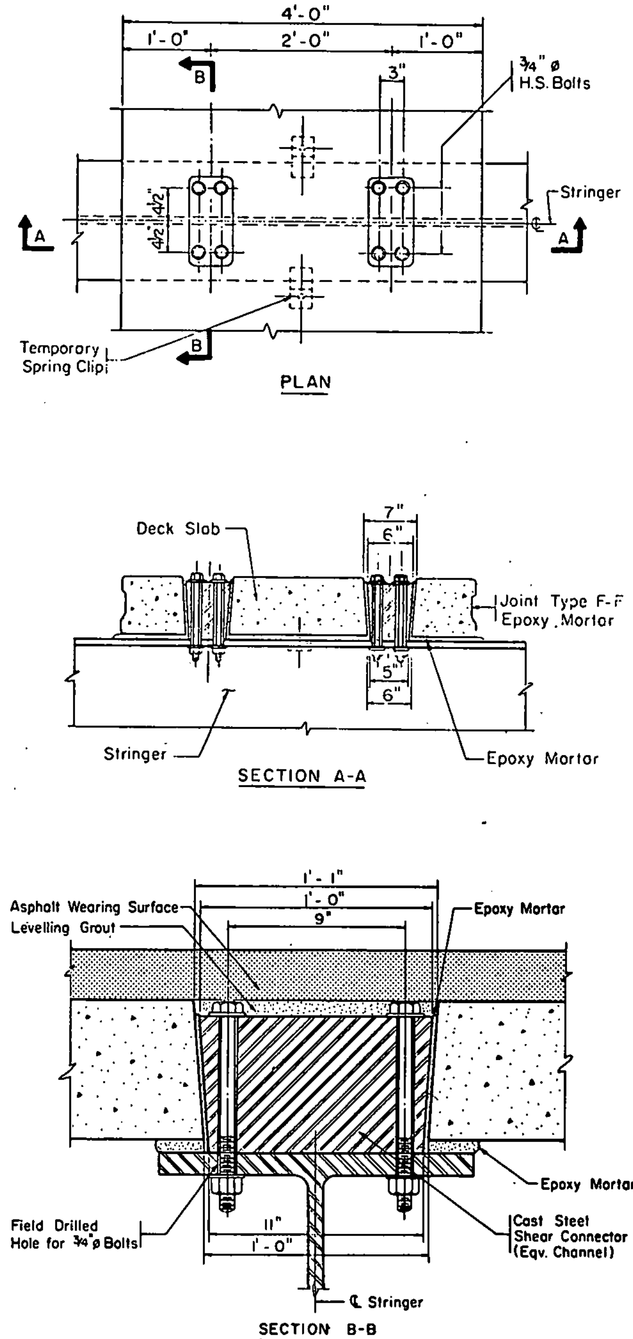


Figure C-11. Connection, type BC3A.

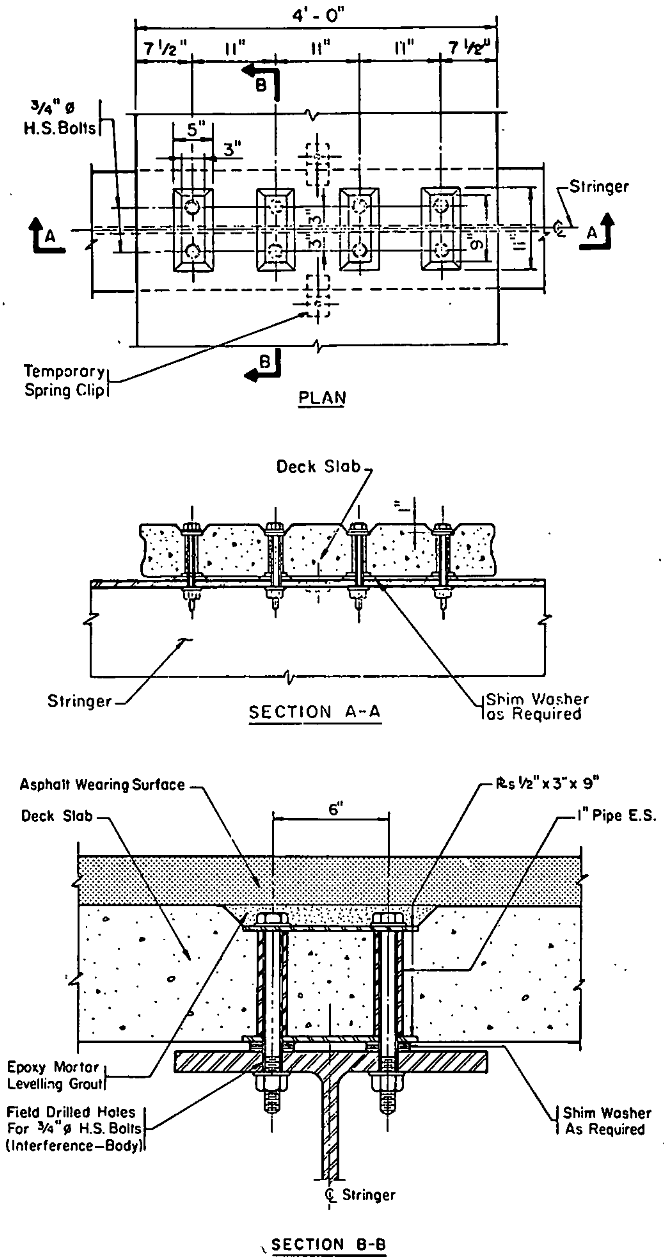


Figure C-12. Connection, type BC4O.

