DESIGNING SAFER ROADS

Practices for Resurfacing, Restoration, and Rehabilitation

Transportation Research Board
National Research Council
1987 TRANSPORTATION RESEARCH BOARD
EXECUTIVE COMMITTEE

OFFICERS

Chairman: Lowell B. Jackson, Executive Director, Colorado Department of Highways, Denver
Vice Chairman: Herbert H. Richardson, Vice Chancellor and Dean of Engineering, Texas A&M University System, College Station
Executive Director: Thomas B. Deen, Transportation Research Board

MEMBERS

Ray A. Barnhart, Administrator, Federal Highway Administration, U.S. Department of Transportation (ex officio)
John A. Clemens, Vice President, Sverdrup Corporation, Boston, Massachusetts (ex officio, Past Chairman, 1985)
Donald D. Engen, Vice Admiral, U.S. Navy (retired), Administrator, Federal Aviation Administration, U.S. Department of Transportation (ex officio)
Francis B. Francois, Executive Director, American Association of State Highway and Transportation Officials, Washington, D.C. (ex officio)
Lester A. Hoel, Hamilton Professor and Chairman, Department of Civil Engineering, University of Virginia, Charlottesville (ex officio, Past Chairman, 1986)
Ralph L. Stanley, Administrator, Urban Mass Transportation Administration, U.S. Department of Transportation (ex officio)
Dairie Steed, Administrator, National Highway Traffic Safety Administration, U.S. Department of Transportation (ex officio)
George H. Way, Jr., Vice President, Research and Test Department, Association of American Railroads, Washington, D.C. (ex officio)
Alan A. Altschuler, Dean, Graduate School of Public Administration, New York University, New York
John R. Borchert, Regents Professor, Department of Geography, University of Minnesota, Minneapolis
Robert D. Bugher, Executive Director, American Public Works Association, Chicago, Illinois
Dana F. Connors, Commissioner, Maine Department of Transportation, Augusta
C. Leslie Dawson, Secretary, Kentucky Transportation Cabinet, Frankfort
Thomas E. Drawdy, Jr., Secretary, Florida Department of Transportation, Tallahassee
Paul H. Faris, Director of Aviation, City of Houston Aviation Department, Texas
Louis J. Gambiaccini, Assistant Executive Director/Trans-Hudson Transportation of The Port Authority of New York and New Jersey, New York
Jack R. Gistrap, Executive Vice President, American Public Transit Association, Washington, D.C.
William J. Harris, Sneed Distinguished Professor of Transportation Engineering, Department of Civil Engineering, Texas A&M University, College Station
Raymond H. Hogrefe, Director-State Engineer, Nebraska Department of Roads, Lincoln
Thomas L. Mainwaring, Chairman, American Trucking Associations Foundation, Alexandria, Virginia
James E. Martin, President and Chief Operating Officer, Illinois Central Gulf Railroad, Chicago
Demian K. McNear, Chairman, President and Chief Executive Officer, Southern Pacific Transportation Company, San Francisco, California
Leno Menghini, Superintendent and Chief Engineer, Wyoming Highway Department, Cheyenne
William W. Miller, Executive Director, Port Authority of Allegheny County, Pittsburgh, Pennsylvania
Milton Pikarsky, Distinguished Professor of Civil Engineering, The City College of New York, New York
James P. Pilz, Director, Michigan Department of Transportation, Lansing
Joe G. Rideout, Chief Commissioner, South Carolina Department of Highways and Public Transportation, Columbia
Ted Tedesco, Vice President, Resource Planning, American Airlines, Inc., Dallas/Fort Worth Airport, Texas
Carl S. Young, County Executive, Broome County, Binghamton, New York
DESIGNING SAFER ROADS

Practices for
Resurfacing,
Restoration, and
Rehabilitation

Transportation Research Board
National Research Council
Washington, D.C. 1987
Transportation Research Board Special Report 214

mode
1  highway transportation

subject areas
21  facilities design
51  transportation safety
52  human factors

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

NOTICE
The project that is the subject of this publication was approved by the Governing Board of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the publication were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study was sponsored by the Federal Highway Administration of the U.S. Department of Transportation.