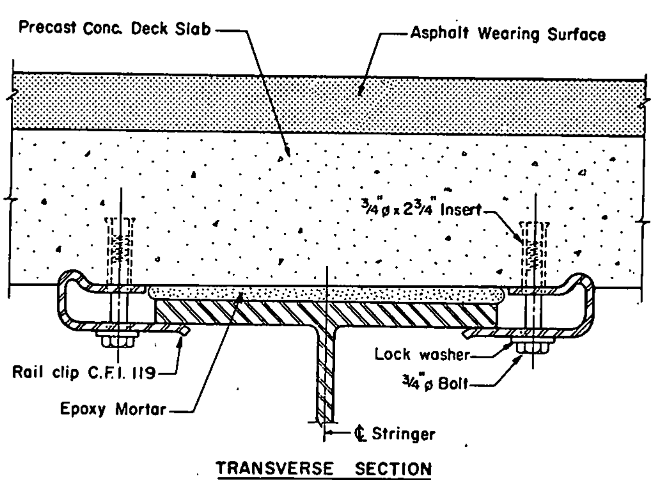


Figure C-13. Connection, type BN1O (Indiana, modified).

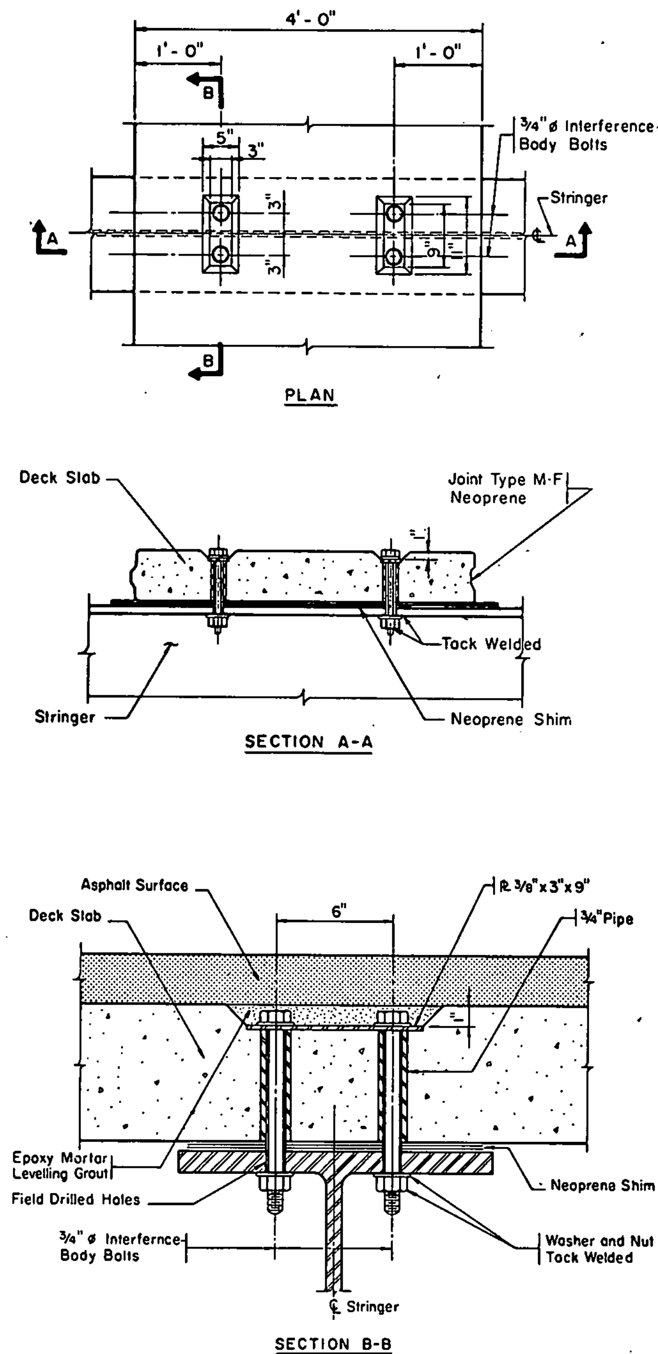


Figure C-14. Connection, type BN2O.

Movable Hinged-Plate Assembly

A construction sequence for removing and replacing sections of bridge decks without detouring traffic has been developed by the New York Thruway Authority. This sequence and the movable hinged-plate assembly that is used to accommodate traffic are shown in Figures C-15 through C-23.

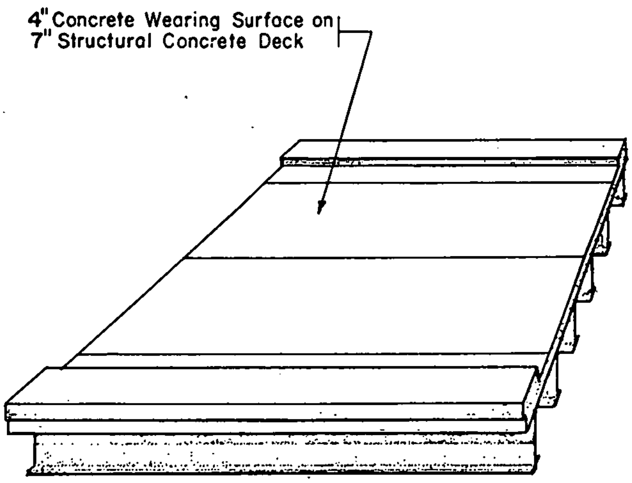


Figure C-15. Typical two-lane Thruway bridge deck.

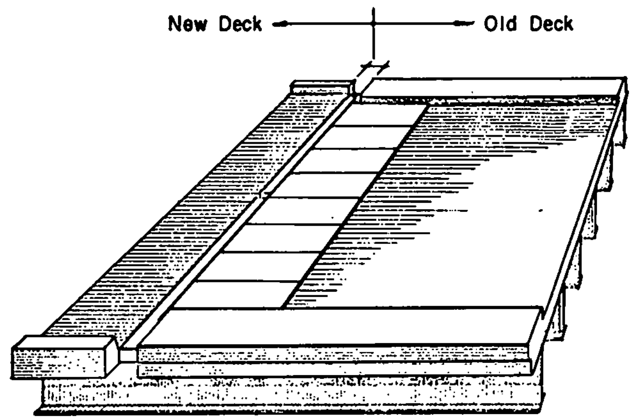


Figure C-16. Hinged plates in place.

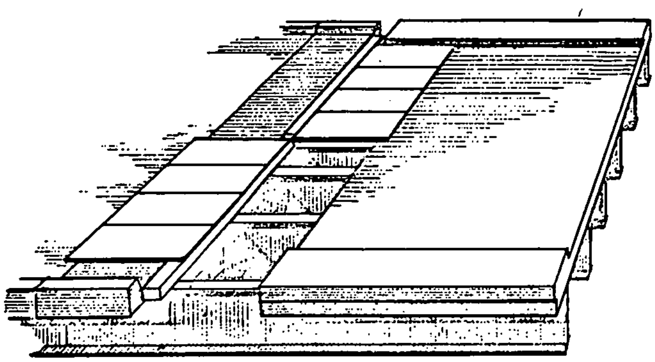


Figure C-17. Deck removal, I.

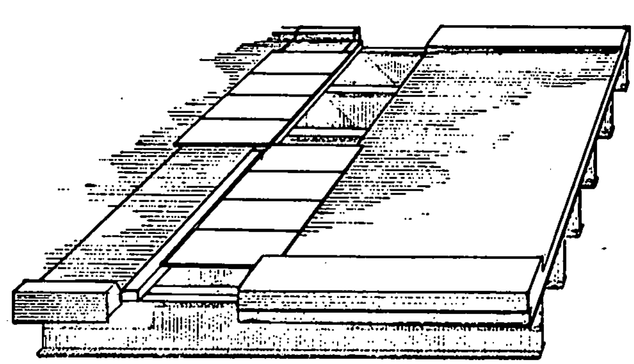
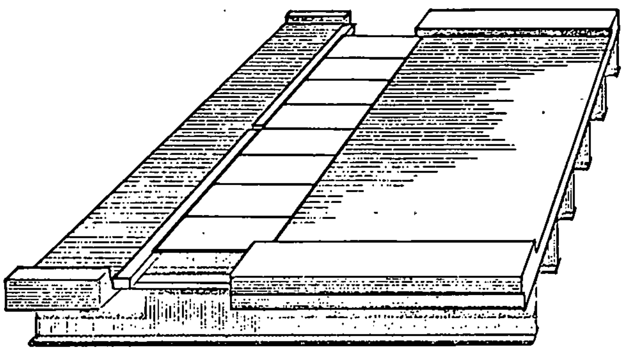
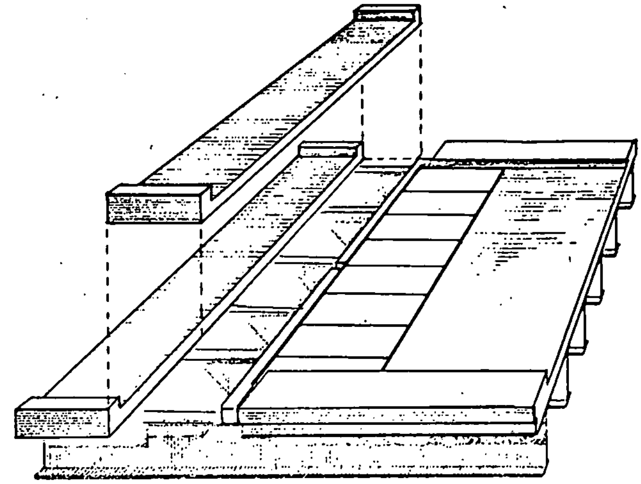


Figure C-18. Deck removal, II.



7) DURING PEAK TRAFFIC HOURS AND WHEN CONSTRUCTION IS SUSPENDED MAINTAIN TRAFFIC ACROSS OPEN DECK WITH STEEL PLATES IN CLOSED CONDITION.