Library of Congress Cataloging-in-Publication Data
COMMITTEE FOR THE STUDY OF
GEOMETRIC DESIGN STANDARDS
FOR HIGHWAY IMPROVEMENTS

PETER G. KOLTMOW, American Trucking Associations, Alexandria,
Virginia Co-Chairman
HERBERT H. RICHARDSON, The Texas A&M University System, College
Station, Co-Chairman
ROY W. ANDERSON, TranSafety, Inc., Springfield, Virginia
LEONARD EVANS, General Motors Research Laboratories, Warren,
Michigan
JOHN C. GLENNON, John C. Glennon Chartered, Prairie Village, Kansas
EZRA HAUSER, University of Toronto, Ontario
W. RONALD HUDSON, University of Texas, Austin
JACK T. KASSEL, Sacramento, California
JAMES L. MARTIN, Fresno, California
BROOKS O. NICHOLS, Arkansas State Highway and Transportation
Department, Little Rock
BRIAN O'NEILL, The Insurance Institute for Highway Safety, Washington,
D.C.
ROBERT H. RAYMOND, Jr., Pennsylvania Department of Transportation,
Harrisburg
JOHN H. SHAFER, New York State Department of Transportation, Albany
RICHARD R. STANDER, Jr., Mansfield Asphalt Paving Company,
Mansfield, Ohio
JAMES I. TAYLOR, University of Notre Dame, Indiana
E. DEAN TISDALE, Idaho Transportation Department, Boise

Liaison Representatives

DAVID J. HENSING, American Association of State Highway and
Transportation Officials, Washington, D.C.
MICHELE A. McMURTRY, National Transportation Safety Board
JEAN SCHIRAG-LAUVER, Senate Environment and Public Works
Committee
SEppo I. SILLAN, Federal Highway Administration, U.S. Department of
Transportation
RICHARD V. TEARLE, House Committee on Public Works and
Transportation
JENNIFER WISHART, Congressional Budget Office
DAVID K. WITHEFORD, Transportation Research Board
CLYDE E. WOODLE, Jr., House Committee on Public Works and
Transportation
Transportation Research Board Staff

ROBERT E. SKINNER, Director for Special Projects
HARRY S. COHEN, Senior Program Officer
JOSEPH R. MORRIS, Senior Program Officer
JOHN A. DEACON, Consultant
RICHARD MARCHIOTTA, Research Associate
MALCOLM QUINT, Research Associate
EDYTHE TRAYLOR CRUMP, Senior Editor
Preface

In response to a provision in the Surface Transportation Assistance Act of 1982, the Secretary of Transportation, acting through the Federal Highway Administration, requested the National Academy of Sciences to study the safety cost-effectiveness of highway geometric design standards and recommend minimum standards for resurfacing, restoration, and rehabilitation (RRR) projects on existing federal-aid highways, except freeways. Specifically, the act called for the Secretary of Transportation to enter into arrangements with the National Academy of Sciences to

conduct a study of the safety cost-effectiveness of geometric design criteria of standards currently in effect for construction and reconstruction of highways, other than highways access to which is fully controlled, to determine the most appropriate minimum standards to apply to resurfacing, restoration, and rehabilitation projects on such highways . . . and to propose standards to preserve and extend the service life of such highways and enhance highway safety.

To carry out the study, the National Research Council, the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, assembled a committee of 16 experts in the various disciplines needed to develop and apply geometric design standards and assess their impact on safety, highway serviceability, cost, environment, and system administration. Committee members included individuals with experience in highway design, traffic engineering, highway safety, accident analysis, highway construction, statistics, economics, highway administration, and law.

The committee began its work with a review of RRR practices in state and local highway agencies. Committee staff visited the state highway agency and
the Federal Highway Administration offices in each of the 15 states selected for case studies and conducted telephone interviews with local highway officials representing 16 counties, 20 cities, and 3 metropolitan planning organizations. Federal, state, and local officials provided valuable information on the types of projects funded with federal aid, procedures used to select RRR projects, current design standards and their use, and the ways in which safety needs are taken into account.

The study committee sponsored critical reviews of prior research on the safety effects of key highway features and special research projects on pavement edge drops and roadside safety. The critical reviews and findings from the special research projects were used to make judgments about relationships between safety and key highway features. For several design features, the committee found sufficient evidence to support quantitative relationships between safety and design improvements. However, these relationships must be viewed as approximate in nature. Although the relationships are based on the best available data, they could be substantially changed by the results of future research.

In addition, the study committee developed relationships between cost and key highway features. These relationships are based on an examination of published cost data, cost records, and cost-estimating procedures for a sample of highway agencies throughout the country. The cost relationships provide estimates of typical costs for making geometric design improvements on RRR projects. However, the cost for a given improvement can vary considerably from site to site because of variations in site conditions, labor and material costs, design practices, and project scale. Thus, actual costs could be much greater or less than estimates developed using the cost relationships.