Figure C-19. Maintenance of traffic.

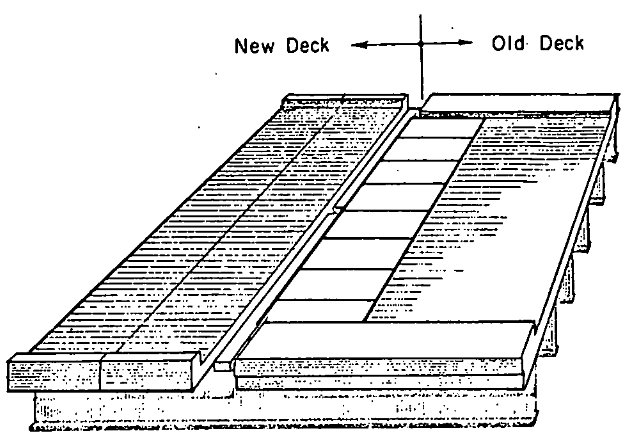


8) MOVE HINGE PLATES FORWARD, LEAVING OPENING IN DECK. HALF LENGTH OF ASSEMBLY CAN BE MOVED AT A TIME TO MAINTAIN TRAFFIC.

9) PREPARE THE SURFACES AS REQUIRED FOR THE CONNECTION METHOD TO BE USED. SHEAR CONNECTORS CAN BE ATTACHED TO STRINGERS AND EPOXY MORTAR CAN BE BUTTERED ON THE TOP OF THE STRINGERS AT THIS STAGE. TRAFFIC CAN BE MAINTAINED ON ONE LANE BY TURNING THE PLATES OVER BY 180°.

10) DROP IN REPLACEMENT SLAB UNIT

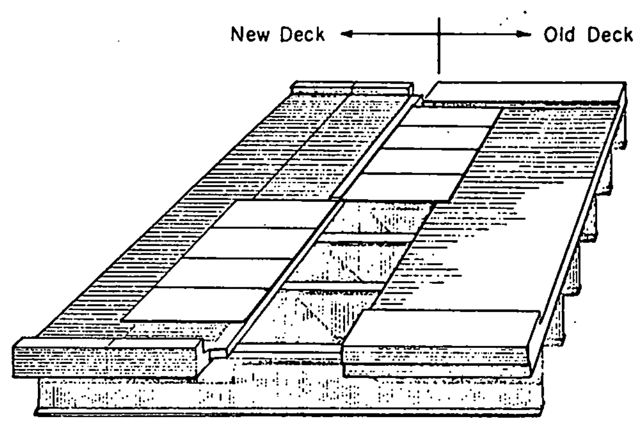
Figure C-20. Insert replacement deck.



11) ANCHOR REPLACEMENT DECK UNIT IN PLACE

12) INSTALL SHEAR CONNECTORS. COMPLETE THE DECK TO STRINGER CONNECTION AND THE TRANSVERSE JOINT.

Figure C-21. Connect replacement deck unit.



13) REPEAT SLAB REMOVAL SEQUENCE

Figure C-22. Repeat slab removal.

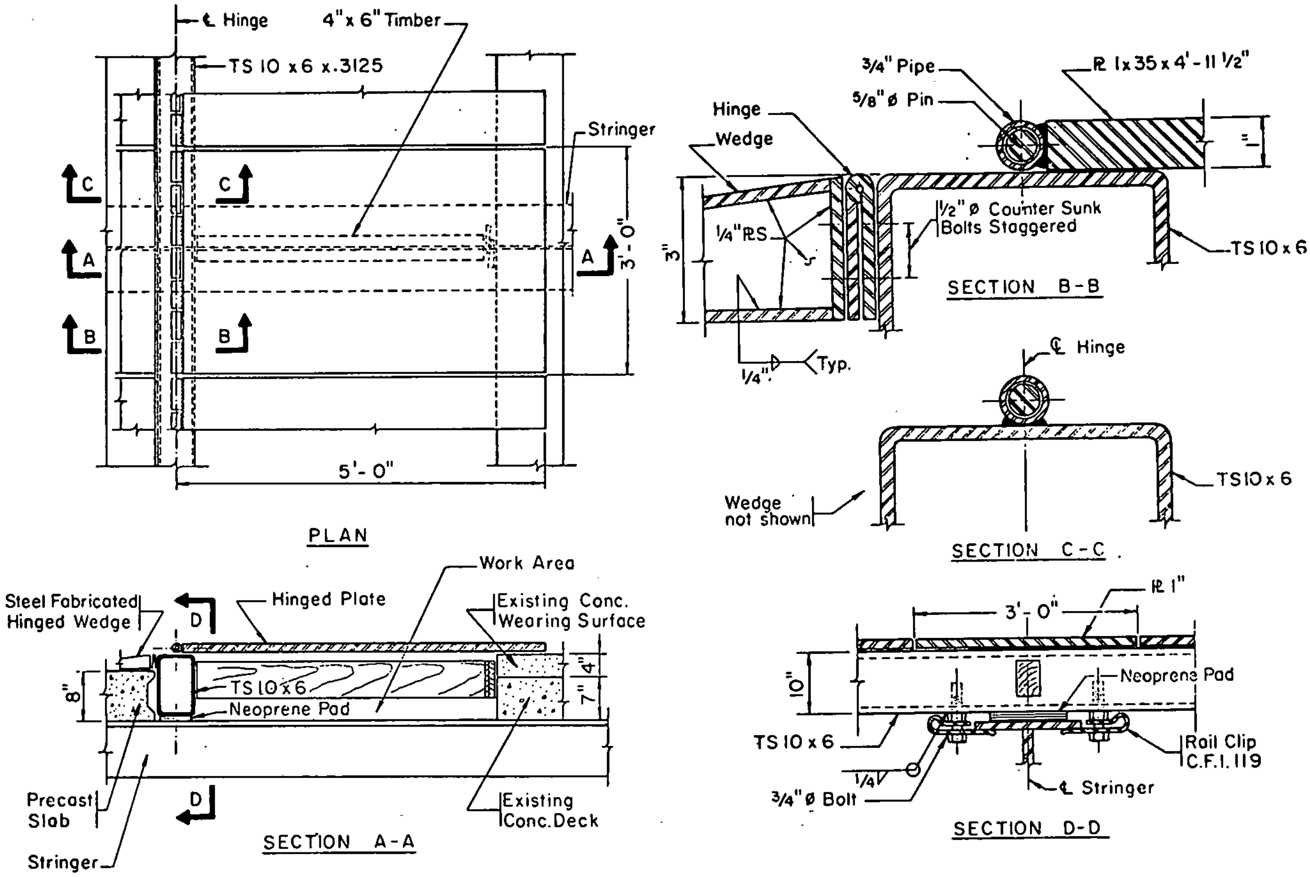


Figure C-23. Hinged-plate assembly.

APPENDIX D

CALIFORNIA PROCEDURE FOR ESTIMATING LANE CLOSURE DELAYS

I. BEFORE CLOSURE—DETERMINING WHEN TO START

A. Before closing any lanes and starting work, make two consecutive 3-minute counts (with 1 minute between), counting vehicles in all lanes at the work location. The required equipment is a hand tally counter and a watch with sweep second hand.

B. Convert each 3-minute count to an hourly volume by multiplying each count by 20.

C. Compare the hourly volumes with the capacity rate in Table D-1 for the type of operation and closure involved. If one or both of the hourly volumes exceeds the value in Table D-1 congestion will develop if the lane closure is made at that time. If possible, the closure should be delayed until two consecutive counts fall below the value in Table D-1.

This method is primarily for determining how soon to start after the peak traffic period. If work is planned ahead, the procedure may be used the day before in order to determine approximate working hours. This will avoid having men and equipment idle waiting for traffic to subside. However, the procedure should be repeated the next day because traffic volumes vary from day to day.

Explanation of Table D-1

The capacity rates given in Table D-1 are in terms of vehicles per hour in one direction. They were determined from the average of several traffic counts taken at the location of some typical operations on Los Angeles area freeways. The rates are only an estimate and could be higher or lower depending on the location of the operation and its distracting characteristics ("gawking" effect). The rates shown should be reduced by about 5 to 10 percent at locations where there are high truck volumes and uphill grades. Capacity rates can be lower for long (length) lane closures. This implies that the length of a lane closure should be as short as possible. The capacities given will probably be lower for night work.

TABLE D-1

ROADWAY CAPACITY RATES FOR SOME TYPICAL OPERATIONS ON FREEWAYS [a]

No. of lanes, one direction (normal operation)	2	3 or 4	4
No. of lanes open, one direction	1	2	3
TYPE OF OPERATION	CAPACITY, ONE DIRECTION (VPH)		
Median barrier or guardrail repair	1500	3200	4800
Pavement repair, mudjacking, pavement grooving	1400	3000	4500
Striping, resurfacing, slide removal	1200	2600	4000
Pavement markers	1100	2400	3600
Middle lanes, any reason	—	2200	3400

[a] See Table 4 for source.

II. AFTER CLOSURE—ESTIMATING DELAY TO MOTORISTS IF CONGESTION OCCURS

After the lane is closed, the traffic upstream from the operation should be checked periodically (operation at a work location does not necessarily indicate whether or not there is congestion). If congestion develops, the following procedure can be used to estimate the maximum delay for each vehicle going through the total length of traffic backup:

A. Determine the actual output rate (number going past work location) by making two 3-minute counts at the location of the work. Multiply the average of the two counts by 20 to obtain the hourly rate.

B. Determine the length of backup, in miles. The length of backup is measured from the location of the work upstream to the point where traffic comes to a virtual stop or where there is a distinct change in traffic density. This length can be determined by mile post markers or by actual