The safety and cost relationships were used to assess the safety cost-effectiveness of geometric design standards. The added cost per accident eliminated that can be expected for improvements to highway geometry was estimated for illustrative projects. When system data were available for existing highway conditions, the study committee examined the effects of alternative RRR standards on systemwide safety and the total expenditure needed to meet the standard on a nationwide basis or for selected states.

Drawing primarily on case studies of current RRR practices and analyses of safety cost-effectiveness, the committee has recommended a variety of practices that encompass the entire RRR process but with special focus on design. In selected instances, federal, state, and local highway agencies can use the recommendations, along with published manuals, design aids, and local experience to develop or modify minimum design standards for RRR projects. For federal-aid RRR work, the Secretary of Transportation is required by statute to ensure that projects are designed and constructed in accordance with standards that extend the service life of highways and enhance highway safety. To
accomplish this, the Secretary, acting through the Federal Highway Admin-
istration, must either set nationwide RRR standards or approve standards
adopted by individual states. In either case, the committee’s recommendations
provide guidance. In addition, the committee has recommended various
research and training activities that federal and state highway agencies can use
to improve their ability to enhance safety through RRR projects.

The study was performed under the overall supervision of Dr. Damian J.
Kulash and Robert E. Skinner, Jr., the former and current Directors for Special
Projects. Robert E. Skinner, Jr., directed the project staff. Dr. Harry Cohen,
Joseph R. Morris, Dr. John A. Deacon, Richard Margiotta, and Malcolm Quint
made significant contributions.

Special appreciation is expressed to Nancy A. Ackerman, TRB Publications
Manager, and Edythe T. Crump, Senior Editor, for editing the final report and
to Marguerite E. Schneider, Frances E. Holland, and Margaret M. Sheriff for
typing the many drafts and the final manuscript.
Contents

EXECUTIVE SUMMARY .................................................. 1

1 GEOMETRIC DESIGN STANDARDS FOR RESURFACING, RESTORATION, AND REHABILITATION PROJECTS: BACKGROUND AND ISSUES ........ 14
   Introduction, 14
   Evolution of Federal Highway Policy, 16
   Federal-Aid Highway Program, 18
   Geometric Design Standards and Federal Rulemaking, 24
   Key Issues, 30
   References, 32

2 STATE AND LOCAL PROCEDURES FOR SELECTION, DESIGN, AND CONSTRUCTION OF HIGHWAY IMPROVEMENT PROJECTS ........... 35
   Review of RRR Practices: Information Sources, 37
   State RRR Programs, 38
   Local RRR Programs, 66
   Summary of Findings, 72
   References, 75

3 RELATIONSHIPS BETWEEN SAFETY AND GEOMETRIC DESIGN ........ 76
   Application of Safety Relationships to Design Standards, 76
   Relationships Between Safety and Key Road Features, 78
   Low-Cost Safety Measures, 100
   Effect of Changing Vehicle Fleet, 102
   Roadway Consistency, 104
   Summary, 105
   References, 106
4 RELATIONSHIPS BETWEEN HIGHWAY COSTS AND GEOMETRIC DESIGN

Cost Relationships—Problems and Limitations, 110
Typical RRR Project Costs, 113
Added Project Costs for Geometric Improvements, 116
Right-of-Way Requirements, 125
Maintenance Cost Implications, 126
Summary, 129
References, 129

5 SAFETY COST-EFFECTIVENESS OF GEOMETRIC DESIGN STANDARDS

Earlier Studies of Safety Cost-Effectiveness in Highway Design, 132
Scope and Framework of Cost-Effectiveness Analyses, 133
Safety-Cost Trade-Offs, 136
Safety-Preservation Trade-Offs, 166
Summary of Findings, 170
References, 172

6 TORT LIABILITY AND GEOMETRIC DESIGN

Background on Tort Liability, 175
Implications for RRR Design Standards and Practices, 178
Summary, 183
References, 184

7 FINDINGS AND RECOMMENDED DESIGN PRACTICES FOR
RESURFACING, RESTORATION, AND REHABILITATION PROJECTS

Findings, 186
Safety-Conscious Design Process, 190
Design Practices for Key Highway Features, 193
Other Design Procedures and Assumptions, 204
Planning and Programming RRR Projects, 207
Safety Research and Training, 208
References, 212

APPENDIX A Summary Comparison of Nonfreeway Geometric Design Standards and Guidelines

APPENDIX B Case Study State and Local RRR Programs

APPENDIX C Summary of Detailed Safety Relationships

APPENDIX D Relationship Between Accidents and Horizontal Curvature

APPENDIX E Relationship Between Accidents and Sight Distance at Crest Vertical Curves