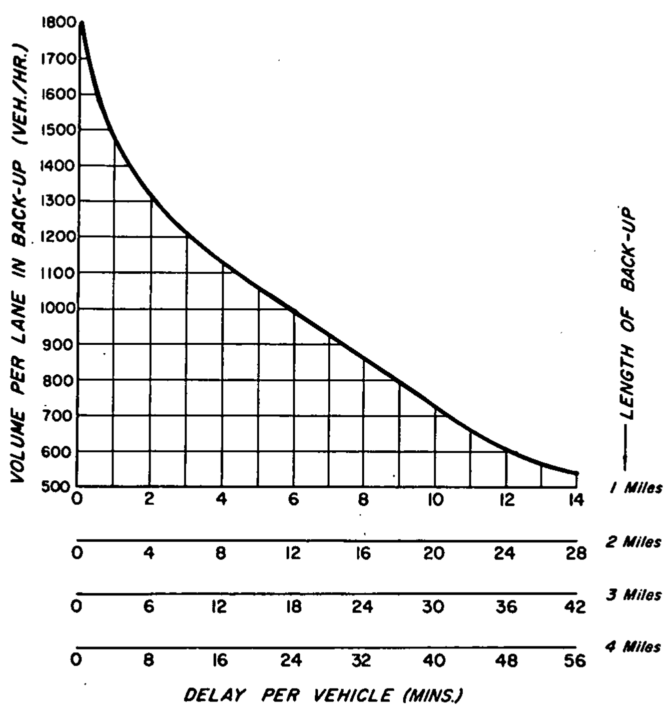


Figure D-1. Delay curve.

odometer measurements. The length should be reduced by about ¼ mile to compensate for the transition area, because in this area traffic is not backed up in as many lanes.

C. Divide the output rate computed in Step A by the number of lanes upstream in the backup. The result is the volume per lane in the backup.

D. The maximum delay for each vehicle can be estimated from Figure D-1 by reading across to the curve opposite the volume per lane computed in Step C, and then reading down to the length of backup determined in Step B. Lengths less than one mile or between even miles can be interpolated from the chart.

If the traffic backup has sections with different numbers of lanes, the length of each section should be measured separately. Steps C and D are determined separately for each section. The maximum delay for each vehicle going through the total length of traffic backup is the sum of the delays calculated for all sections.

SAMPLE CALCULATIONS

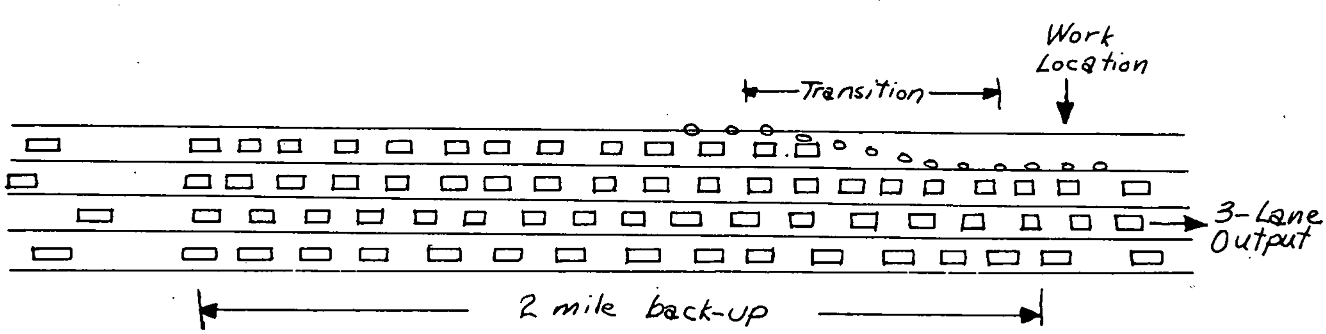
Example 1—Determining When to Start

Given a 4-lane freeway; it is proposed to close Lane 1 for a median barrier repair job starting after the morning peak traffic period. Two consecutive 3-minute counts made at 9:00-9:03 and 9:04-9:07 AM were 260 and 220 vehicles, respectively. Multiplying these counts by 20 results in hourly volumes of 5,200 and 4,400. The 5,200 value is higher than the capacity rate of 4,800 as shown in Table D-1 for this type of operation. Therefore, the closure should be delayed until two consecutive 3-minute counts fall below 4,800, otherwise there is a high probability that congestion will develop.

Subsequent counts made at 9:20-9:23 and 9:24-9:27 AM resulted in hourly volumes of 4,700 and 4,300, respectively. As both values were below the value of 4,800 from Table D-1, the lane was closed and work was started.

Example 2—Estimating Maximum Delay per Vehicle

After one lane of a 4-lane freeway is closed for repair of the median barrier, a backup is observed at 2:00 PM. It is desired to estimate the maximum delay per vehicle at that time. Conditions appear as in the following sketch:



The actual output rate is determined by taking two 3-minute counts, resulting in 210 and 230 vehicles, respectively. Multiplying the average of the two counts by 20 gives an output rate of 4,400 vehicles per hour. This is slightly less than the value of 4,800 from Table D-1 and could occur for a variety of reasons.

The length of backup is reduced by ¼ mile to give an approximation of the effective length of backup, 1.75 miles. This reduction is necessary to adjust for the fact that in the transition area and at the work location, density of traffic is not as great as in the main backup. (Backups of less than ¼ mile do not cause serious delays—1 to 3 minutes. However, operation is still congested and hazards exist.)

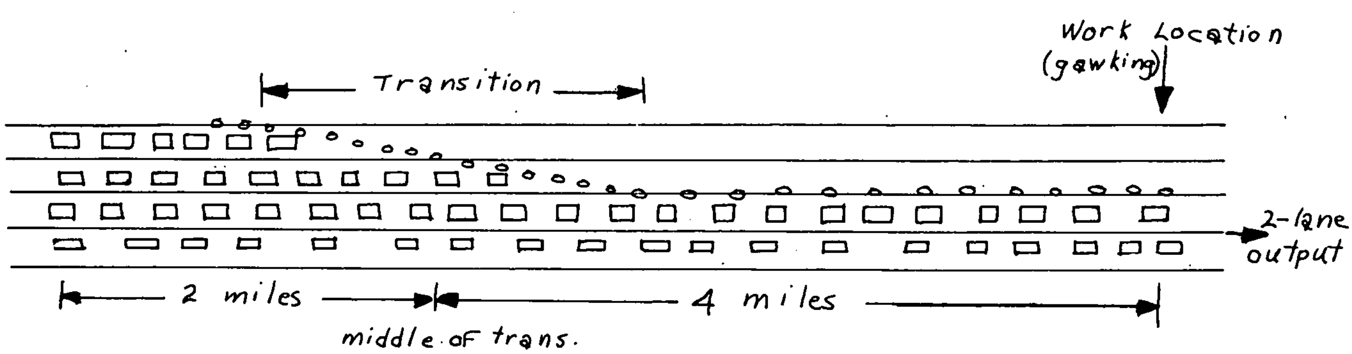
The volume per lane in the backup is calculated by dividing the output rate by the number of lanes upstream: 4,400/4 = 1,100 vph.

The maximum delay per vehicle can then be interpolated from Figure D-1 by reading across to the curve opposite 1,100 and then down to 1 mile. The result is about 4.3 min per mile. Multiplying 4.3 by 1.75 miles gives a maximum delay per vehicle of about 7½ min.

If traffic is increasing, the length of backup will increase. Each additional mile of backup will result in an additional 4.3-min delay per vehicle. This information can be used to make decisions on whether or not to suspend operations.

If significant lengths of the backup are in sections with varying number of lanes, to obtain a more accurate estimate of delay the backup must be broken into sections and the delay calculated separately for each section (see Example 3).

Example 3—Estimating Delay When Backup Extends into Sections with Varying Number of Lanes



Given the 4-lane section shown above with two lanes closed for installation of pavement markers. The backup extends 2 miles upstream in the 4-lane section. Calculations are performed separately for each section.

Multiplying the average of two 3-min counts by 20 results in a 2-lane output rate of 2,600 vph.

The volume per lane in the 2-lane section is 2,600/2, or 1,300 vph. [The length of backup in the 2-lane section is measured from the location of the work (where motorists slow down to "gawk").] The volume per lane in the 4-lane section is 2,600/4 or 650 vph.

From Figure D-1, the delay in the 2-lane section is 8 min per vehicle and the delay in the 4-lane section is about 22 min. The total maximum delay per vehicle in the backup is the sum of these values (8 and 22), or 30 min.

APPENDIX E

MICHIGAN SPECIAL PROVISION FOR CONCRETE PAVEMENT PATCHING

STATE OF MICHIGAN
DEPARTMENT OF STATE HIGHWAYS

SPECIAL PROVISION

CONCRETE PAVEMENT PATCHING
(FAST SETTING)

Description:

This special provision covers the mixing, placing, and curing of a special 9.0 sack fast-setting concrete with or without calcium chloride to be used for cast-in-place repairs of pavements to be opened to traffic when a flexural strength of 300 psi. is attained. The 9.0 sack concrete without calcium chloride is to be used only in areas designated by the Engineer which can be closed to traffic overnight. Seasonal limitations shall not apply except that air temperatures shall be not less than 25 degrees and the subgrade shall not be frozen.

This work shall be performed in accordance with the 1970 Standard Specification unless otherwise provided herein.

Materials:

All materials shall meet the requirements of the Standard Specifications except as provided herein. When chloride is to be added the concrete shall be transported in a transit mix truck.

	Pounds Per Cubic Yard
*Air entrained cement, Type IA	846
Water (including moisture in aggregate)	315 (approx.)
**Fine Aggregate (2NS sand)	1017 dry weight
**Coarse Aggregate (6A)	1656 dry weight
Calcium Chloride (flake, 77%)	See table below

(*) If not available use Type I cement and add air entraining agent so that air content is between 5 to 8%.

(**) The aggregate weights are based on specific gravity of 2.65 and shall be adjusted by the Engineer if materials used differ from this value.

Recommended Chloride Addition Rate

Ambient Temperature	Calcium Chloride per Cubic Yard of Mix
Less than 45° F	36 lbs.
45 to 65° F	27 lbs.
Above 65° F	18 lbs.

Table I

Approximate Time to Attain Required Strength
(For Information Only)

Calcium Chloride added per cu. yd of Concrete Mix	Approx. time to attain 300 psi flexure strength
36 lbs	4 to 7 hrs
26 lbs	5 to 8 hrs
18 lbs	6 to 12 hrs
9 lbs	10 to 14 hrs
0 lbs	14 to 18 hrs

The above time values are for an air temperature of 65° F. The initial set of a mix containing 36 lbs of calcium chloride with a slump of 3 to 4 in. and poured in 72° F temperature will occur approximately 15 to 20 minutes after addition of the calcium chloride.

Mixing:

The basic 9.0 sack concrete mix shall be completely mixed except for chloride addition upon arrival at patch location. When air temperature is less than 45° F the concrete temperature shall be not less than 60° F.

The flake chloride shall be lump free and after addition of the calcium chloride the mixer will be given 20 revolutions at mixing speed before concrete is placed. Water may be added at the job site, slump shall not exceed 4 inches.

Concrete Placement:

Removal of the distressed concrete, placement and compaction of the subbase, where required, and form setting shall be completed prior to the arrival of the concrete. Each repair shall be poured in one continuous operation. The concrete shall be consolidated in place by use of an immersion type vibrator and the surface shall be finished by screeding, floating and brooming. The placement operations shall be scheduled in such manner that each repair is completed 20 minutes after addition of the calcium chloride.

Test beams shall be cast as directed by the Engineer to determine the Modulus of Rupture. When the beam tests indicate that a modulus of rupture of 300 psi has been attained, the Contractor will be permitted to open the concrete pavement patch to traffic.

If the beam tests indicate that a modulus of rupture of 300 psi cannot be attained under the prescribed temperature and calcium chloride addition rate, adjustment in the amount of calcium chloride added to each cubic yard shall be made to attain the required strength for the next day's repairs within the allowed lane closure time.

Curing:

When air temperature is below 65° F, insulation blankets 2-in. thick shall be placed over the new concrete as soon as it can be supported without damage to the surface. The test beams shall receive the same curing as the patch and curing blankets may be removed as soon as 300 psi strength is attained.

Method of Measurement:

Method of measurement shall be as specified in Section 3.06.08 of the Standard Specifications except calcium chloride and insulated blankets shall be incidental to the item of Concrete Pavement Patching.

Basis of Payment:

Basis of payment shall be as described in Section 3.06.09 except the cost of calcium chloride and insulated blankets shall be included in the unit price of Concrete Pavement Patching.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

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

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20

* Highway Research Board Special Report 80.

Rep. No.	*Title*
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20

Rep. No.	Title
50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2) 148 p., $6.00
61	Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
62	Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols (Proj. 7-1), 144 p., $5.60
63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5/1), 55 p., $2.80
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60

Rep. No.	Title
76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $2.00
77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., $3.20
79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
91	Effects of Deicing Salts on Water Quality and Biota —Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20
92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
95	Highway Fog (Proj. 5-6), 48 p., $2.40
96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p. $5.00
99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60
102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
104	Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40

Rep. No.	*Title*
105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
130	Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20
133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 23 p., $2.80
135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., $4.60
137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20
138	Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., $4.00
139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., $4.40
140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., $5.60
141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., $8.40
142	Valuation of Air Space (Proj. 11-5), 48 p., $4.00
143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., $16.00
144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., $4.40
145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17) 120 p., $6.00
146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., $4.00
147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., $4.80
148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., $4.00
149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., $4.00
150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., $4.80

Synthesis of Highway Practice

No.	*Title*
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20
2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
3	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20
4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20
5	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40
6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40
8	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40
9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $2.80
11	Development of Management Capability (Proj. 20-5, Topic 12), 50 p., $3.20
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., $2.80
13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., $2.80
14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00
15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., $3.60
16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., $2.80
17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., $3.60
18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., $4.00
19	Design, Construction, and Maintenance of PCC Pavement Joints (Proj. 20-5, Topic 3-04), 40 p., $3.60
20	Rest Areas (Proj. 20-5, Topic 4-04), 38 p., $3.60
21	Highway Location Reference Methods (Proj. 20-5, Topic 4-06), 30 p., $3.20
22	Maintenance Management of Traffic Signal Equipment and Systems (Proj. 20-5, Topic 4-03) 41 p., $4.00
23	Getting Research Findings into Practice (Proj. 20-5, Topic 11) 24 p., $3.20
24	Minimizing Deicing Chemical Use (Proj. 20-5, Topic 4-02), 58 p., $4.00
25	Reconditioning High-Volume Freeways in Urban Areas (Proj. 20-5, Topic 5-01), 56 p., $4.00

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 150 committees and task forces composed of more than 1,800 administrators, engineers, social scientists, and educators who serve without compensation. The program is supported by state transportation and highway departments, the U.S. Department of Transportation, and other organizations interested in the development of transportation.

The Transportation Research Board operates within the Division of Engineering of the National Research Council. The Council was organized in 1916 at the request of President Woodrow Wilson as an agency of the National Academy of Sciences to enable the broad community of scientists and engineers to associate their efforts with those of the Academy membership. Members of the Council are appointed by the president of the Academy and are drawn from academic, industrial, and governmental organizations throughout the United States.

The National Academy of Sciences was established by a congressional act of incorporation signed by President Abraham Lincoln on March 3, 1863, to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance. It is a private, honorary organization of more than 1,000 scientists elected on the basis of outstanding contributions to knowledge and is supported by private and public funds. Under the terms of its congressional charter, the Academy is called upon to act as an official—yet independent—advisor to the federal government in any matter of science and technology, although it is not a government agency and its activities are not limited to those on behalf of the government.

To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.

TRANSPORTATION RESEARCH BOARD

National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

000015M003
MATERIALS ENGR

IDAHO DEPT OF HIGHWAYS
P O BOX 7129
BOISE ID 83707